

# Water Quality Index: Important Instrument for Environmental Monitoring of Anambra State Central Senatorial Zone Water Resources

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Abstract	Article History
<p>Physicochemical parameters are fundamental indicators for assessing the quality and suitability of water for human consumption and ecological sustainability. This study evaluated selected physicochemical indices to determine the overall status and potability of surface water sources within the study area using water quality index (WQI). The key parameters examined included pH, temperature, total dissolved solids, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, ammoniacal nitrogen and phosphate to determine their influence on water quality and microbial proliferation. The results were compared with established permissible limits recommended by the World Health Organization (WHO) and other regulatory bodies to ascertain compliance and potential health implications. The cumulative findings demonstrated noticeable Oraukwu recorded the highest mean temperature (<math>29.50 \pm 0.01</math> °C), whereas Alor showed the lowest value (<math>28.80 \pm 0.05</math> °C). The highest pH was observed in Oba (<math>6.61 \pm 0.00</math>), while Idemili North had the lowest pH (<math>5.51 \pm 0.02</math>). Total suspended solids were greatest in Nri (<math>9.50 \pm 0.02</math> mg/L) and least in Dunukofia (<math>0.72 \pm 0.01</math> mg/L). Dissolved oxygen peaked in Umudioka (<math>44.50 \pm 0.30</math> mg/L) but was lowest in Awka South (<math>36.50 \pm 0.50</math> mg/L). Biochemical oxygen demand was highest in Nibo (44.80 mg/L). Chemical oxygen demand was highest in Njikoka and lowest in Awka South. Ammoniacal nitrogen was highest in Aniocha, while phosphate concentration was highest in Dunukofia. Statistical analysis revealed significant differences among the physicochemical parameters (<math>p &lt; 0.05</math>). Furthermore, the twenty-one sampling sites showed WQI fall under category III (polluted category) and category II (slightly polluted category). The exceeding limits indicated contamination risks, while acceptable values reflected stability. Thus, physicochemical assessment using water quality index supports monitoring, risk evaluation, and sustainable freshwater protection integrity.</p> <p><b>Keywords:</b> Ecological sustainability, Physicochemical assessment, Risk evaluation, Surface water sources, Water quality index</p>	<p>Received: 23 Apr 2026 Accepted: 19 May 2026 Published: 30 May 2026</p>  <p>Scan QR code to view*</p>
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## Introduction

Water is fundamental to life and remains one of the most indispensable natural resources for human survival, ecosystem stability, and socio-economic development. It accounts for a substantial proportion of daily human dietary intake, yet unlike many other nutrients, it is not stored in significant quantities in the body, thereby necessitating continuous replenishment (Agboli *et al.*, 2017). Beyond its biological importance, water underpins agriculture, industry, sanitation, and energy production, making it central to

sustainable development. However, the availability of water alone does not guarantee its suitability for use. Water quality is increasingly recognized as a critical global concern, as it is influenced by a complex interplay of natural processes, geological formations, climatic variability, anthropogenic pressures, and environmental activities (UNDSEA, 2001). Rapid urbanization, industrial discharge, agricultural runoff, climate change, and population growth have further exacerbated the deterioration of freshwater resources worldwide as described by several authors (Uba, 2019a;

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2019b; 2019c; Uba *et al.* 2019b; 2019c; WHO, 2022; UNEP, 2023; Uba *et al.*, 2017; Uba *et al.*, 2020a; 2020b; 2020c; 2020d; 2020e; 2020f; 2020g; Umeh *et al.*, 2020; 2021).

Potable water is defined as water that is free from pathogenic microorganisms, devoid of harmful chemical substances at concentrations capable of causing acute or chronic health effects, and aesthetically acceptable for human consumption (WHO, 2017; Onuorah *et al.*, 2017a). Access to safe drinking water is a fundamental human right and a core target of Sustainable Development Goal 6 (SDG 6), which seeks to ensure the availability and sustainable management of water and sanitation for all (United Nations, 2023). Nevertheless, a significant proportion of populations in developing countries continue to face challenges in accessing safe and reliable drinking water supplies. Inadequate infrastructure, poor sanitation, and weak regulatory enforcement often result in contamination of surface and groundwater sources, thereby increasing the burden of waterborne diseases such as cholera, typhoid fever, and diarrheal illnesses (WHO & UNICEF, 2023; (Egurefa *et al.* 2020a; 2020b; Okafor *et al.*, 2023; Ubani *et al.*, 2024a; 2024b; 2025). Consequently, the provision of potable water to both rural and urban communities remain essential for safeguarding public health and improving quality of life (Onuora *et al.*, 2017b; Mere *et al.*, 2025).

Assessment of water quality relies heavily on physicochemical and microbiological parameters that collectively determine its suitability for specific uses. Physicochemical indices are derived from measurable attributes of water samples and are indispensable tools for routine monitoring and environmental management (Atiku *et al.*, 2017; Okolo *et al.*, 2025; Okpalaunegbu *et al.*, 2025; Obiefuna *et al.* 2025; Obiefuna *et al.* 2026). Parameters such as pH, temperature, turbidity, electrical conductivity, dissolved oxygen, biochemical oxygen demand, total dissolved solids, nitrate, phosphate, and heavy metals are widely accepted indicators of water quality status. These variables may directly influence microbial survival and proliferation, alter the efficiency of disinfection processes, or exert independent toxicological effects on human health (Shukla *et al.*, 2017; WHO, 2017; Dokubo *et al.*, 2022a; 2022b; Anidu *et al.*, 2023; Obiefoka *et al.*, 2023; Uba and Obiefuna, 2023; Ubajekwe *et al.*, 2025; Ekwenze *et al.*, 2025). When their concentrations exceed permissible limits established by regulatory bodies such as the World Health Organization (WHO, 2011; 2017, 2022), they compromise the safety and potability of drinking water supplies (Orji & Oghonim, 2023).

Given the complexity of interpreting multiple water quality variables simultaneously, the Water Quality Index (WQI) has emerged as a valuable mathematical and statistical tool for synthesizing large datasets into a single, comprehensible value that reflects the overall quality status of a water body (Rumman *et al.*, 2012; Uba and Chukwura, 2016; Uba *et al.* 2016; 2018a; 2018b; 2018c; 2019d; 2019e). By integrating

diverse physicochemical parameters into a unified scale, WQI facilitates communication of water quality information to policymakers, stakeholders, and the general public. It enhances understanding of spatial and temporal trends, supports decision-making processes, and evaluates the effectiveness of water protection and management strategies (Gorde and Jadhav, 2013; Tyagi *et al.*, 2020; Alisa *et al.*, 2020; Anukam *et al.*, 2020a; 2020b; Uba *et al.*, 2021a; 2021b). As such, WQI serves as an important instrument for environmental monitoring and sustainable water resource planning.

In Anambra State, Nigeria, the reliability of conventional water supply systems remains inconsistent in several communities, including in Anambra Central Senatorial Zone, Anambra State. This irregularity has compelled residents to rely predominantly on surface water sources, particularly streams, for domestic, agricultural, and small-scale industrial uses. Although numerous studies have investigated water quality within areas of study, there is limited empirical data regarding the comprehensive assessment of water quality indices in these adjoining communities. Detailed evaluation of the physicochemical characteristics and WQI of these streams is therefore crucial for identifying potential contamination sources, determining their suitability for consumption, and guiding appropriate water management interventions to mitigate public health risks. Accordingly, this study aims to evaluate the physicochemical parameters, determine the Water Quality Index (WQI), and assess the potability status of twenty - one selected streams in Anambra Central Senatorial Zone, Anambra State, Nigeria. The findings are expected to contribute to the existing body of knowledge on freshwater quality in the region and provide evidence-based recommendations for sustainable water resource management and public health protection.

## Materials and Methods

### Description of Study Area

The studied areas as shown in Figure 1 include: Mmiri St John Alor, Mmiri Mgbo Nnobi, Oba Stream in Idemili South Local Government Area, Ukwu Apku Stream Eziowelle, Mmiri Oraukwu Oraukwu, Mbuda Spring Water Abacha in Idemili North, Otti Spring Enugu Ukwu, Abagana Stream, Ogbujilekwe Stream Nimo in Njikoka Local Government Area Umudioka Stream, Ali Ukpo Stream Ukpo, Onyekwena Spring Water Ifitedunu, in Dunukofia Local Government Area, Agulu Lake Agulu, Adazi Nnukwu Stream, Nri Stream in Anaocha Local Government Area, Nkwelle Awka Stream, Abor River in Umuawulu, Umuaba River Nibo in Awka South Local Government Area and Umuife Iyiohia Urum Stream, Araka Stream Mgbakwu, Ogbanabo Stream Isuaniocha in Awka North Local Government Area all located in Anambra Central Senatorial Zone, Anambra State Nigeria. Their geological and anthropogenic characteristics have been described in our previous publications (Alfred *et al.* 2023; 2025; Idu *et al.*, 2026a; 2026b).

