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Physicochemical Examination of Water Quality from Ero Dam, Ekiti State, Nigeria

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Abstract

Physicochemical examination of water quality from Ero Dam, Ekiti State, is an important study to assess the water's portability, safety, its use for irrigation, and environmental sustainability. The water quality parameters were analyzed during January, March, and June 2025, and these are the early and late dry seasons and the beginning of the rainy seasons, respectively. The study aimed to determine the seasonality, identify possible anthropogenic effects, and parameter interactions based on hierarchical cluster analysis. Water samples were collected by using standard procedures and analyzed for temperature, pH, turbidity, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total hardness, calcium, magnesium, nitrate, sulphate, and heavy metals i.e. lead (Pb), cadmium (Cd), copper (Cu), zinc (Zn), chromium (Cr). Results indicated that temperature was quite constant, with a pH range of 5.4 to 6.9 (weakly acidic to almost neutral), and there was also an increase in EC and TDS through June, indicating seasonality or enrichment with dissolved ions. DO was between 5.6 and 6.8 mg/L. maximum BOD (6.1 mg/L) and COD (16.2 mg/L) values recorded in June, owing to an increase in loading of organic matter due to the runoff. The levels of nitrate and sulphate were low across the board. Heavy metals analysis showed that Pb (0.1280.138 mg/L) and Cd (0.0100.014 mg/L) values were always exceeding the WHO standards; therefore, these metals can be considered as the indicators of anthropogenic pollution, while the values for Cu, Zn, and Cr were varied between permissible standards. Hierarchical cluster analysis showed a strong correlation.

Keywords: *Ero Dam, Physicochemical Analysis, Heavy Metals, Seasonal Variation, Hierarchical Cluster Analysis.*

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I. INTRODUCTION

Water is essential to all life on earth and plays a huge role in the function of the body, agriculture, industrialization, and the environment. It is also perhaps one of the most accessible natural resources, but yet access to clean and safe water is major challenge globally, especially in developing countries where water politicization, contamination and human demand on the existing supply are at an alarming level (UNICEF & WHO, 2021) More than 400 million people in sub, Saharan Africa do not have access to basic facilities for drinking water which significantly increases the risk of water borne diseases, as well as socio, economic vulnerabilities (WHO, 2022).

Nigerian surface water bodies comprise rivers, streams, lakes, and dams supplying the urban and rural areas of the country. One of such dams in Ekiti state is the Ero dam, which is most suitable for domestic, farming, and industrial purposes. Unfortunately, most of the water in the reservoirs is getting polluted as a result of human activities like the release of agricultural effluent, improper disposal of municipal waste, open defecations, and dump disposal not controlled (Akindele *et al.*, 2023; Nnaji *et al.*, 2020). The Ero Dam, located in Moba Local Government Area, provides the supply of water to various communities, and the water supply is under the management of Ekiti State Water Corporation.

Similar to other freshwater ecosystems in Nigeria, the Ero Dam depends on land use patterns and seasons, and so, it is a matter of consideration worthy of regular quality monitoring.

The research carries out a comparative water quality assessment of physicochemical parameters of water for Ero Dam water samples collected in a period of six months (January, March, and June, 2025). The duration is sufficient so that it caters to rainy and dry seasons with their related environmental attributes. The research of parameters such as pH, temperature, turbidity, electrical conductivity, total dissolved solids, dissolved oxygen, biochemical oxygen

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demand, chemical oxygen demand, total hardness, nitrate, sulphate, chloride, calcium, and magnesium was therefore undertaken to determine the variation throughout the seasons and the anthropogenic impact. Due to environmental degradation and medical health risk, the quality of water in the world has gained more attention (Kwaw and Sackey, 2011; Musa *et al*., 2023).

Based on how the physicochemical properties of the dam water changed, some works of literature in Nigeria found that there was an extent of the dam water quality degradation (Nasr *et al*., 2021; Wang *et al*., 2021; Nasir *et al*., 2023). With respect to chemical oxygen demand, surface water pollution by farm leachate and sewer inflow was reported by Ololade *et al.* (2008) and Tijani *et al.* (2011). According to Omotosho *et al.* (2020a), the seasonal variation in the physicochemical parameters of DO, BOD, and turbidity of Eleyele Dam, Ibadan, maximized during the rainy season because of overload of organic matter from the rain runoff. In line with this, Adesakin *et al.* (2022a) revealed that the water of the rainy season of Ureje Dam, Ado-Ekiti have high TDS, turbidity, and conductivity at the effluent sites as a result of dilution and leaching from the close proximity of the farmlands and settlements.

