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Determination of Optimal Sampling Strategy and Water Quality Characterization of Ikere Reservoir, Iseyin, South-West Nigeria

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ABSTRACT

Water resources are essential for sustaining human life and socioeconomic activities, with reservoirs serving as critical water bodies. However, limited data on the Ikere reservoir's current water quality hinders effective management. This research aims to assess the quality of water variation to develop an optimal sampling strategy for the Ikere Gorge Dam, Iseyin, Oyo State. Nigeria. Laboratory analysis was conducted on six (6) water samples from both the rainy and dry seasons at the study area, adhering to APHA (2017) Standard Methods for the Examination of Water and Wastewater, and encompassing physicochemical and biological parameters as well as heavy metals. The results were compared to Nigeria's Food and Drug Administrative Control (NAFDAC, 2020) and World Health Organization (WHO, 2017) standards. Principal Component Analysis (PCA) and Cluster Analysis (CA) were employed for the statistical analysis of the water quality parameter data to determine the optimal sampling strategy within the study area. The physicochemical, heavy metals, and biological parameters for the rainy and dry seasons, including pH, electrical conductivity, temperature, turbidity, total dissolved solids, E. coli e.t.c showed values ranging from 6.41 to 6.77, 72.23 to 91.37 µS, 24.10 to 29.23°C, 1.30 to 10.23 NTU, 0.01 to 0.10 mg/L, and 12.33 to 47.67 MPN/100mL. Parameters such as turbidity, phosphates, DO, and E. coli exceeded WHO and NAFDAC standards. This indicates potential health risks and environmental pollution. PCA results indicate the variance distribution across five principal components, with significant clustering patterns. In conclusion, integrating CA and PCA is essential for effective water quality assessment at Ikere Gorge Dam. CA identified distinct clusters, while PCA revealed key factors like COD and hardness reflecting natural influences and turbidity and copper indicating pollution.

INTRODUCTION

Water resources serve a significant role in maintaining human existence while facilitating an extensive range of economic and social endeavors, with reservoirs constituting among the most important forms of water bodies (Loucks *et al.*, 2017). Reservoirs serve multiple purposes, including the provision of water for domestic consumption, irrigation, industrial processes, and fisheries. Ho and Goethals, (2019). However, with increasing population pressure and industrial development, the management of reservoirs has become a complex challenge, necessitating careful monitoring and sustainable use (Guo *et al.*, 2021).

The Ikere Reservoir, located in Iseyin, Southwest Nigeria, serves as a critical water source for various purposes, including domestic use, irrigation, and fisheries. Concerns regarding its water quality have escalated due to increasing human activities around the reservoir, such as agriculture, industrial discharge, and urbanization, all of which contribute to pollution (Ogunbisi *et al*., 2021). Agricultural runoff, particularly from the use of fertilizers and pesticides, has been known to introduce harmful contaminants like nitrates and phosphates into water bodies, leading to eutrophication and the degradation of water quality (Ogunbisi *et al*., 2021).

Conversely, despite the importance of the Ikere Reservoir, there is a lack of comprehensive data on its current water quality, which makes it challenging to formulate effective management and intervention strategies. The Ikere Gorge Dam is a significant earth-fill dam on the Ogun River in Oyo States Iseyin local government area in the southwest of Nigeria. Nigeria's Oyo region includes the town of Iseyin. Iseyin Local Government Area, however, is one of the local governments that make up Oyo State's Oke Ogun Region. Geographically, the Local Government is located at 7°58′ 0″ N and 3°36′ 0″ E. Olusegun Obasanjo's military regime planned the dam, which has a 690 million m^3 reservoir capacity. Construction on the dam started in 1982, during the administration of Shehu Sagari. The dam was planned to produce 37.5 Megawatts of electricity in addition to supplying water for irrigation, drinking, recreation, and navigation (Abegunrin *et al*., 2021).

Furthermore, an equally significant issue is the absence of an optimal sampling strategy for monitoring the quality of water in Ikere Reservoir. The parameters of water quality can exhibit spatial and temporal variations depending on various factors, such as hydrological conditions, the nature of pollutant sources, and seasonal changes (Ibrahim *et al.,* 2021).

The research focused on creating a study map using ArcGIS 10.8 after a reconnaissance survey was conducted to identify the most optimal sampling locations.