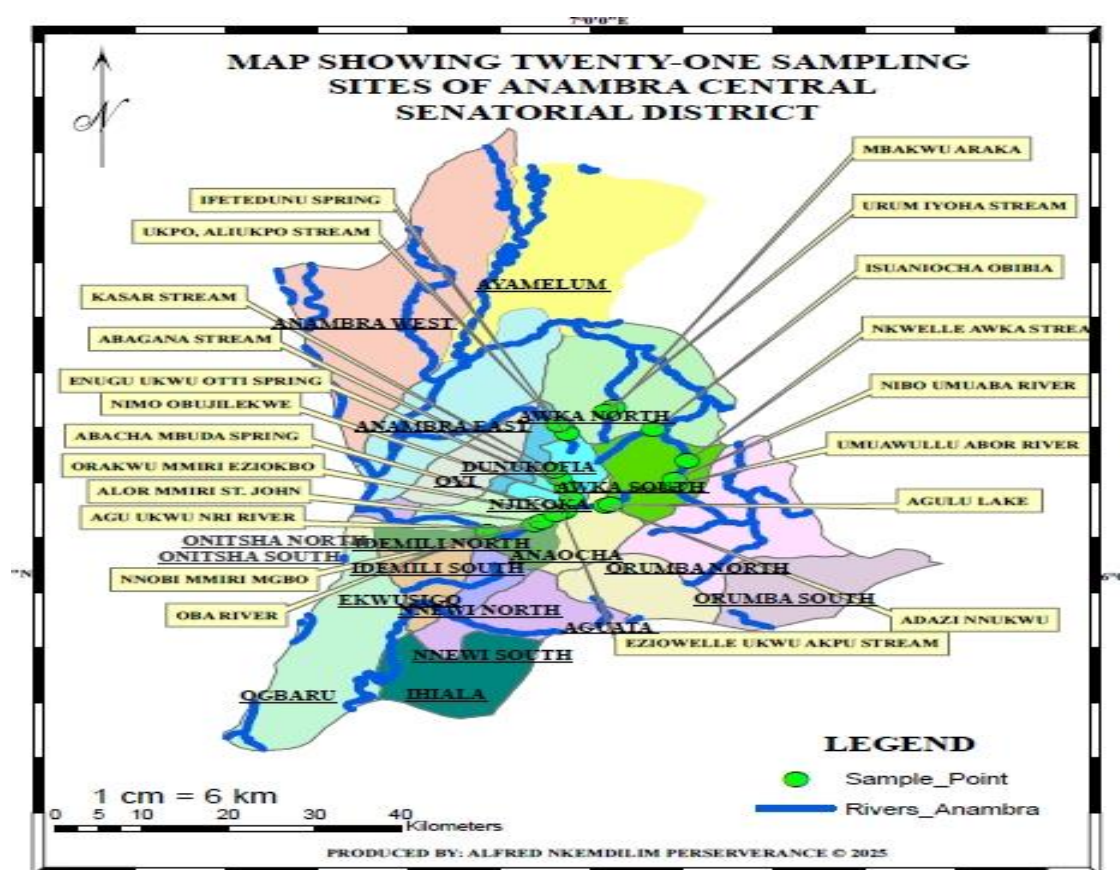


Figure 1: Map of twenty - one sampling sites in Anambra Central Senatorial Zone of Anambra State, Nigeria.

### Collection of Water Sample

Samples of Spring and Lake water were aseptically collected in triplicates from each of the four towns in four local government areas (Njikoka (Enugu Ukwu), Idemili North (Abacha), Anaocha (Agulu) and Dunukofia (Ifitedunu) using sterile sample bottles. The sampling method used for the rivers and stream water collection was the grab method as described by Oghonim (2023); Oghonim *et al.* (2023); (2026a); (2026b); Orji and Oghonim (2023); Dokubo *et al.* (2024); Uba and Okonkwo (2025); Okwonkwo *et al.* (2026) and Uba *et al.* (2026a) at Alor stream, Nnobi stream, Oba stream, Eziowelle stream, Oraukwu river, Abacha Spring Water, Otti Spring Enugu Ukwu, Abagana Stream, Ogbujilekwe Stream Nimo, Ali Ukpo Stream, Onyekwena Spring Water Ifitedunu, Agulu Lake, Adazi Nnukwu Stream, Nri Stream, Nkwelle Awka Stream, Abor River Umuawulu, Umuaba River Nibo, Umuife Iyohia Urum, Araka Stream Mgbakwu and Ogbanabo Stream Isuaniocha respectively (Alfred *et al.* 2025; Okolo *et al.* 2025). The river and stream water samples were collected in triplicates from different sampling points; downstream, middle stream and upstream using sterile 5 L cylindrical plastic containers, labeled, placed in a cooler and immediately were transported to the laboratory for analysis as described by Dibua *et al.* (2020), Ibo *et al.* (2020); Ibe *et al.* (2023), Chukwura *et al.* (2025); and Dibua *et al.* (2025a); (2025b); (2025c).

### Culture Media

The following media namely Nutrient agar, Chromocult Coliform Agar (CCA), Bile Aesculin Azide Agar (BAA), Thiosulfate Citrate Bile Salt Sucrose Agar (TCBS), Mannitol

Salt Agar (MSA) and Salmonella - Shigella Agar (SSA), Cetrimide Milk Agar (CMA), Bacillus Selective agar (BSA) Buffered Peptone Water and Nutrient Broth were used and prepared according to the manufacturer's specification (Ofunwa *et al.* 2024; Anameze *et al.*, 2023; Ele *et al.*, 2025; Ezeamama *et al.*, 2025a; 2025b; Uba and Udaba, 2026).

### Sterilization

As stated in Willey *et al.* (2008), conical flasks (Pyrex), prepared media and other plastic materials were sterilized by autoclaving at 121 °C for 15 min at a pressure of 15 psi. Glass wares such as pipettes, glass spreader, Petri dishes, measuring cylinder, and other glass materials were sterilized in the laboratory hot air oven at a temperature of 160°C for 1 hr before use (Nkamigbo *et al.* 2020a; 2020b; Uba, 2019; Okafor *et al.* 2021a; 2021b).

### Bacterial Isolation Technique

A direct spread plate with volumes of 0.1ml of aliquot was used. A ten-fold serial dilution method was used. Then, 0.1 mL from dilutions  $10^{-3}$  were inoculated onto a Nutrient agar, Chromocult Coliform Agar (CCA), Bile Aesculin Azide Agar (BAA), Thiosulfate Citrate Bile Salt Sucrose Agar (TCBS), Mannitol Salt Agar (MSA) and Salmonella - Shigella Agar (SSA), Cetrimide Milk Agar (CMA) and Bacillus Selective agar (BSA) respectively. The inoculated plates were incubated inverted at 37 °C for 24 hr. The respective counts were determined after incubation using an electric colony counter and colonies counted were expressed at CFU/mL (APHA, 2012; Iheukwumere *et al.*, 2012a; 2012b; Mundi *et al.*, 2013; 2014; Okoye *et al.*, 2013; 2014; 2020a; 2020b;

2020c; Uba *et al.*, 2024; Ifediegwu *et al.* 2023a; 2023b; Ifediegwu *et al.* 2024a, 2024b; 2024c; Uba and Umennadi, 2026; Umennadi *et al.*, 2026a; 2026b).

### Physicochemical Analysis

The following physicochemical parameters: temperature, pH, dissolved oxygen, biochemical oxygen demand (BOD<sub>5</sub>), chemical oxygen demand (COD), total suspended solid, ammoniacal nitrogen (NH<sub>3</sub>) and phosphate were determined using standard procedures (APHA, 2012; Njoku *et al.*, 2019a; 2019b Dokubo and Uba, 2023; Nwigwe *et al.*, 2022, Nwigwe *et al.*, 2023, Nnaka *et al.*, 2024; Okoye *et al.*, 2026; Ofunwa *et al.* 2026a; 2026b).