According to Udoessien *et al.* (2023) and Akande *et al.* (2024), climatic variance and man-induced stressors collectively induced disabilities in the water security of reservoirs of Nigeria. Such studies gave way to further promotion of monitoring with improvement initiatives for the watershed management sector.

Through physicochemical analysis of Ero Dam water quality throughout the seasons, the present research work aims to contribute to the body of knowledge on evaluation of freshwater quality in Nigeria and provide empirical evidence that may suffice for decision-making of water managers, policy makers, and public health experts.

II. MATERIALS AND METHODS

A. Description of the study area

Ero Dam represents a very important surface water storage reservoir in Moba Local Government Area in the Ekiti State of South West Nigeria. The dam is appropriately situated at 7° 55' N latitude and 5° 25' E longitude in a tropical climatic region in Nigeria with impulsive wet and dry seasons. Built from 1985 to commission in 1987, the dam was manufactured to supply water for household use to more than six Local Governments of Ekiti State, i.e., Oye, Ikole, Ido/Osi, Ilejemeje, Ifaki-Ekiti, and Moba LGAs (Figure 1).

The dam impounds the water from the Ero River, which is one of the large tributaries of the catchment of the Osun River, with a capacity of 25.5 million cubic meters. The dam drains a catchment of approximately 92.6 square kilometers and serves many human uses, such as the supply of water to households, irrigation, fishing, and recreation. The Ekiti State Water Corporation is a water owned and operated by the Ekiti State Water Corporation (EKSWC), which supplies treated water to the peri- and urban towns.

The Ero Dam catchment comprises resultant forest and savanna-type vegetation, small farm areas, and scattered settlements. Dominant land uses are agriculture, which is made up of subsistence farming, commercial agricultural (farm) production at a small scale, stock grazing, and residential settlements. These land uses are the leading sources of non-point sources of pollution, which is mostly during the wet season when run-off carries sediment, fertilizers, and organic waste into the dam.

It climatically experiences a tropical humid climate with an average annual rainfall of between 1,200 mm and 1,500 mm coming mostly from the period between April and October. During the period between November and March, it is a dry season with the average daily temperature varying from 24 °C to 34 °C. Climate change has a direct impact on the volume and the flow rate of water and the quality dynamics of the dam.

Strategically located for application for drinking water supply and livelihood, Ero Dam has both rural development and public health importance. However, like most surface waters in Nigeria and are fraught with enormous risks of anthropogenic contamination, climatic uncertainty, and watershed degradation. Its quality should therefore be checked from time to time in this application and in the decision on suitable interventions.

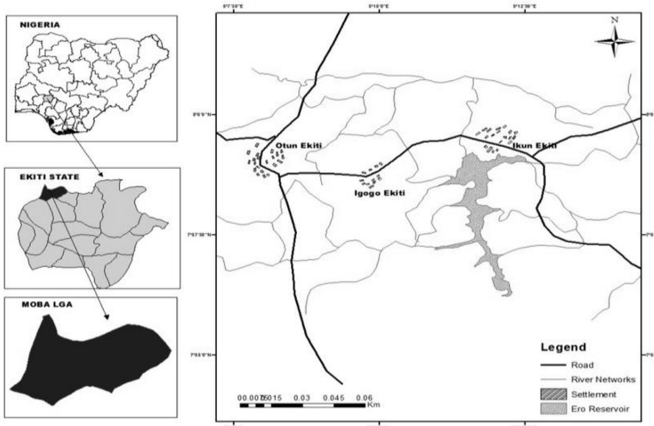

Figure 1. Map of the Study Area.