RESEARCH METHODOLOGY

Mapping Sampling Points Across the Reservoir

Sampling points across Ikere Reservoir were determined using a combination of field reconnaissance and geospatial analysis. Coordinates of potential sampling locations were recorded using a GPS device along each tributary. These points were selected to capture differences in water quality across the reservoir. The data were imported into ArcGIS software, where a study map was created.

Sampling Collection and Analysis

Sampling Collection

Samples of water were taken from six (6) sampling locations which include Owu, Alagbon, Asamu, Damside, Gate 1, and Gate 2 around the Ikere reservoir using conventional techniques and procedures, as illustrated in Figure 1.0. The field research was done from September 2023 to September 2024, encompassing both the dry and wet seasons, respectively. Samples were collected in a 2 L plastic container that had been prepped by rinsing in diluted hydrochloric acid and then washed in distilled water. This preparation ensures that sample contamination is minimized, providing accurate results for subsequent analysis. The sample vials were labeled with the sample points and dates. At each sample collecting station, the plastic containers were washed multiple times with surface water.

Fast-changing parameters such as temperature were determined in situ, while other physicochemical properties like pH, color, turbidity, total hardness, conductivity, total dissolved solids (TDS), total suspended solids (TSS), total alkalinity, and samples for biochemical oxygen demand (BOD), chemical oxygen demand, and heavy metals were collected separately. Heavy metal samples were acidified with nitric acid to maintain pH < 2.

Figure 1: Collection of Water samples across the Study Area

All samples were preserved at temperatures below 4°C and transported to the Water Resources and Environmental Laboratory (LAUTECH) Ogbomoso, Oyo State, Nigeria, where all ex-situ analyses were conducted.

Laboratory Analysis

The laboratory analysis of water samples collected from the study area was examined highlighting the physico-chemical properties, bacteriological characteristics, and concentrations of heavy metals in the water quality. The pH is assessed using a calibrated pH meter, while color determination relies on a spectrophotometer measuring absorbance at 455 nm. Turbidity is measured with a nephelometric turbidimeter, expressed in NTU, by ISO (2016). Total hardness is determined through EDTA titration, with Eriochrome Black T as the indicator, following APHA (2017).

Conductivity is evaluated using a conductivity meter calibrated with KCl solutions, while TDS and TSS are analyzed through the evaporation and filtration methods, respectively. Total alkalinity is determined by titration with H_2SO_4, using phenolphthalein or methyl orange as indicators, as described by APHA (2017). In addition, BOD is assessed by monitoring DO levels before and after a 5-day incubation period, and COD is analyzed using the dichromate reflux method. Heavy metals, including Pb, Cd, and Hg, are examined using atomic absorption spectrophotometry (AAS), adhering to standards provided by the U.S. EPA (2017) and APHA (2017).

Statistical Analysis of the water quality parameters

Cluster Analysis (CA)

Cluster Analysis (CA) was used as a multivariate statistical method to group similar water quality parameters based on their characteristics and behaviors. This analysis classified the sampling points that shared similar water quality profiles, which helped in identifying pollution sources or regions with specific water quality challenges. The analysis was performed using SPSS statistical software, and the results were presented as a dendrogram. This dendrogram illustrated the similarity between different water quality parameters or sampling sites, offering insights into regional or temporal variations in water quality.

Principal Component Analysis

Principle Component Analysis (PCA) was used to decrease the dimensionality of the water status dataset by combining each of the initial variables into a smaller variety of principal components. These components captured the maximum variance in the data, making it possible to identify the most significant factors influencing water quality. PCA was applied to highlight the key variables responsible for variations across the sampling sites. Each principal component was evaluated in terms of its eigenvalue and the percentage of total variance explained. SPSS Statistical software was used to carry out the analysis.

Optimal Sampling Strategy

Following the use of Cluster Analysis (CA) and Principal Component Analysis (PCA), the optimal sampling strategy for water quality assessment was determined. CA grouped sampling points into distinct clusters based on similar water quality profiles, enabling the selection of representative locations while reducing redundancy. PCA further refined the strategy by identifying key parameters driving water quality variation. This allowed the sampling focus to be directed at critical parameters, minimizing resource use while still capturing essential data.

RESULTS AND DISCUSSIONS

Anthropogenic Activities in the Study Area

A detailed overview of various locations, highlighting the activities performed at each site and their potential impacts on water quality parameters, is provided in Figure 2. The activities observed at Damside, including clothes washing, motorcycle use, and bathing, were shown to have significant effects on water quality, particularly by increasing turbidity and altering pH levels. Baba, (2020) supported these findings by demonstrating how domestic activities in peri-urban areas lead to sedimentation, increasing turbidity, and introducing chemicals that change the water's pH balance.