### Water Quality Classification

Classification in water quality index (WQI) was determined based on the water quality index as expressed below (Hanafiah *et al.*, 2018; Uba *et al.*, 2025):

$WQI = 0.22 \times SIDO + 0.19 \times SIBOD + 0.16 \times SICOD + 0.15 \times SIAN + 0.16 \times SITSS + 0.12 \times SIpH$  where: SIDO = SubIndex DO (% saturation), SIBOD = SubIndex BOD, SICOD = SubIndex COD, SIAN = SubIndex NH<sub>3</sub>-N, SISS = SubIndex SS and SipH = SubIndex pH.

### Statistical Analysis

The results of the data generated were expressed as mean  $\pm$  standard deviation (SD) using GraphPad Prism version 8.0.2. The data means were analyzed by two-way Analysis of Variance (ANOVA) followed by Tukey's to compare differences in the diversity of the pathogen composition of the three sampling sites and different sampling points. Threshold values less than 5 % ( $p < 0.05$ ) were considered statistically significant at 95 % confidence interval (Emmy – Egbe *et al.*, 2015; Enemchukwu *et al.*, 2026a; 2026b; Afulukwe *et al.*, 2025; 2026; Umezulora *et al.*, 2026a; 2026b).

### Results

The result of mean physicochemical profile of the twenty-one sampling sites as shown in Figure 1 - 8 revealed that Oraukwu sample had the highest temperature value of  $29.50 \text{ }^\circ\text{C} \pm 0.02$  while Alor sample had the lowest temperature value of  $28.80 \text{ }^\circ\text{C} \pm 0.03$  (Figure 1) which indicates moderates' temperature. Oba sample had the highest pH of  $6.61 \pm 0.01$  which shows the pH is slightly acidic while Abacha had the lowest pH of  $5.14 \pm 0.01$  which shows the pH is acidic (Figure 2). Nri sample had the highest total suspended solid of  $9.50 \pm 0.10$  mg/L while Ifitedunu and Agulu sample had the lowest total suspended solid of  $0.10 \pm 0.00$  mg/L (Figure 3). Umudioka had the highest dissolved oxygen of  $44.50 \pm 1.25$  mg/L while

Isuaniocha had the lowest dissolved oxygen of  $37.00 \pm 1.40$  mg/L (Figure 4). Nibo had the highest biochemical oxygen demand of  $44.80 \pm 0.87$  mg/L while Enugu-Ukwu had the lowest biochemical oxygen demand of  $28.00 \pm 1.60$  mg/L (Figure 5). Ukpo had the highest chemical oxygen demand of 350 mg/L while Nkwelle-Awka had the lowest chemical oxygen demand of  $65.00 \pm 1.50$  mg/L (Figure 6). Agulu had the highest ammoniacal nitrogen content of  $0.65 \pm 0.03$  ppm while Abagana had the lowest ammoniacal nitrogen content of  $0.46 \pm 0.02$  ppm (Figure 7). Ukpo had the phosphate value of  $15.81 \pm 0.50$  ppm while Urum had the lowest phosphate value of  $0.79 \pm 0.02$  ppm, respectively (Figure 8). Statistically, there were non-significant ( $p > 0.05$ ,  $F = 0.97$ ,  $p = 0.50$ ) differences detected among the means of sampling points and sites but there were significant ( $p < 0.05$ ,  $F = 141.3$ ,  $p < 0.0001$ ) differences detected among the means of physicochemical parameters.

Table 1 revealed cumulatively that Idemili North LGA had the highest temperature value of  $29.20 \pm 0.01$  while Awka North LGA had the lowest temperature value of  $28.70 \pm 0.05$ . Njikoka LGA had the highest pH value of  $6.30 \pm 0.00$  while Idemili North LGA had the lowest pH value of  $5.51 \pm 0.02$ . Anaocha LGA had the highest total suspended solid of  $3.23 \pm 0.02$  mg/L while Dunukofia LGA had the lowest total suspended solid of  $0.72 \pm 0.01$  mg/L. Idemili North LGA had the highest dissolved oxygen of  $42.10 \pm 0.30$  mg/L while Awka South LGA had the lowest dissolved oxygen of  $36.50 \pm 0.50$  mg/L. Awka South LGA had the highest biochemical oxygen demand of  $40.13 \pm 0.14$  mg/L while Awka North LGA had the lowest biochemical oxygen demand of  $27.50 \pm 0.35$  mg/L. Njikoka LGA had the highest chemical oxygen demand of  $311.70 \pm 6.05$  mg/L while Awka South LGA had the lowest chemical oxygen demand of  $168.30 \pm 3.50$  mg/L. Awka South LGA had the highest ammoniacal nitrogen content of  $0.57 \pm 0.01$  ppm while Njikoka and Idemili South LGA had the lowest ammoniacal nitrogen content of  $0.51 \pm 0.01$  ppm. Dunukofia LGA had the highest phosphate value of  $13.16 \pm 0.20$  ppm while Awka North LGA had the lowest phosphate value of  $6.77 \pm 0.10$  ppm, respectively. Statistically, there were non-significant ( $p > 0.05$ ,  $F = 1.136$ ,  $p = 0.3588$ ) differences detected among sampling site Local Government Area but there were significant ( $p < 0.05$ ,  $F = 194.8$ ,  $p < 0.001$ ) differences detected among the means of physicochemical parameters.

Water quality index (WQI) result of the sampling sites as shown in Figure 4.1 revealed that Oba had the highest WQI value of 74 and Alor had the lowest WQI value of 33, respectively.

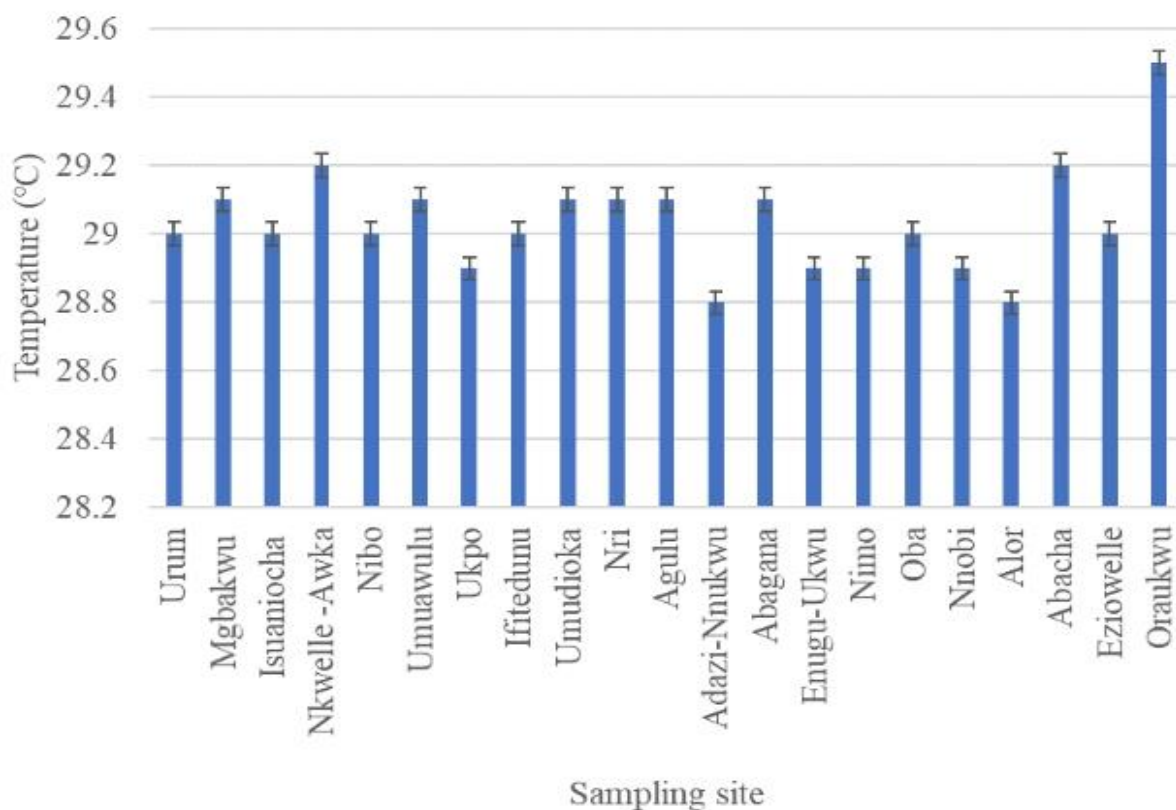


Figure 1: Temperature profile of the 21 sampling sites studied  
*N.B: Error bar = mean standard deviation; °C = Degree celsius*