B. Sampling

Water samples were taken from four selected stations (Ero River A, B, C, and D) in Ero Dam in January, March, and June 2025, representing the early dry season, late dry season, and early rainy season, respectively. These months were chosen with strategic precision to assess the seasonal influence of physicochemical characteristics of the river section studied, thanks to the differences in hydrological regimes, temperature, and anthropogenic activities in each of them.

Sampling procedures were strictly followed as per the recommendations of Standard Methods for the Examination of Water and Wastewater, as recommended by the American Public Health Association (APHA, 2017). At the locations, composite samples were collected by submerging sterile 1-liter polyethylene bottles under the surface (30 cm below the water surface) to avoid contamination from the surface films and to get a sample representative of the physicochemical profile of the water column.

Before sampling, bottles were thoroughly rinsed and sterilized three times with distilled water in order to minimize possible contamination. Upon collection, each sample was clearly labelled and immediately placed in cold, insulated boxes to ensure that transportation was completed within 6 hours, thereby preserving chemical and biological integrity. Parameters that need to be maintained, such as dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), etc., were stabilized with the help of suitable preservatives according to usual protocols (e.g., Winkler titration for DO). Temperature, pH, and electrical conductivity were measured in situ with a calibrated portable multiple-parameter probe to avoid alteration during transportation.

This systematic sampling protocol helped to obtain reliable and representative data to capture variations both in space and time (season) in the water quality of Ero Dam.

C. *Physicochemical analysis*

The physicochemical parameters of the water samples were analyzed according to standard analytical procedures as specified by the APHA (2017), WHO (2017), and UNEP (2020). Each analysis was repeated three (3) times, results were expressed in mean ± standard deviation to guarantee the accuracy and reliability.

In situ measurements of temperature, pH, electrical conductivity (EC), and total dissolved solids (TDS) parameters were taken at the sampling sites with the use of a HANNA digital multiparameter probe that was calibrated before use. These parameters play critical roles in establishing thermal and ionic equilibrium of aquatic environs where there are major implications in chemical reactivity and ecological relevance (Edokpayi *et al.*, 2017).

Turbidity was measured with a HACH 2100P nephelometric turbidimeter and the values recorded in Nephelometric Turbidity Units (NTU), a measure of suspension particulate matter and possible organic pollution in the water body (Adefemi and Awokunmi, 2010).

Dissolved oxygen (DO) and biochemical oxygen demand (BOD) were determined from the Winkler titrimetric method, and BOD was measured after 5 days of incubation at 20 °C. These parameters give insight into the capacity of the aquatic system to support life as well as indicating levels of organic contamination (Akan *et al.*, 2010; Arimoro *et al.*, 2021).

Chemical oxygen demand (COD) was measured by using the closed reflux titrimetric method with dichromate as oxidizing agent. COD is a measure of the total amount of oxygen needed to oxidise the organic components of water, biodegradable and non-biodegradable, thus, it is a broad index of organic pollution (Zhou *et al.*, 2021).

Total hardness, calcium hardness, and magnesium hardness were determined by ethylenediaminetetraacetic acid (EDTA) complexometric titration. These parameters affect the suitability of water for domestic, agricultural, and industrial uses (Chinedu and Chukwuemeka, 2018).

Nitrate, sulphate, and chloride concentrations were also determined by spectrophotometry in accordance with APHA (2017) guidelines, as these parameters can indicate anthropogenic effects, such as agricultural runoff and residential waste discharge (Kumar *et al.*, 2020).

All analytical instruments were calibrated before use, and analytical grade reagents ensured high precision and accuracy. Triplicate determinations were used for all parameters to reduce random errors and increase the statistical strength of the parameters (Njoku *et al.*, 2021).

D. *Data analysis and processing*

All the physicochemical amount data obtained were statistically processed to identify spatial and temporal oscillations of water quality for three sampling campaigns (January, March, and June 2025) attributed to different seasons (early dry, late dry, and early rainy seasons, respectively).

Descriptive statistics such as mean, standard deviation, minimum, and maximum were calculated in order to give a summary of the data. IBM SPSS Statistics (Version 25). Furthermore, the relationships between physicochemical parameters were discussed through hierarchical cluster analysis (HCA) as provided by the dendrogram and confirmed by the agglomeration schedule. These tools allowed for identifying of statistically similar water quality variables, such as the close clustering of total dissolved solids (TDS) with electrical conductivity (EC), and biochemical oxygen demand (BOD) with dissolved oxygen (DO), suggesting the potential common sources of pollution or naturally interlinked processes (Gupta *et al.*, 2022; Alemayehu *et al.*, 2020).