Furthermore, at Owu, agricultural activities like farming and garri processing were observed to increase Total Dissolved Solids (TDS) and cyanide contamination in the water. This is in line with Adjei *et al*., (2023) who noted that cassava processing releases cyanide, it creates concerns for the marine environment and the safety of humans. Moreover, Ndubuisi and Chidiebere (2018), emphasized that agricultural runoff contributes significantly to the introduction of suspended solids and nutrients, further exacerbating water pollution.

Moreover, in Alagbon, animal husbandry and agriculture were shown to elevate nutrient levels and introduce heavy metals into the water. Nadarajan and Sukumaran, (2021) Observed similar trends, noting that nutrient overloading from livestock waste leads to eutrophication and oxygen depletion, while fertilizers and pesticides release harmful heavy metals into nearby water bodies. However, Wakwella *et al*., (2023) offered a contrasting perspective, demonstrating that integrated watershed management can effectively address these challenges, showcasing the potential for sustainable practices to protect water quality in areas heavily reliant on agriculture and livestock.

The water quality at Asamu, where fishing, farming, garri processing, and animal husbandry were prevalent, demonstrated further evidence of water degradation through increased TDS and nutrient runoff. Finally, the activities at Gate 1, such as fish frying, fishing, and clothes washing, introduced a variety of contaminants that adversely impacted water quality, notably increasing turbidity and reducing dissolved oxygen levels. Bashir *et al*., (2020) provided similar evidence, demonstrating how fish processing, in particular, contributes to higher turbidity and oil contamination, which degrade aquatic habitats.

Characterization of Water Quality

During the dry season, the electrical conductivity measured 76.53 µS, rising to 86.33 µS in the rainy season. These values remained well below the standard of 1000 µS, indicating acceptable levels of NSDWQ (2017). Temperature remained relatively constant around 25.5°C in both seasons, falling within the ambient range. Turbidity was 1.30 NTU in the dry season, increasing to 2.10 NTU during the rainy season, still below the standard of 5 NTU. Total Dissolved Solids (TDS) were also within acceptable limits, measuring 0.04 mg/l in the dry season and 0.06 mg/l in the rainy season. While, in the dry season, Owu showed an electrical conductivity of 78.03 µS, rising to 87.90 µS in the rainy season, both below the WHO (2021) and NSDWQ, (2017), standards. Temperature ranged from 24.23°C in the dry season to 24.10°C in the rainy season, remaining within the recommended ambient range.