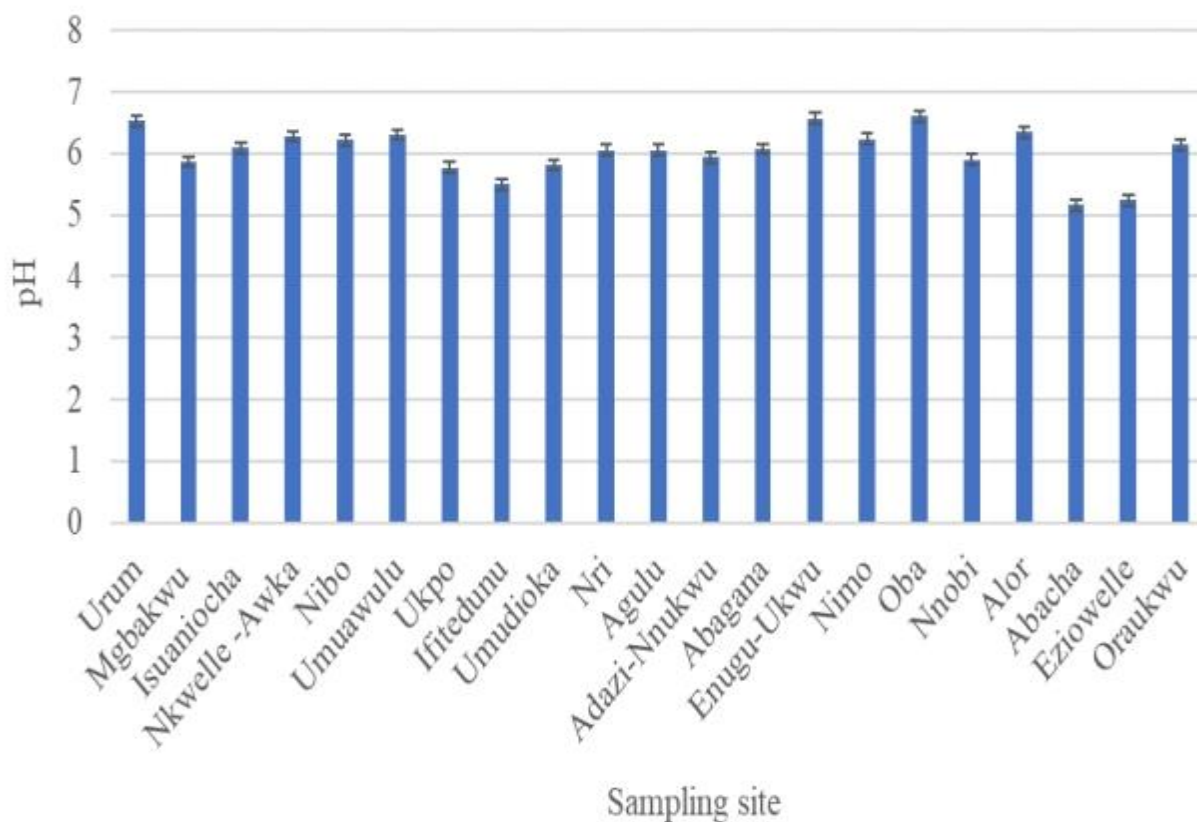


Figure 2: pH profile of the 21 sampling sites studied  
*N.B: Error bar = mean standard deviation*

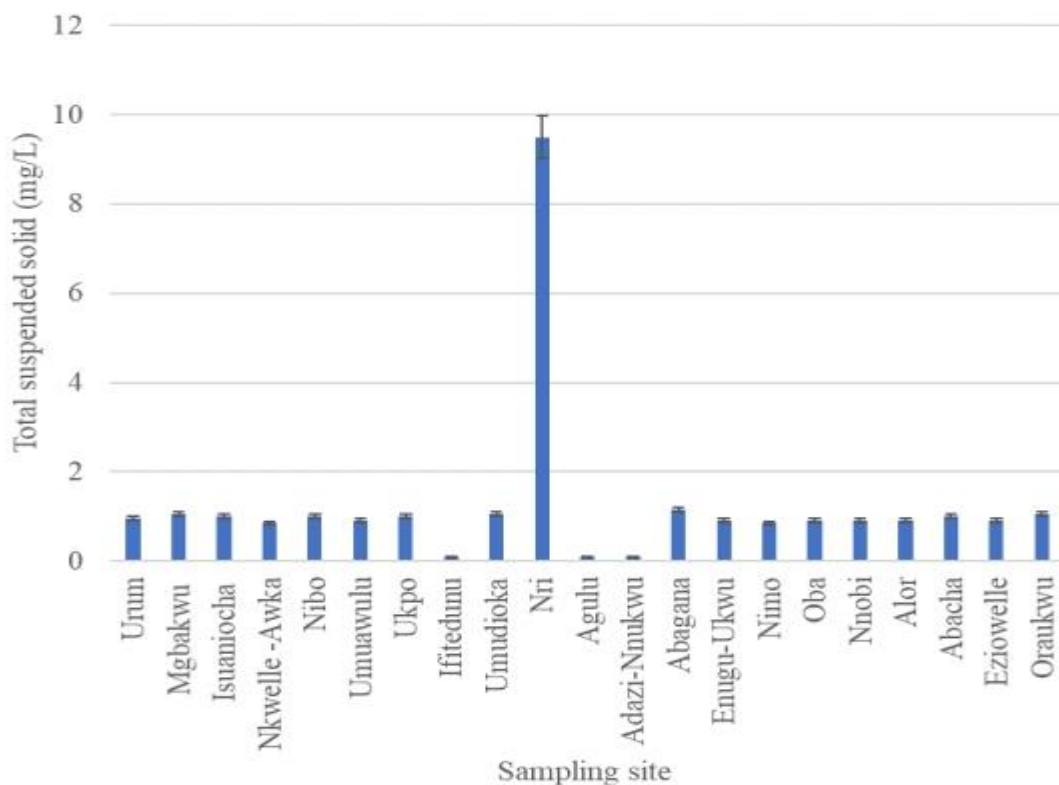


Figure 3: Total suspended solid profile of the 21 sampling sites studied  
*N.B: Error bar = mean standard deviation; mg/L = Milligram per litre*

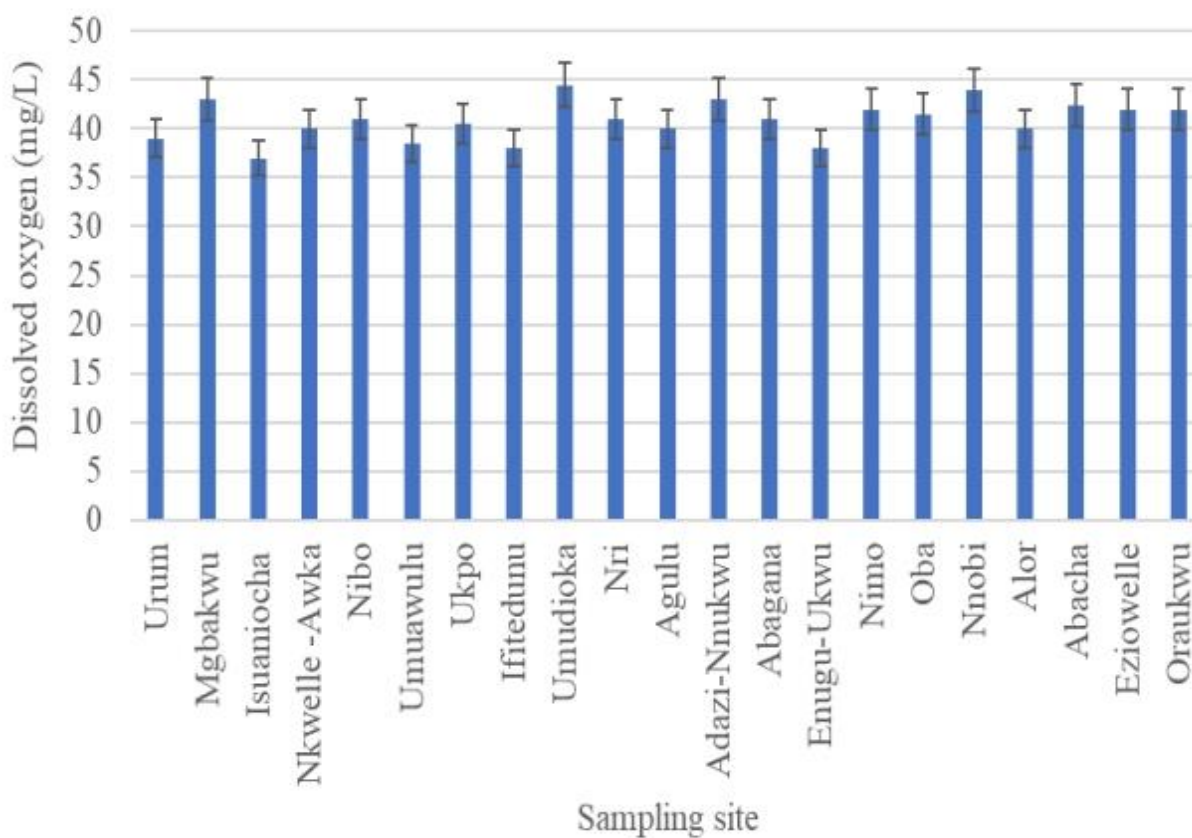


Figure 4: Dissolved oxygen (DO) profile of the 21 sampling sites studied  
*N.B: Error bar = mean standard deviation; mg/L = Milligram per litre*