The resultant results were then compared with the tolerable limit of the World Health Organization (WHO, 2017) and Nigeria Standard for Drinking Water Quality (NSDWQ, 2015) for the determination of water usage of Ero Dam for drinking and domestic works purposes.

This integrated statistical procedure gave both quantitative and inferential bases to the physicochemical data interpretation, to the benefit of identifying possible patterns of pollution as well as informing water quality management practices (Wang *et al.*, 2022).

III. RESULTS

Physicochemical water quality of water samples collected from Ero Dam for three subsequent months (January, March, and June 2025) was found to fluctuate in a number of vital parameters, which indicated the influence of seasonal processes and possible anthropogenic intervention in the dam catchment (Tables 1-3).

Table 1. Monthly average of physicochemical parameters for January 2025

Parameters	Ero River A	Ero River B	Ero River C	Ero River D	Mean	STD	CV (%)
DO (mg/L)	4.88	6.98	5.23	4.69	5.45	1.05	19.2
BOD (mg/L)	1.78	1.76	1.97	1.87	1.85	0.10	5.2
COD (mg/L)	3.21	2.34	3.21	2.32	2.77	0.51	18.3
Conductivity (µS/cm)	111	167	187	145	152.50	32.55	21.3
Temperature (°C)	26.1	27.2	26.9	27.3	26.88	0.54	2.0
Acidity (mg/L)	42.7	54.7	49.3	48.7	48.85	4.91	10.0
Alkalinity (mg/L)	34.9	77.2	44.8	47.3	51.05	18.24	35.7
Free carbon dioxide (mg/L)	185	203	217	246	212.75	25.75	12.1
pH	6.5	5.4	6.2	6.7	6.20	0.57	9.2
Total hardness (mg/L)	173.6	165.6	148.2	102.4	147.45	31.85	21.6
Calcium hardness (mg/L)	98.3	78.5	78.3	65.4	80.13	13.58	16.9
Magnesium hardness (mg/L)	75.3	87.1	69.9	37	67.33	21.45	31.9
Chloride (mg/L)	32.6	32.2	30.5	31.2	31.63	0.95	3.0
Total dissolved solids (mg/L)	71.04	106.88	119.68	92.8	97.60	20.83	21.3
Total suspended solids (mg/L)	1.29	1.22	1.72	1.02	1.31	0.29	22.5
Total Solids	72.33	108.1	121.4	93.82	98.91	21.00	21.2
Turbidity (NTU)	0.2	0.1	0.1	0.1	0.13	0.05	40.0
Phosphate (mg/L)	0.27	0.31	0.21	0.21	0.25	0.05	19.6
Nitrate (mg/L)	0.12	0.14	0.12	0.15	0.13	0.02	11.3
Cd (mg/L)	0.022	0.042	0.035	0.042	0.04	0.01	26.8
Cr (mg/L)	0.017	0.013	0.021	0.018	0.02	0.00	19.2
Cu (mg/L)	0.129	0.144	0.134	0.132	0.13	0.01	4.8
Pb (mg/L)	0.143	0.136	0.154	0.152	0.15	0.01	5.7
Zn (mg/L)	2.53	3.94	3.34	3.51	3.33	0.59	17.7