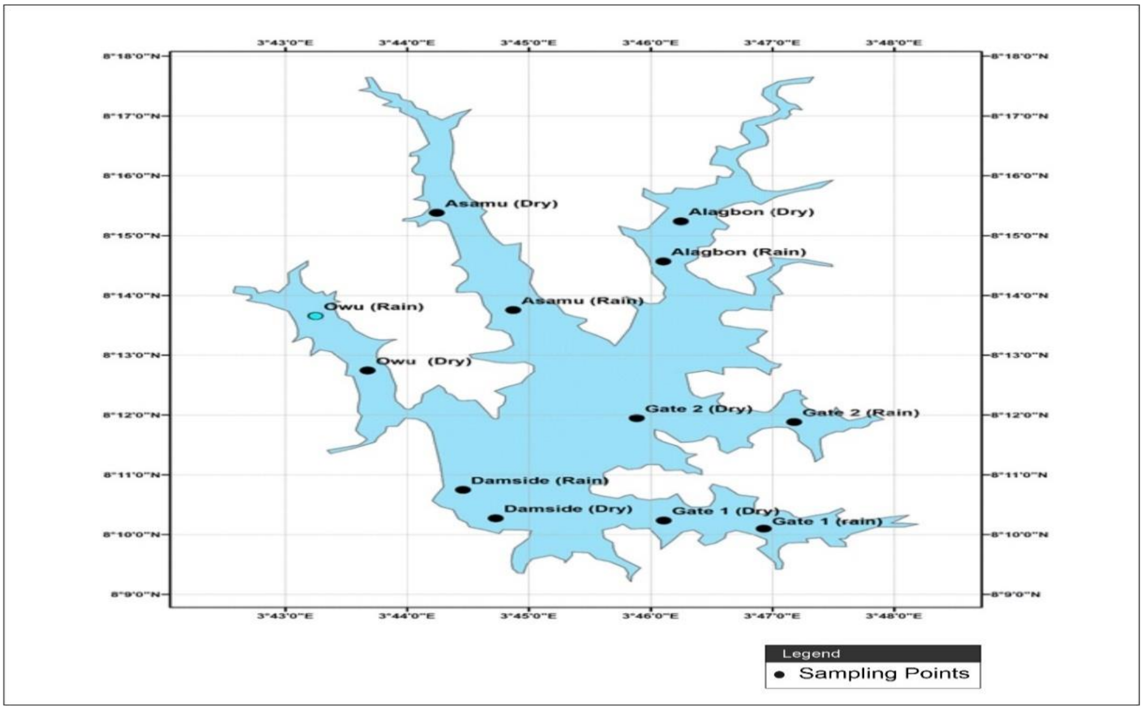

Figure 2: Sampling points across the Study Area

Similarly, Alagbon exhibited similar trends, with electrical conductivity values of 76.03 µS in the dry season and 86.30 µS in the rainy season, both below the standard limits. Temperature ranged from 29.07°C to 29.23°C across seasons, remaining within the ambient range. Turbidity levels were within limits, with 2.93 NTU in the dry season and 3.63 NTU in the rainy season as shown in Figure 4.2. TDS levels were also acceptable at 0.02 mg/l in both seasons. Asamu experienced comparable electrical conductivity values of 81.47 µS in the dry season and 91.37 µS in the rainy season, both below the standard limits. Temperature remained stable at around

27.5°C in both seasons. Turbidity levels were slightly elevated, reaching 1.63 NTU in the dry season and 2.57 NTU in the rainy season, still within acceptable limits. TDS levels were 0.08 mg/l in the dry season and 0.10 mg/l in the rainy season, slightly above the standards.

Both Gate 1 and Gate 2 displayed similar trends. Electrical conductivity values were within acceptable limits, ranging from 72.23 µS to 74.27 µS in the dry season and from 82.53 µS to 87.37 µS in the rainy season. Temperature remained stable within the ambient range. Turbidity levels exceeded the standard, with values ranging from 3.63 NTU to 9.13 NTU in the dry season and from 5.23 NTU to 5 NTU in the rainy season. TDS levels were generally low, ranging from 0.03 mg/l to 0.08 mg/l across seasons. These values fall within the WHO (2021) and NSDWQ (2017), standard range of 6.5-8.5, indicating acceptable acidity levels. Dissolved Oxygen (DO) concentrations ranged from 7.08 to 7.12 mg/L in the dry season and from 7.89 to 7.93 mg/L in the rainy season, meeting the standard of 8 mg/L as shown in Figure 3. Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) levels were within acceptable limits.

However, In Owu, pH values ranged from 6.55 to 6.54 during the dry season and 6.53 to 6.57 in the rainy season, meeting standard limits. Dissolved oxygen (DO) levels were acceptable, ranging from 8.56 to 8.60 mg/L in the dry season and 7.89 to 7.93 mg/L in the rainy season. Both BOD and COD concentrations complied with standards. Hardness levels were below the standard limit, ranging from 40.33 to 40.73 mg $CaCO_3$/L in the dry season and 36.00 to 36.40 mg $CaCO_3$/L in the rainy season. In Alagbon, pH ranged from 6.56 to 6.53 in the dry season and 6.54 to 6.57 in the rainy season, meeting standards. DO levels ranged from 8.23 to 8.27 mg/L in the dry season and 7.89 to 7.93 mg/L in the rainy season with BOD, COD, and hardness also within permissible limits.