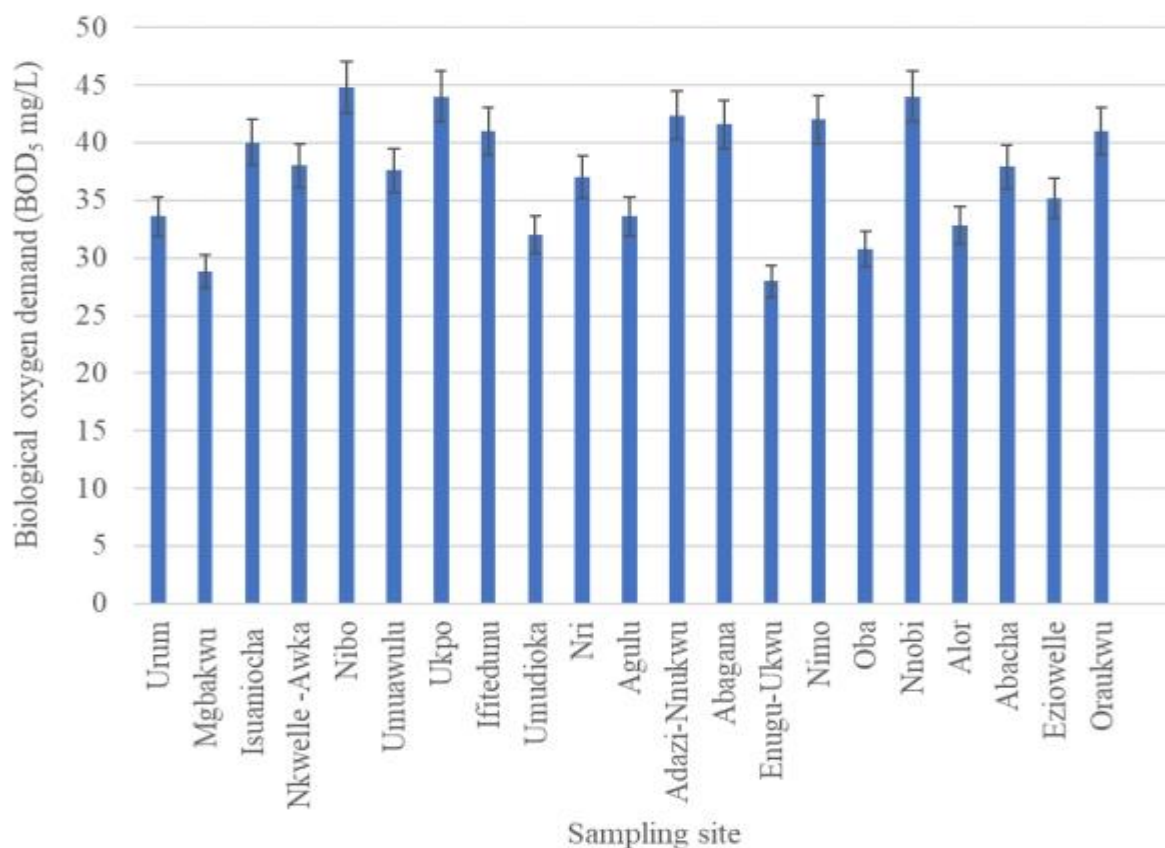


Figure 5: Biological oxygen demand (BOD<sub>5</sub>) profile of the 21 sampling sites studied  
*N.B: Error bar = mean standard deviation; mg/L = Milligram per litre*

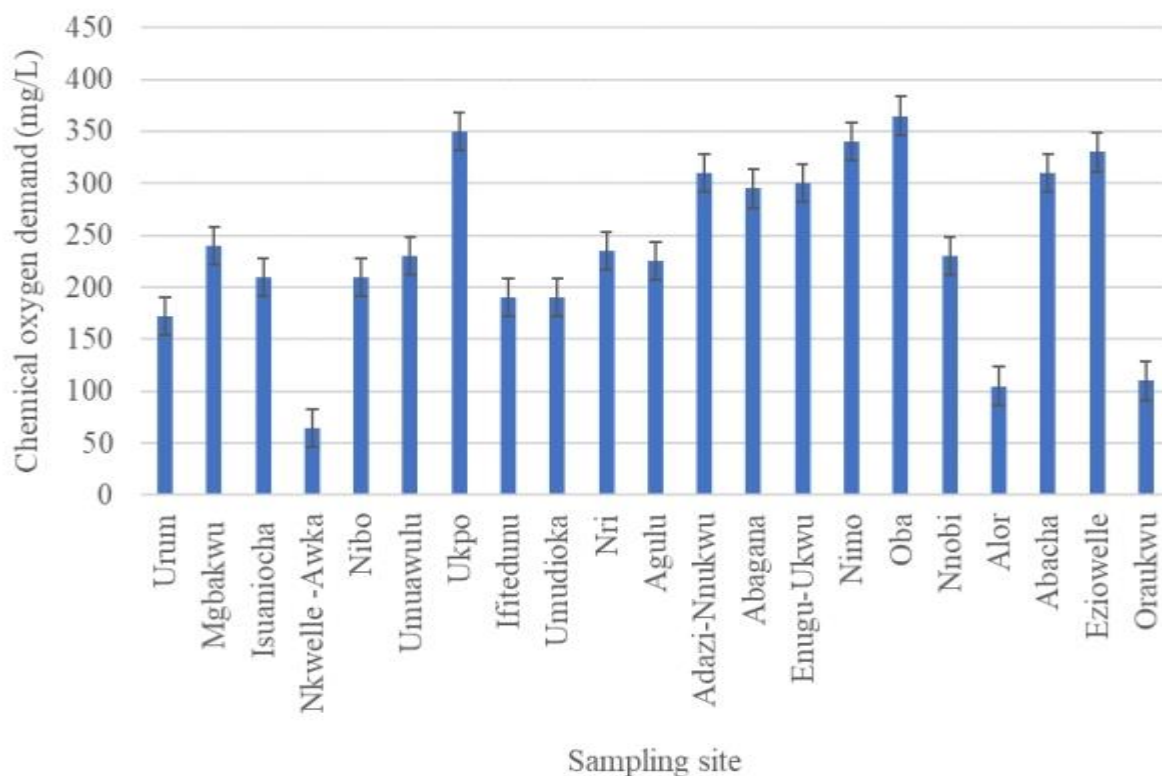


Figure 6: Chemical oxygen demand profile of the 21 sampling sites studied  
*N.B: Error bar = mean standard deviation; mg/L = Milligram per litre*