Table 2. Monthly average of physicochemical parameters for March 2025

Parameters	Ero River A	Ero River B	Ero River C	Ero River D	Mean	STD	CV (%)
DO (mg/L)	4.81	6.58	5.43	4.87	5.42	0.82	15.1
BOD (mg/L)	1.42	1.68	1.69	1.78	1.64	0.16	9.4
COD (mg/L)	3.18	2.47	3.27	2.41	2.83	0.46	16.1
Conductivity (µS/cm)	121	172	169	156	154.50	23.39	15.1
Temperature (°C)	26.2	26.2	26.3	26.3	26.25	0.06	0.2
Acidity (mg/L)	45.2	44.5	44.8	45.2	44.93	0.34	0.8
Alkalinity (mg/L)	39.9	47.1	42.4	44.1	43.38	3.02	7.0
Free carbon dioxide (mg/L)	172	192	187	189	185.00	8.91	4.8
pH	6.8	6.4	6.4	6.5	6.53	0.19	2.9
Total hardness (mg/L)	189.6	198.2	175.3	177.1	185.05	10.83	5.9
Calcium hardness (mg/L)	98.6	89.6	75.9	95.7	89.95	10.09	11.2
Magnesium hardness (mg/L)	91	87.1	99.4	81.4	89.73	7.56	8.4
Chloride (mg/L)	22.4	22.8	27.1	26.7	24.75	2.49	10.1
Total dissolved solids (mg/L)	77.44	110.08	108.16	99.84	98.88	14.97	15.1
Total suspended solids (mg/L)	0.98	0.82	0.96	0.91	0.92	0.07	7.8
Total Solids	78.42	110.9	109.12	100.75	99.80	14.92	15.0
Turbidity (NTU)	0.2	0.1	0.1	0.1	0.13	0.05	40.0
Phosphate (mg/L)	0.31	0.28	0.25	0.27	0.28	0.03	9.0
Nitrate (mg/L)	0.17	0.16	0.15	0.16	0.16	0.01	5.1
Cd (mg/L)	0.019	0.027	0.026	0.032	0.03	0.01	20.6
Cr (mg/L)	0.022	0.019	0.021	0.021	0.02	0.00	6.1
Cu (mg/L)	0.134	0.132	0.134	0.138	0.13	0.00	1.9
Pb (mg/L)	0.111	0.121	0.123	0.141	0.12	0.01	10.1
Zn (mg/L)	3.42	3.48	3.76	3.71	3.59	0.17	4.7

Table 3. Monthly average of physicochemical parameters for June 2025

Parameters	Ero River A	Ero River B	Ero River C	Ero River D	Mean	STD	CV (%)
DO (mg/L)	4.56	5.81	4.48	5.45	5.08	0.66	13.0
BOD (mg/L)	1.56	1.78	1.81	1.72	1.72	0.11	6.5
COD (mg/L)	3.02	2.89	3.52	2.99	3.11	0.28	9.1
Conductivity (µS/cm)	151	192	167	176	171.50	17.14	10.0
Temperature (°C)	26.7	26.8	26.7	26.7	26.73	0.05	0.2
Acidity (mg/L)	42.1	44.5	45.9	45.7	44.55	1.75	3.9
Alkalinity (mg/L)	32.1	42.7	45.7	44.8	41.33	6.28	15.2
Free carbon dioxide (mg/L)	182	159	176	172	172.25	9.74	5.7
pH	6.2	6.3	6.4	6.4	6.33	0.10	1.5
Total hardness (mg/L)	169.6	178.2	176.1	166.4	172.58	5.51	3.2
Calcium hardness (mg/L)	76.2	81.3	72.6	82.2	78.08	4.51	5.8
Magnesium hardness (mg/L)	93.4	87.1	103.5	84.2	92.05	8.54	9.3
Chloride (mg/L)	32.1	28.9	27.8	28.2	29.25	1.95	6.7
Total dissolved solids (mg/L)	96.64	122.88	106.88	112.64	109.76	10.97	10.0
Total suspended solids (mg/L)	1.21	1.12	1.19	1.19	1.18	0.04	3.4
Total Solids	97.85	124	108.07	113.83	110.94	10.93	9.9
Turbidity (NTU)	0.2	0.2	0.1	0.1	0.15	0.06	38.5
Phosphate (mg/L)	0.27	0.27	0.25	0.28	0.27	0.01	4.7
Nitrate (mg/L)	0.18	0.19	0.15	0.16	0.17	0.02	10.7
Cd (mg/L)	0.023	0.021	0.031	0.032	0.03	0.01	20.8
Cr (mg/L)	0.016	0.022	0.024	0.026	0.02	0.00	19.6
Cu (mg/L)	0.203	0.195	0.187	0.176	0.19	0.01	6.1
Pb (mg/L)	0.121	0.132	0.135	0.152	0.14	0.01	9.5
Zn (mg/L)	3.431	3.621	3.726	3.741	3.63	0.14	3.9