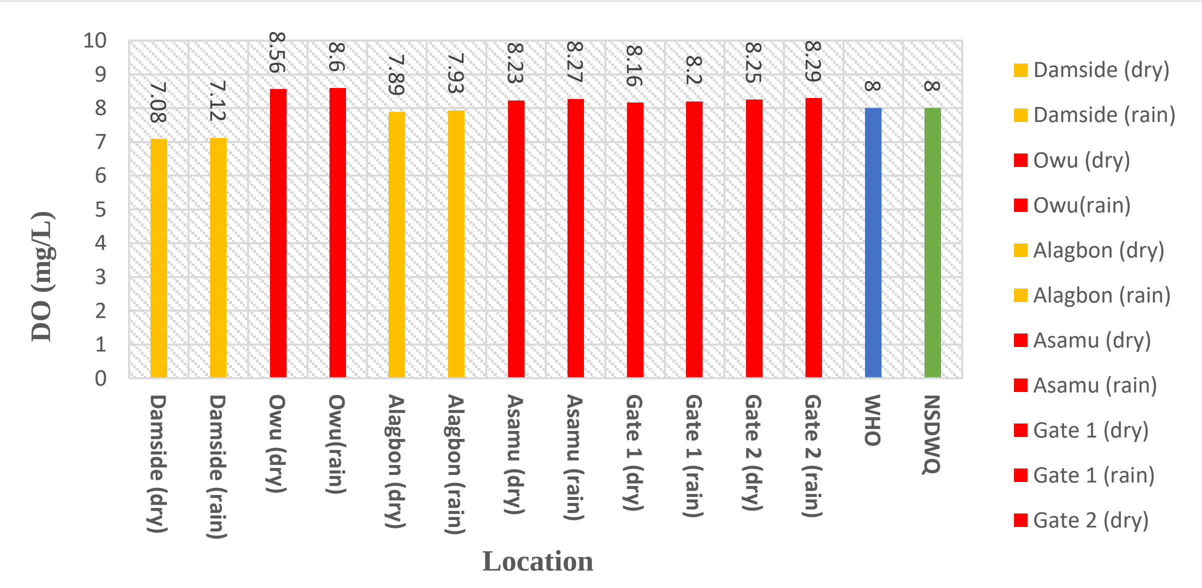

Figure 3: Comparison of dissolved oxygen level to WHO and NSDWQ Standards

Lastly in Asamu, pH values ranged from 6.54 to 6.57 in the dry season and from 6.41 to 6.88 in the rainy season, meeting the standard range. DO concentrations were within acceptable limits, ranging from 8.20 to 8.27 mg/L in the dry season and from 8.23 to 8.29 mg/L in the rainy season.

BOD and COD levels were also within standards. Hardness levels ranged from 41.00 to 41.40 mg $CaCO_3$/L in the dry season and from 42.00 to 42.40 mg $CaCO_3$/L in the rainy season, below the standard limit. Additionally, at Gate 1 and Gate 2, pH values remained within the standard range, with DO concentrations meeting the recommended levels. BOD and COD levels were within acceptable limits. Hardness levels were also below the standard limit. Overall, the water quality parameters across all locations and seasons generally complied with the WHO (2021) and NSDWQ (2017), standards, suggesting satisfactory water quality for consumption and other uses.

The metal concentration at Damside during the dry season, zinc (Zn) levels ranged from 0.52 to 0.53 mg/L, while during the rainy season, they increased slightly, ranging from 0.53 to 0.64 mg/L. Chromium (Cr) concentrations remained consistently below detection limits in both seasons. Nickel (Ni) levels ranged from 0.02 to 0.02 mg/L in the dry season and decreased slightly to 0.02 to 0.01 mg/L in the rainy season. Copper (Cu) concentrations varied from 0.02 to 0.03 mg/L in the dry season and increased slightly to 0.04 to 0.06 mg/L during the rainy season. Manganese (Mn) concentrations were stable, ranging from 0.02 to 0.02 mg/L in the dry season and 0.01 to 0.01 mg/L in the rainy season. Overall, heavy metal levels at Damside generally remained within acceptable limits based on WHO (2021) and NSDWQ (2017), standards.

The recorded phosphate levels across various locations show slight increases between dry and rainy seasons. At Damside, levels rose from 1.37 mg/L to 1.40 mg/L, and at Owu, from 1.76 mg/L to 1.80 mg/L. Alagbon showed an increase from 1.26 mg/L to 1.30 mg/L, while Asamu's levels rose from 1.10 mg/L to 1.14 mg/L. Gate 1 and Gate 2 exhibited similar trends, with increases from 1.02 mg/L to 1.06 mg/L and 1.78 mg/L to 1.82 mg/L, respectively, as shown in Figure 4. However, Owu exhibited generally low heavy metal concentrations, with most of the values remaining below the detection limits, suggesting minimal contamination from heavy metals. Zinc, chromium, nickel, copper, and manganese levels were consistently minimal in both the dry and rainy seasons, indicating satisfactory water quality in terms of heavy metal contamination at this location. Similar to Owu, heavy metal concentrations at Alagbon were predominantly below detection limits or very low. Zinc, chromium, nickel, copper, and manganese levels remained minimal in both seasons, suggesting good water quality in terms of heavy metal contamination.