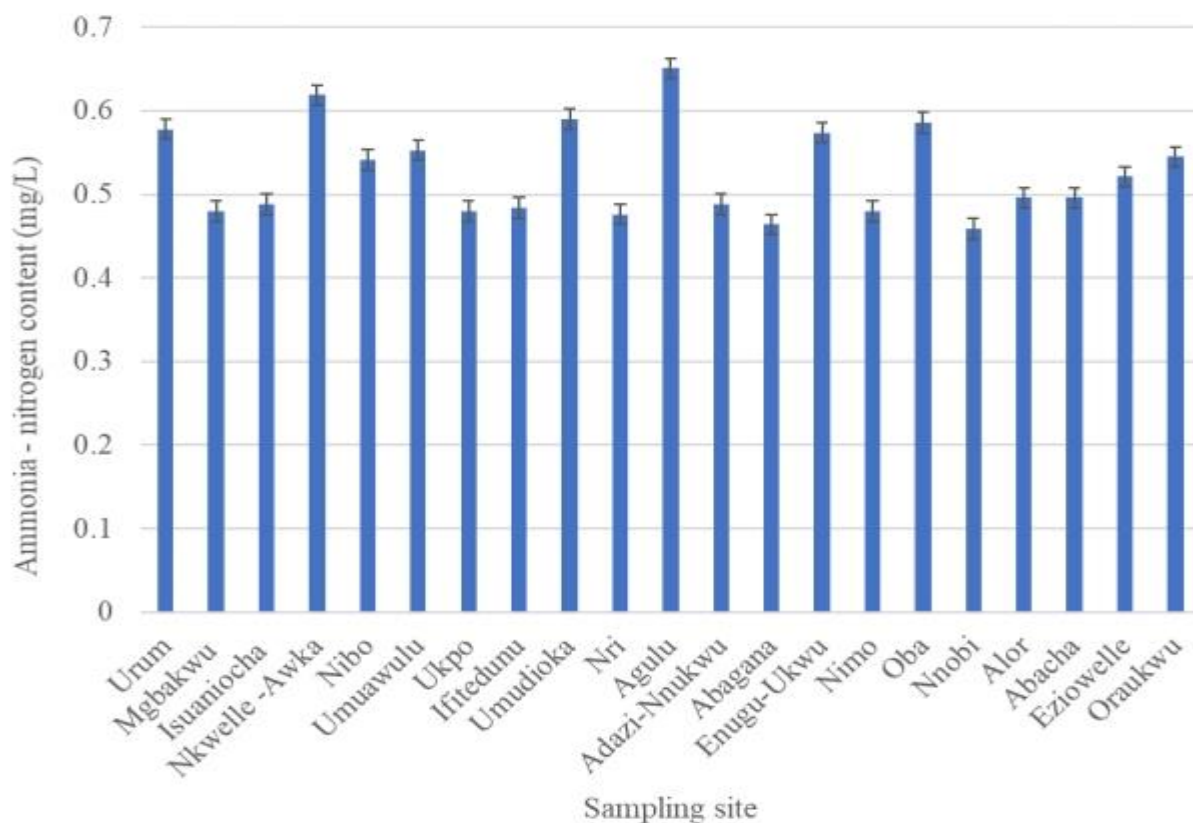


Figure 7: Ammonia – nitrogen profile of the 21 sampling sites studied  
*N.B: Error bar = mean standard deviation; mg/L = Milligram per litre*

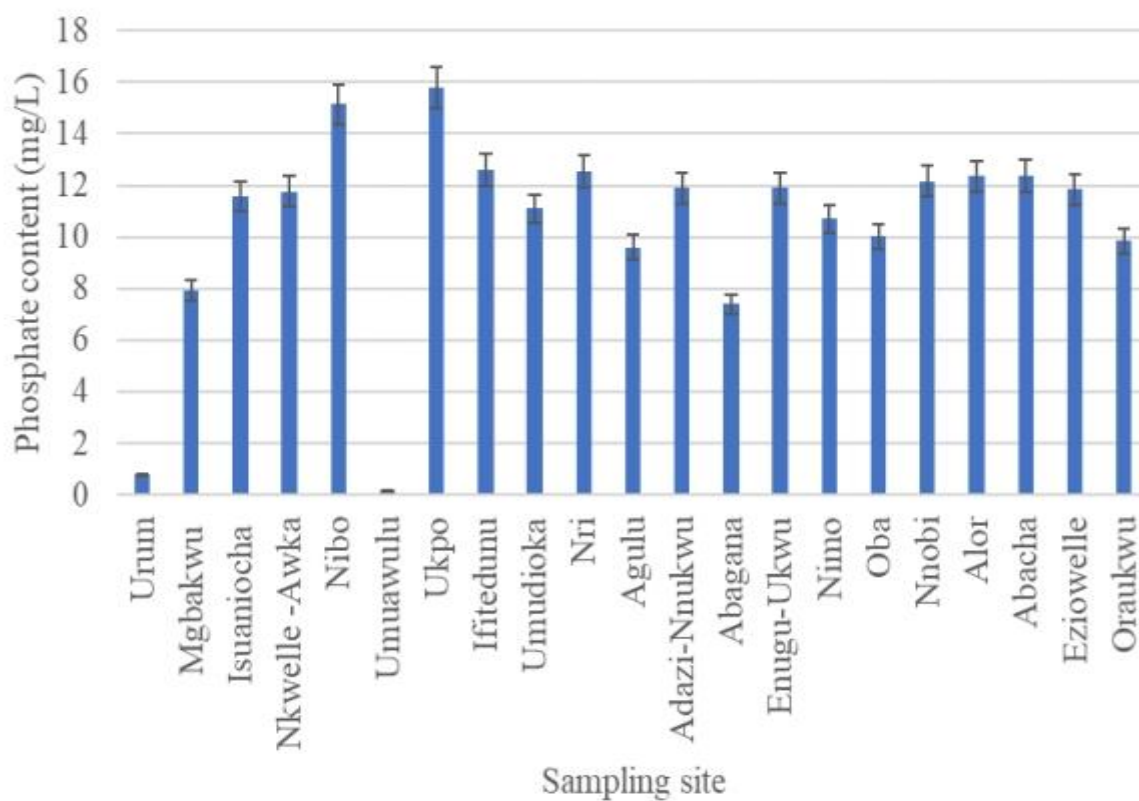


Figure 8: Phosphate content profile of the 21 sampling sites studied  
*N.B: Error bar = mean standard deviation; mg/L = Milligram per litre*

Table 1: Cumulative mean physicochemical profile of different sampling sites at the seven Local Government Areas

Sampling site	Colour	Odour	Temp (°C)	pH	TSS (mg/L)	DO (mg/L)	BOD <sub>5</sub> (mg/L)	COD (mg/L)	NH <sub>3</sub> (ppm)	PO <sub>4</sub> <sup>3-</sup> (ppm)
Awka North	Not clear	Unobjectionable	28.70±0.05	6.02±0.02	1.00±0.01	37.70±0.78	27.50±0.35	219.30 ±2.30	0.52±0.03	6.77±0.10
Awka South	Clear	Objectionable	29.10±0.01	6.27±0.01	0.92±0.01	36.50±0.50	40.13±0.14	168.30±3.50	0.57±0.01	9.02±0.05
Dunukofia	Clear	Unobjectionable	29.00±0.02	5.70±0.02	0.72±0.01	41.00±0.35	39.00±0.35	243.30±2.35	0.52±0.02	13.16±0.20
Anaocha	Clear	Objectionable	29.00±0.02	6.02±0.01	3.23±0.02	41.30±0.25	37.67±0.21	256.70±4.50	0.54±0.02	11.35±0.08
Njikoka	Clear	Objectionable	29.00±0.01	6.30±0.00	0.97±0.02	40.30±0.15	37.20±0.50	311.70±6.05	0.51±0.01	10.00±0.05
Idemili South	Clear	Objectionable	28.90±0.02	6.29±0.01	0.90±0.01	41.80±0.20	35.90±0.20	233.30±3.00	0.51±0.01	11.51±0.10
Idemili North	Not clear	Unobjectionable	29.20±0.01	5.51±0.02	0.98±0.01	42.10±0.30	38.04±0.17	250.00±3.35	0.52±0.04	0.52±0.04

N.B.: TEMP = Temperature; TSS = Total suspended solid; DO = Dissolved oxygen; BOD<sub>5</sub> = Biological oxygen demand; Chemical oxygen demand; NH<sub>3</sub> = Ammonia nitrogen content; PO<sub>4</sub><sup>3-</sup> = Phosphate content; Error bar ± = mean standard deviation; °C = Degree Celsius; mg/L = Milligram per litre; ppm = part per million.