Temperature readings during all three testing periods were relatively consistent at 26.1 °C - 27.3 °C, with an average of 26.88 °C in January, 26.25 °C in March, and 26.73 °C in June. These are within the range suggested by WHO for aquatic ecosystems and indicate an acceptable thermal status of aquatic organisms. pH values for the whole period of the months are mild to slight acidity, between 5.4 and 6.8, with a minimum in January and higher in March and June. While below the acceptable range (6.5-8.5) set by the WHO in the samples, the values are not indicative of extreme acidity.

Concentration of dissolved oxygen (DO) ranged from 4.48 to 6.98 mg/L, with the highest mean in January (5.45 mg/L), moderate in March (5.42 mg/L), and the lowest was in June (5.08 mg/L). DO levels were adequate in the maintenance of aquatic organisms. Biochemical oxygen demand (BOD) changed slightly with the month and ranged from 1.42 to 1.97 mg/L. June had the highest BOD (1.72 mg/L), and December had the lowest BOD, not much different from that of January (1.64 mg/L), showing moderate microbial activity and organic pollution. As a result, there was a variation of chemical oxygen demand (COD) among months ranged between 2.32 and 3.52 mg/L, with the highest average value recorded for June (3.11 mg/L), showing increased content of oxidizable organic substances during the initial rainy season. The values of electrical conductivity (EC) also varied between 111 and 192 uS/cm with mean values of 152.5 uS/cm in January, 154.5 uS/cm in March, and 171.5 uS/cm in June.

This increasing trend reflects the higher ionic concentration, which could be a result of run-off during the early rainy season. Total dissolved Solids (TDS) also showed the same trend, increasing from 97.60 mg/L in January to 109.76 mg/L in June, but all the values were within the acceptable value of WHO for drinking water (< 1000 mg/L). Turbidity was low throughout the period (0.1-0.2 NTU), which reflected low suspended particulate matter.

Hardness was between 102.4 and 198.2 mg/L, with a maximum in March, and calcium, with a maximum in March (98.6 mg/L), and magnesium, with a maximum in June (103.5 mg/L), which indicates that for all practical purposes, there is a minor seasonal variation in water mineral composition for all the parameters analyzed. Alkalinity ranged between 32.1 and 77.2 mg/L, reflecting the buffer capacity of water. On the contrary, acidity levels showed little variation with values ranging from 42.1 to 54.7 milligrams per liter.

Nutritive value-wise, the nitrates were extremely low in all the months (0.12-0.19 mg/L), much lower than the WHO tolerance limit of 50 mg/L. The phosphate levels varied very little from 0.21 to 0.31 mg/L. Chloride levels varied somewhat, with March having a decrease in levels (mean: 24.75 mg/L) and June having an increase in levels (mean: 29.25 mg/L) within safety limits.

Heavy metal analysis showed traces, but detectable levels were found. Cadmium (Cd) concentration varied from 0.019-0.042 mg/L, which is much higher than the WHO allowable limit of 0.003 mg/L for all months of the year, indicating anthropogenic inputs of pollution by agricultural runoff or industrial effluents. Lead (Pb) concentrations (0.111-0.154 mg/L) were also above the WHO allowable level of 0.01 mg/L, suggesting potential health problems if present for prolonged periods. Concentrations of Copper (Cu), Chromium (Cr), and Zinc (Zn) were in acceptable concentrations with moderate variations from one month to another in the case of Cu and Zn. The biggest concentration of zinc was found in January (3.94 mg/L), and the lowest one was in June (3.43 mg/L), below the WHO threshold of 5 mg/L.

Overall, the results indicate that most of the physicochemical water values of Ero Dam are within the safe limits of WHO, except an elevated rate of lead and cadmium, which raises questions about possible contamination of water with toxic elements. Seasonal variation, and in particular at the beginning of the rainfall appear to affect some parameters such as conductivity, hardness, and COD, which are due to the increased surface runoff and leaching of land usage in the surrounding area (Chukwuma *et al*., 2019).