Heavy metal concentrations in Asamu were also within acceptable limits, with most values below detection limits or very low. Zinc, chromium, nickel, copper, and manganese levels showed minimal variation between the dry and rainy seasons, indicating consistent water quality in terms of heavy metal contamination. At Gate 1 and Gate 2, heavy metal concentrations generally fell within acceptable limits.

Zinc, chromium, nickel, copper, and manganese levels were mostly below detection limits or very low in both seasons, suggesting satisfactory water quality in terms of heavy metal contamination at these sampling sites. In Damside, both during dry and rainy seasons, the E. coli levels were notably elevated at 45.67 MPN/100mL and 47.67 MPN/100mL, respectively, surpassing the acceptable limit of 0 MPN/100mL set by both standards. Similarly, at Owu, Alagbon, Asamu, Gate 1, and Gate 2, the recorded E. coli levels during both dry and rainy seasons exceeded the permissible limits, ranging from 27.67 to 42.33 MPN/100.

Statistical Analysis

The data obtained from the laboratory analysis of water quality parameters undergoes statistical analysis. Specifically, Cluster Analysis (CA) and Principal Component Analysis (PCA) were applied to discern patterns and relationships within the dataset. This analytical approach aimed to identify the most effective sampling strategy in the study area.

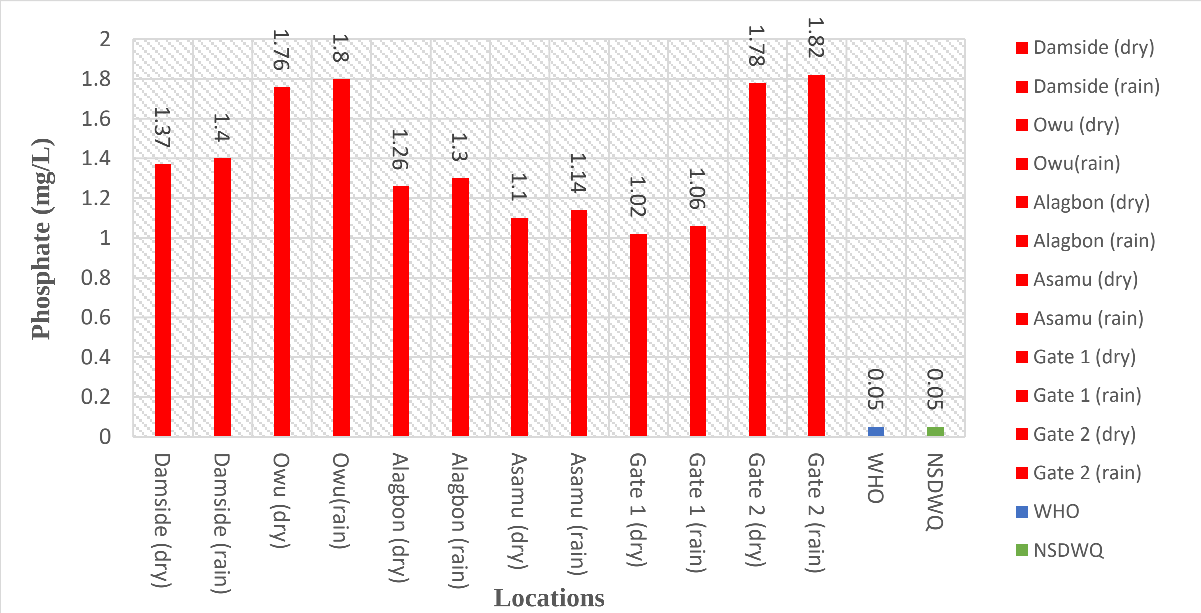

Figure 4: Comparison of Phosphate level to WHO and NSDWQ Standard

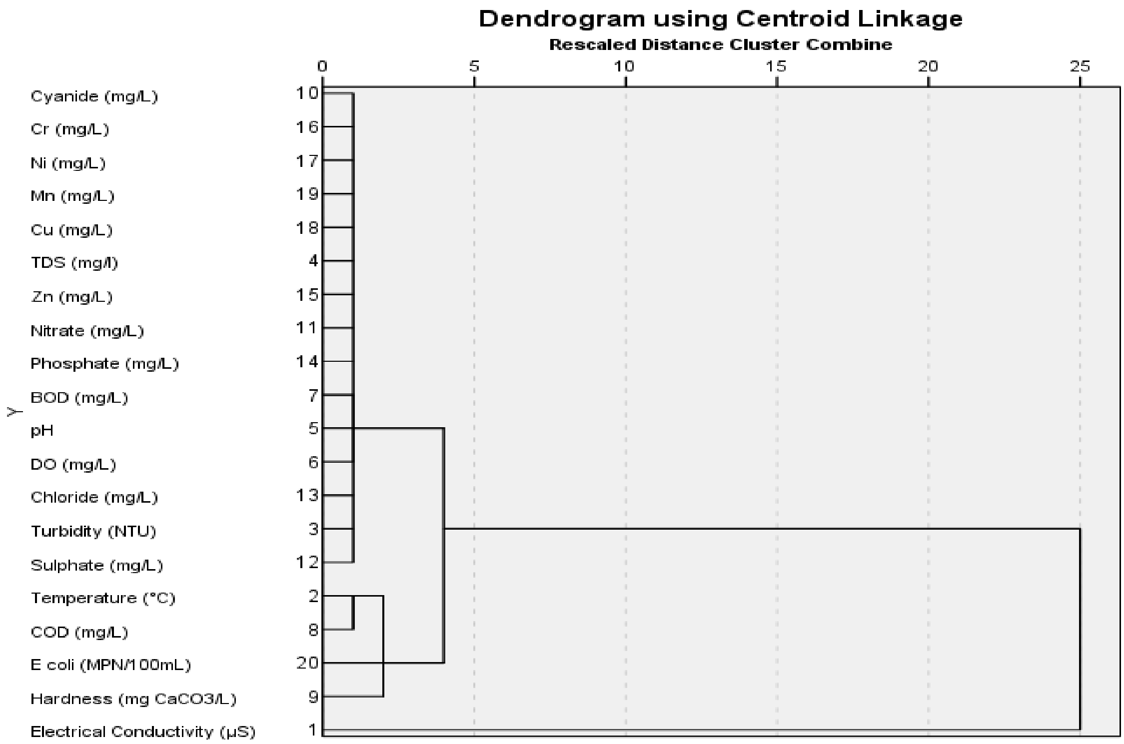

Figure 5: Dendrogram showing Cluster Member relationship.

Cluster Analysis

The cluster membership of water quality parameters reveals crucial insights, indicating variability in parameter associations that can significantly influence sampling strategies as depicted in Figure 5. In the analysis, the identification of six clusters demonstrates the distinct characteristics of various parameters, underscoring their potential implications for sampling. For example, in this six-cluster scenario, Electrical Conductivity (µS) consistently appears in Cluster 1, while E. coli (MPN/100 mL) is