The Pearson’s correlation matrix between bacterial count and physicochemical parameters of twenty-one sampling sites are presented in Table 2. THABC was observed to have a positive significant correlation with TSSC (r = 0.54), TVC (r = 0.55), TSC (r = 0.69), TBC (r = 0.44), DO (r = 0.56) and COD (r = 0.37). TCC had a positive correlation with TFCC (r = 0.62), TSSC (r = 0.56) and a poor negative correlation with BOD<sub>5</sub> (r = - 0.34) and PO<sub>4</sub><sup>3-</sup> (r = - 0.25). TPC had positive correlation with TBCC (r = 0.34) and COD (r = 0.36), DO had a positive correlation with THBAC (r = 0.56), TSC (r = 0.41) and TBC (r = 0.44). pH had a positive weak correlation with NH<sub>3</sub> (r = 0.39) at P < 0.05

Table 2: Pearson correlation matrix between bacterial group and physicochemical parameter in twenty-one sampling sites studied

	THABC	TCC	TFCC	TSSC	TVC	TPC	TFSC	TSC	TBCC	Tem	pH	TSS	DO	BOD <sub>5</sub>	COD	NH <sub>3</sub>	PO <sub>4</sub> <sup>3-</sup>
THABC	1.00																
TCC	0.41	1.00															
TFCC	0.25	0.62	1.00														
TSSC	0.54	0.56	0.26	1.00													
TVC	0.55	-0.05	-0.09	0.40	1.00												
TPC	0.26	0.42	-0.15	0.53	0.12	1.00											
TFSC	0.00	-0.22	-0.15	-0.18	0.03	-0.21	1.00										
TSC	0.69	0.54	0.04	0.43	0.49	0.31	-0.27	1.00									
TBCC	0.44	0.06	-0.17	0.30	0.41	0.34	0.17	0.39	1.00								
TEM	-0.05	0.12	0.16	0.19	-0.07	0.09	0.23	-0.21	-0.19	1.00							
pH	-0.43	0.16	0.06	-0.36	-0.33	-0.02	-0.06	-0.11	-0.57	-0.13	1.00						
TSS	-0.07	-0.06	0.07	-0.09	-0.06	0.01	-0.08	-0.03	-0.15	0.14	0.04	1.00					
DO	0.56	0.16	0.05	0.11	0.13	0.17	0.18	0.41	0.44	0.10	-0.35	0.04	1.00				
BOD <sub>5</sub>	-0.08	-0.34	-0.41	-0.24	-0.16	-0.12	-0.15	-0.04	-0.06	-0.02	-0.26	-0.03	0.08	1.00			
COD	0.37	0.06	0.19	0.25	0.29	0.36	-0.17	0.17	0.20	-0.38	-0.03	-0.03	0.06	-0.07	1.00		
NH <sub>3</sub>	-0.30	-0.10	-0.01	-0.25	0.07	-0.15	0.25	-0.20	-0.23	0.30	0.39	-0.23	-0.17	-0.48	-0.15	1.00	
PO <sub>4</sub> <sup>3-</sup>	0.07	-0.25	-0.36	-0.22	0.07	-0.09	-0.41	0.26	0.13	-0.22	-0.36	0.11	0.22	0.30	-0.22	-0.26	1.00

N.B: THABC = Total heterotrophic aerobic bacterial count; TCC = Total coliform count; TFCC = Total faecal coliform count; TSSC = Total Salmonella Shigella count; TVC = Total Vibrio count; TPC = Total Pseudomonas count; TFSC = Total faecal Streptococcal count; TSC = Total Staphylococcal count; TBCC = Total Bacillus cereus count; Tem = Temperature, DO = Dissolved oxygen, BOD<sub>5</sub> = Biochemical oxygen demand, COD = Chemical oxygen demand, TSS = Total suspended solid, NH<sub>3</sub> = Ammoniacal nitrogen, PO<sub>4</sub><sup>3-</sup> = Phosphate; Correlation is significant at 0.05 level (2 – tailed)

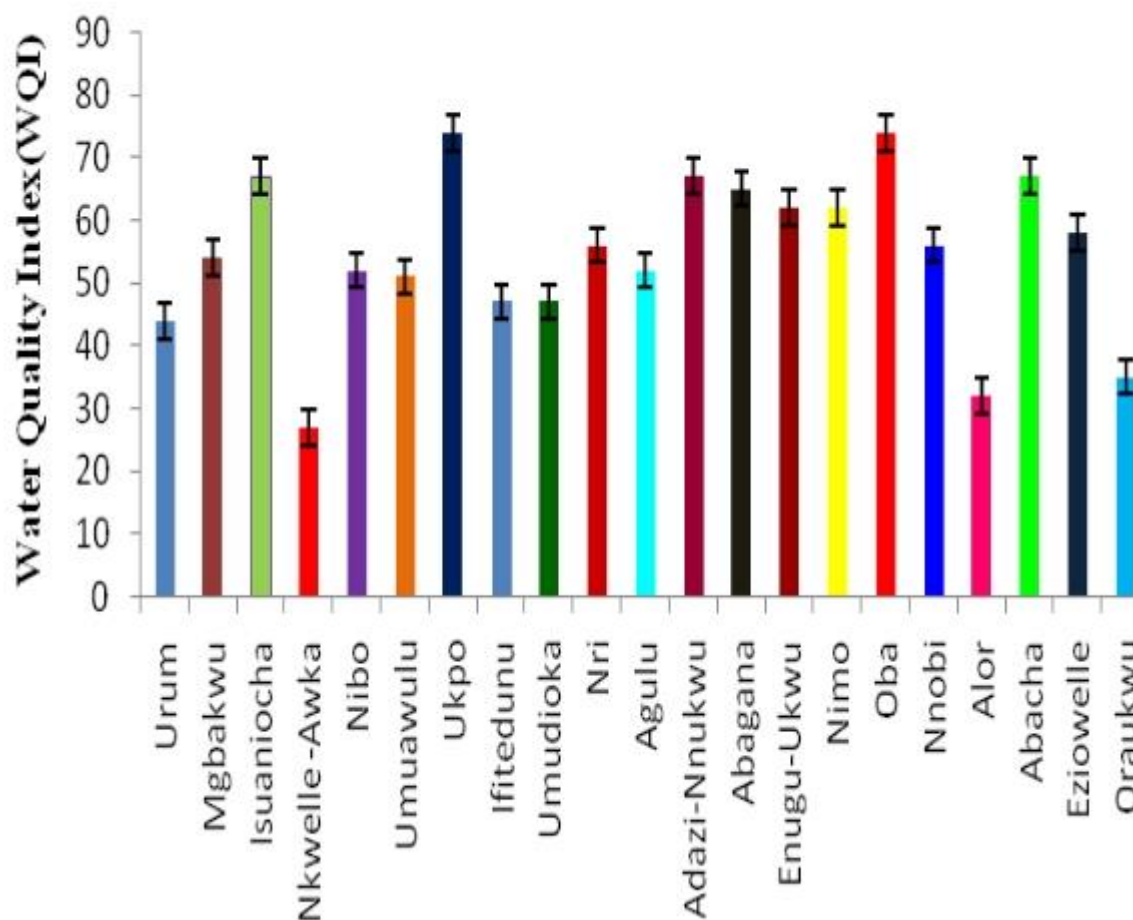


Figure 9: Water quality profile of the 21 sampling sites studied

## Discussion

Physicochemical parameters of water are indices used in determining water quality. The parameters analyzed in this study were pH, temperature, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, total suspended solid, ammonical – nitrogen and phosphate, respectively as previously described by Anichebe *et al.* (2019), Alfred *et al.* (2023), Nnaka *et al.* (2024); Okeke *et al.* (2025a), (2025b), Uba *et al.* (2020h), Uba *et al.* (2026b), Uba *et al.* (2026c) and Dokubo and Uba (2026).

In determining the quality of water, temperature is one of the physicochemical parameters used to evaluate quality of potable water. It affects many phenomena including the rate of chemical reactions in the water body, reduction in solubility of gases and amplification of taste and colour of water (Alfred *et al.*, 2023). The parameter is important in water analysis because it gives the idea of regulating temperatures based on seasonal variations (Baba *et al.*, 2020). When the Temperatures are high, it can have an adverse effect on the aquatic animals because it reduces dissolved oxygen that could cause the mortality of fish and other aquatic organisms (Usman, 2016; Baba *et al.*, 2020). The mean temperature from the current research ranged from  $28.80^{\circ}\text{C} \pm 0.03$  to  $29.50^{\circ}\text{C} \pm 0.02$ , respectively which showed moderate temperature. Temperature values were above WHO (2017) recommended level ( $15^{\circ}\text{C} - 25^{\circ}\text{C}$ ).

pH is a significant consideration as it has an impact on a variety of biological and chemical processes in watercourses. It is a method of determining acidity or alkalinity, as well as the sum of hydrogen ions in water. The pH values ranged from 5.16 to 6.61 (Figure 2). The pH value of 5.16 showed the water sample is acidic and 6.61 showed slightly acidic. However, in this study minimum pH value varied from ( $5.16 \pm 0.01$  to  $6.35 \pm 0.01$ ) respectively were below WHO WHO (2017) standard (6.5 - 8.5) indicating that these water samples are too acidic for human consumption and can lead to acidosis. Low pH values do have synergistic effects on heavy metal toxicity in water bodies (Adesakin *et al.*, 2020) while maximum value  $6.61 \pm 0.01$  was recorded from Urum sample and fall within WHO (2017) standard (6.5 - 8.5).