The solution is to provide the physicochemical parameters of Ero Dam surface water in 2025 (spanning January (early dry season), March (late dry season) and June (early rainy season)) using the principal function analysis (Saks *et al*., 1987; Sanders *et al*., 2004) in the form of hierarchical cluster analysis (HCA) (Hierarchical cluster analysis, also known as multi-response separations, refers to the exploration of a collection of subjects within several categories or dimensions). The dendrogram (Figure 2) gives a graphical representation of how the parameters were grouped together in terms of their statistical similarities, thus showing underlying patterns that were related to seasonal variations.

Complementing this, the bar chart (Figure 3) displays the frequency of clustering of each parameter, and in this way addresses how independent each parameter is of the others or how dependent they are over the course of the three months. Parameters with higher numbers of clusters seem to be more independent, and parameters with lower numbers show greater correlations with others.

The Agglomeration Schedule (Table 4) further describes the clustering process, illustrating the step-wise merging of the parameters using the average linkage method, which is based on the calculation of similarity based on the average distance between all the members of each cluster. The associated coefficients at the prices in the schedule are a measure of the lack or similarity of the price at each stage, with smaller amounts indicating greater similarity. Collectively, these tools provide a global insight into physicochemical characteristics in response to environmental and hydrological changes in a tropical reservoir system.

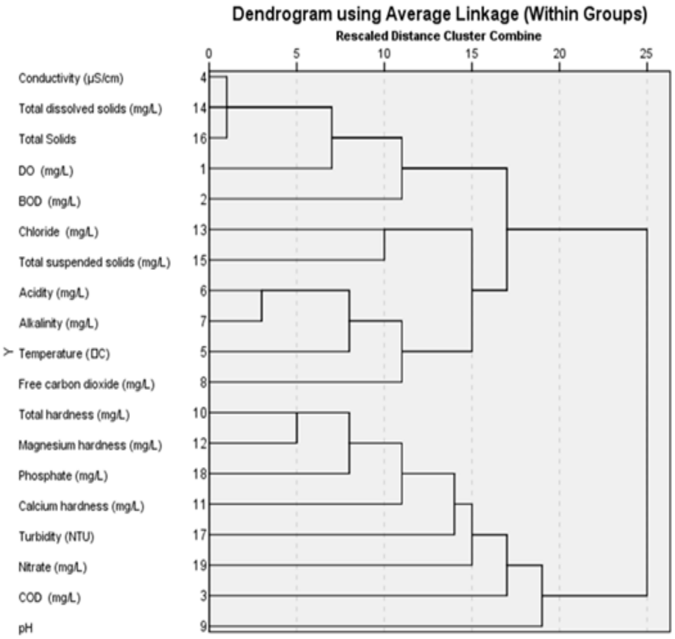

Figure 2. Hierarchical cluster analysis (HCA) of physicochemical compositions of Ero Dam.

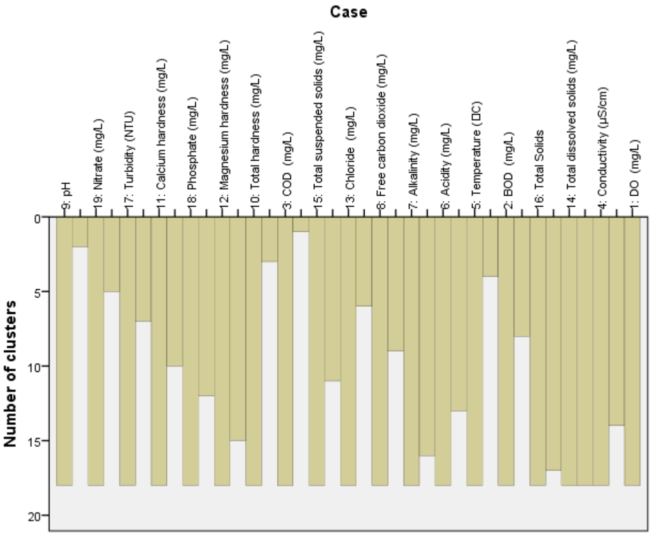

Figure 3. The clustering frequency of each parameter is presented in a bar chart

Table 4. Agglomeration Schedule for Physicochemical Parameters in Ero Dam.