assigned to Cluster 6. This clear demarcation suggests that these parameters may require different sampling considerations, as they may respond differently to environmental conditions. Moreover, the transition to a three-cluster scenario reveals emergent patterns among the parameters. Notably, Cluster 2 encompasses Temperature (°C), Chemical Oxygen Demand (COD) (mg/L), Hardness (mg CaCO3/L), and E. coli (MPN/100 mL), indicating potential similarities or shared trends in their behaviour.

Furthermore, Cluster 3 emerges as a significant group comprising parameters such as Turbidity (NTU), Total Dissolved Solids (TDS) (mg/L), pH, Dissolved Oxygen (DO) (mg/L), Biological Oxygen Demand (BOD) (mg/L), and various metal concentrations including Zinc (Zn), Chromium (Cr), Nickel (Ni), Copper (Cu), and Manganese (Mn). The aggregation of these parameters suggests commonalities in their characteristics, which may necessitate a focused sampling approach to effectively capture their interactions and fluctuations. This observation aligns with the work of Amoatey and Baawain, (2019), who found that grouping similar parameters could enhance the understanding of pollutant behavior and inform targeted management strategies in freshwater systems.

Principal Component Analysis

Principal Component Analysis (PCA) transformed the data obtained from the laboratory analysis of water quality parameters into a new coordinate system where the principal components, orthogonal axes capturing maximum variance, were identified. Table 1 and 2 shows the eigenvalues for principal components and the contribution of the major variables (%) of the data obtained from the laboratory analysis.

According to the results of the PCA, the dataset can be succinctly summed up by a number of important elements, each of which accounts for a fraction of the overall variance. Strong positive loadings on parameters like Chemical Oxygen Demand (COD), Hardness, Nickel (Ni), Biochemical Oxygen Demand (BOD), Nitrate, Chromium (Cr), Manganese (Mn), and Chloride are characteristics of the first principle component (F1), which explains 39.09% of the overall variance.