Total suspended solid (TSS) include a wide variety of material, such as silt, decaying plant animal matter, industrial waste and sewage. High concentrations of suspended solids can cause many problems for stream health and aquatic life (Alfred *et al.*, 2023). The maximum threshold limit of TSS for Malaysian rivers which support aquatic life is 150 mg/L (Al - Badaii *et al.*, 2013). TSS values recorded in this study ranged from  $0.10 \pm 0.00$  to  $1.05 \pm 1.05$  mg/L are within the range of the limit (Figure 3).

Dissolved oxygen (DO), refers to the quantity of oxygen gas present in a water body. All types of life, including species responsible for self-purification mechanisms in aquatic ecosystems, require oxygen (Ostroumo, 2017). Dissolved oxygen (DO) measures the amount of gaseous oxygen dissolved in aqueous solution. Oxygen gets into water by diffusion from the surrounding air, by aeration and as a waste product of photosynthesis from phytoplankton, algae, seaweed and other aquatic plants (Othman *et al.*, 2012). The amount of dissolved oxygen varies depending on temperature, pressure and salinity. Solubility of oxygen decreases as temperature increases. This is due to the fact that warmer surface water requires less dissolved oxygen to reach 100 % air saturation compared to cooler water. In freshwater systems such as lakes, rivers and streams, dissolved oxygen concentrations will vary by season, location and water depth and it will decrease with higher temperature, salinity and elevation (Alfred *et al.*, 2023). The DO from this study ranged between  $(37.00 \pm 1.40 - 44.50 \pm 1.25 \text{ mg/L})$  (Figure 4). The result was above the WHO (2017) standard (10 – 12 mg/L) for dissolved oxygen in fresh water.

Biochemical oxygen demand after 5 days ( $BOD_5$ ) is a measurement of the amount of dissolved oxygen used by aerobic microorganisms when decomposing organic matter in water. Microorganisms such as bacteria are responsible for decomposing organic waste. When organic matter such as dead plants, leaves, grass clippings, manure, sewage or even food waste is present in a water supply, the bacteria will begin the process of breaking down this waste. When this happens, much of the available dissolved oxygen is consumed by aerobic bacteria, affecting oxygen level needed for other aquatic organisms (USGS, 2016). Although no guideline set for the maximum tolerable limit of  $BOD_5$  in drinking water, for fisheries and aquatic life, European Union and Ethiopia recommend 3 - 6 mg/L and less than 5 mg/L, respectively. The  $BOD_5$  values ranged from  $28.00 \pm 1.60$  to  $44.00 \pm 0.65 \text{ mg/L}$ , respectively (Figure 5). The observed results were above permissible limits. This suggests that stream water sources were polluted by organic matter and corroborated with previous study by Alfred *et al.* (2023).

Chemical Oxygen Demand (COD) is a measurement of the oxygen required to oxidize soluble and particulate organic matter in water (Kunlasak *et al.*, 2013; Uba *et al.* 2026b; 2026c). It is used to measure the total quantity of oxygen-consuming substances in the complete chemical breakdown of organic substances in water. It does not differentiate between biologically available and inert organic matter. COD measurements can be made in a few hours while  $BOD_5$  measurement takes five days (Othman *et al.*, 2012). Generally, the lower COD level indicates a low level of pollution, while the high level of COD points out the high level of pollution of water in the study area (Hanafiah *et al.*, 2018). The COD value obtained in this study varied from  $(105.00 \pm 1.45 - 365 \pm 2.50 \text{ mg/L})$  which showed high level of pollution (Figure 6).

Ammoniacal nitrogen ( $NH_3$ ) is common pollutant in freshwater ecosystem is associated with organic compound or sometimes from industrial effluents (Magdalena *et al.*, 2015).

AbdelRaouf (2012) stated that the presence of  $NH_3$  in the water is mainly originated from the domestic sewage and waste water from certain types of industries. Ammoniacal nitrogen indicates nutrient status, organic enrichment and health of water body (Radojevic *et al.*, 2007). Higher  $NH_3$  value can be toxic to fish, but in small concentrations, it could serve as nutrients for excessive growth of algae (Al-Badaii *et al.*, 2013). The maximum threshold level of  $NH_3N$  for Malaysian rivers which support aquatic life is 0.901 ppm. The value of  $NH_3N$  obtained from this study varied from  $0.46 \pm 0.02 - 0.65 \pm 0.03 \text{ ppm}$  are still within the range (Figure 7).

Detection of phosphate in the aquatic ecosystem are soils and dissolving of sedimentary rocks, manure, organic wastes in sewage, industrial effluent, and agricultural fertilizers when it rains, varying amounts of phosphates wash from farm soils into nearby waterways, and stimulate the growth of plankton and water plants that provide food for fish (Rai *et al.*, 2012). In this study, the value varied from  $0.79 \pm 0.02 - 15.81 \pm 0.50 \text{ ppm}$  (Figure 8). Generally, standard value of phosphate in streams is 0.0100 ppm (EPA, 2019). The values obtained were above EPA permissible level. Statistically, there were non-significant ( $p > 0.05$ ,  $F = 0.97$ ,  $p = 0.50$ ) differences detected among the means of sampling points and sites but there were significant ( $p < 0.05$ ,  $F = 141.3$ ,  $p < 0.0001$ ) differences detected among the means of physicochemical parameters.

Water quality index (WQI) present water quality in terms of index number and provides very useful information to the public on the water for any use or to help reduce pollution where it is eminent as well as water quality management (Qureshimatva *et al.*, 2015). Surface water with WQI value of 0 to 59 is considered polluted and falls under Class III category, 60 to 80 is slightly polluted and falls under Class II category and 81 to 100 is considered the water body is clean and falls under Class I category (Hanafiah *et al.*, 2019). A higher value indicates a better quality of water (Rashid *et al.*, 2013). The result obtained from this study of the twenty-one sampling sites (Figure 9) showed WQI fall under category III (polluted category) and category II (slightly polluted category) and corroborated with the findings of Alfred *et al.* (2023) but contradicts the report of Otene and Alfred – Ackiya, (2019) who stated the WQI of the three locations were found to be 31.269, 29.050 and 26.429, respectively. Furthermore, the results of Pearson correlation matrix in Table 2 revealed that there were significant ( $p < 0.05$ ) ecological interactions among different bacterial groups physicochemical quality parameters in twenty-one sampling sites respectively. In our study, we observed positive correlations between bacterial counts and the physicochemical parameters of the selected freshwater bodies. The occurrence of positive correlations between bacterial counts and the physicochemical parameters of the freshwater bodies agreed with the study of Adesakin *et al.* (2020) on the assessment of bacteriological quality and physico-chemical parameters of domestic water sources in the Samaru community, Nigeria. These findings demonstrated that these pathogenic bacterial communities are greatly influenced by pH, temperature, dissolved oxygen, biological oxygen demand, chemical oxygen demand, total suspended solid, ammoniacal nitrogen and phosphate (Table 1). It is

reported that faecal coliform levels were lower at higher temperature, high dissolved oxygen and high pH implying that one of the faecal coliform sources could be related to human recreational activities (Al-Badaii *et al.*, 2013). Hanafiah *et al.* (2018) reported that water with lower pH value helps in maintaining the survival of indicator bacteria. They also stated that the optimal pH value for coliform survival is between pH 6 and pH 7 and other pH value above or below these range can cause rapid decline in fecal coliform population. The bacteria population is influenced by favourable condition and food sources provided by the sediments for the bacteria. Lower temperature of surface water can cause rapid decline in coliform and *E. coli* population in the water.

## Conclusion

This study demonstrated significant spatial variations in the physicochemical characteristics of water bodies across the selected Local Government Areas. The differences observed in temperature, pH, total suspended solids, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, ammoniacal nitrogen, and phosphate concentrations indicate varying degrees of environmental influence and anthropogenic impact. Parameters such as elevated biochemical and chemical oxygen demand in certain areas suggest organic pollution and potential ecological stress, while variations in nutrient levels reflect possible inputs from domestic, agricultural, or industrial activities. The statistically significant differences among the measured parameters confirm that water quality is not uniform across the study locations. These findings underscore the importance of continuous physicochemical monitoring to detect early signs of environmental degradation and to safeguard public health. Overall, the study provides essential baseline data for water quality management and highlights the need for effective regulatory enforcement and sustainable water resource protection strategies within the zone.

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