Hence, these variables are indicative of natural factors influencing water quality. The second principal component (F2) explains 16.92% of the total variance and exhibits strong positive loadings on parameters like Copper (Cu), Turbidity, and moderate positive loadings for Phosphate, indicating contributions from organic pollution and potentially anthropogenic sources. Similarly, the third principal component (F3) explains 11.71% of the total variance and shows strong loadings on Total Dissolved Solids (TDS), Sodium (Na), and Chloride, suggesting a salinity-related factor. However, the fourth principal component (F4) explains 9.99% of the total variance and contributes to the understanding of water quality dynamics. It shows loadings on parameters that may represent additional factors influencing water quality, although with less explanatory power compared to the previous components.

Moreover, the fifth principal component (F5) explains 6.35% of the total variance and provides further insight into the dataset. Similar to F4, it captures additional variability in water quality parameters, though to a lesser extent. Parameters with significant loadings on F5 may contribute to specific patterns or trends in water quality, adding to the overall understanding of the system. The eigenvalues provide insight into each principal component, with higher values indicating greater explanatory power. The cumulative percentage of variance reveals the variability captured by each principal component, highlighting patterns, relationships, and potential contamination sources influencing the quality of water in the study area.

Table 1: Eigenvalues for Principal Components.

Component	Eigenvalues	% of Variance	Cumulative %
F1	7.82	39.09	39.09
F2	3.38	16.92	56.01
F3	2.34	11.71	67.71
F4	2.00	9.99	77.70
F5	1.27	6.35	84.05
F6	0.96	4.77	88.83
F7	0.72	3.62	92.44
F8	0.55	2.77	95.21
F9	0.32	1.58	96.79
F10	0.30	1.48	98.27
F11	0.17	0.85	99.12
F12	0.09	0.45	99.57
F13	0.04	0.19	99.76
F14	0.02	0.09	99.85
F15	0.01	0.07	99.92
F16	0.01	0.04	99.96
F17	0.01	0.03	99.99
F18	0	0	100

Table 2: Contribution of the Major Variables (%).

Parameters	Component				
	F1	F 2	F3	F4	F5
COD (mg/L)	0.982				
Hardness (mg $CaCO_3$/L)	0.897				
Ni (mg/L)	0.881				
BOD (mg/L)	0.856				
Nitrate (mg/L)	0.822				
Cr (mg/L)	0.820				
Mn (mg/L)	0.818				
DO (mg/L)	-0.786				
Chloride (mg/L)	0.754				
Sulphate (mg/L)	-0.706				

Cu (mg/L)		0.932			
Turbidity (NTU)		0.758			
Phosphate (mg/L)		0.688			
Temperature (°C)		-0.66			
E coli (MPN/100mL)					
Zn (mg/L)	0.629		-0.658		
Electrical Conductivity (μS)				0.885	
Cyanide (mg/L)				0.648	
TDS (mg/l)					0.63
pH					0.618

Optimal sampling strategy

In the assessment of water quality at Ikere George Dam, both Cluster Analysis and Principal Component Analysis (PCA) play pivotal roles in developing an optimal sampling strategy. Cluster Analysis categorizes water quality parameters into distinct clusters based on similarities in their behavior. This method aids in identifying groups of parameters that exhibit similar trends or respond similarly to environmental factors. For example, in the provided discussion, Cluster Analysis revealed distinct groupings of parameters, such as Electrical Conductivity consistently residing in Cluster 1 and E. coli consistently appearing in Cluster 6. Understanding these clusters informs sampling strategies by highlighting which parameters may require targeted monitoring due to their unique behaviour or characteristics.

On the other hand, PCA complements Cluster Analysis by shedding light on the links and underlying trends seen in the water quality information. PCA reduces the dimensionality of the data and identifies key variables driving variability in water quality. By examining the loadings of parameters on the principal components, the study shows the factors influencing water quality dynamics. For instance, PCA in this study identified principal components such as F1, characterized by parameters like COD and Hardness, indicative of natural influences, and F2, associated with parameters like Turbidity and Copper, suggesting contributions from organic pollution and anthropogenic sources.

CONCLUSION

The study observed that cluster analysis revealed distinct groupings, with electrical conductivity in Cluster 1 and E. coli in Cluster 6. PCA identified COD, BOD, and turbidity as key influencers, highlighting natural and anthropogenic impacts, aiding water quality management strategies. It is recommended to integrate these techniques into ongoing water quality monitoring programs at Ikere George Dam.

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