Stage	Cluster Combined		Coefficients	Stage Cluster First Appears		Next Stage
	Cluster 1	Cluster 2		Cluster 1	Cluster 2	
1	4	14	1.000	0	0	2
2	4	16	1.000	1	0	5
3	6	7	0.909	0	0	6
4	10	12	0.841	0	0	7
5	1	4	0.726	0	2	11
6	5	6	0.718	0	3	10
7	10	18	0.698	4	0	9
8	13	15	0.610	0	0	13
9	10	11	0.593	7	0	12
10	5	8	0.590	6	0	13
11	1	2	0.573	5	0	15
12	10	17	0.476	9	0	14
13	5	13	0.424	10	8	15
14	10	19	0.407	12	0	16
15	1	5	0.350	11	13	18
16	3	10	0.332	0	14	17
17	3	9	0.261	16	0	18
18	1	3	0.008	15	17	0

The dendrogram (data processing, figure 4) based on the hierarchical cluster analysis with average linkage between the groups presented a representation of the interrelationship between the heavy metals identified in dam water and indicates a probable source, as well as the seasonal dynamics (Yuan *et al.*, 2023).

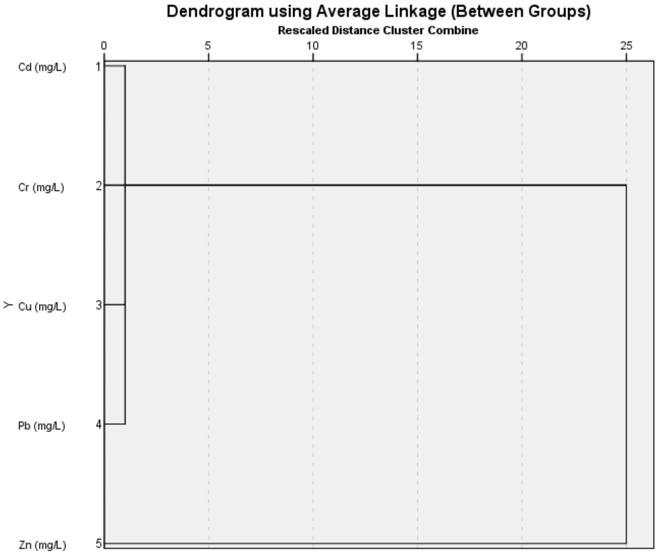

Figure 4. Dendrogram illustration of the interrelationship among the heavy metals detected in the Ero dam.

The cluster bars chart (Figure 5) and agglomeration schedule give information regarding the clustering patterns of heavy metals (Cd, Cr, Cu, Pb, and Zn) in Ero Dam water samples that were gathered in three months throughout the year (Jan., Mar., and Jun. 2025). These analyses help to show similarities/disparities in metal concentrations, which are affected by seasonal variations as well as by sources of pollution.

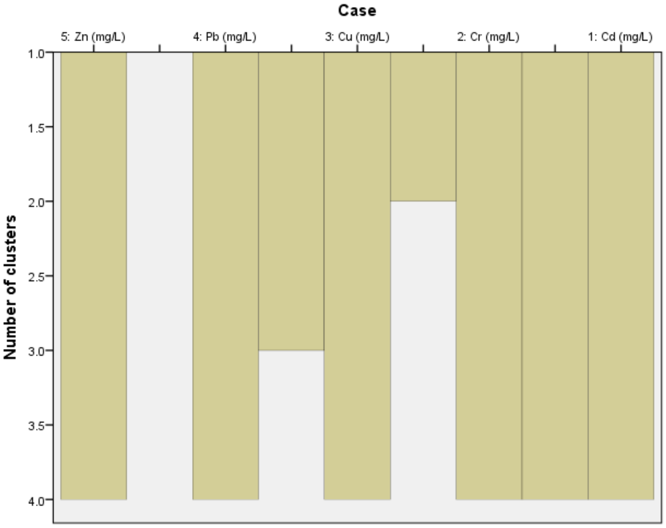

Figure 5. The clustering frequency of the heavy metals parameter is presented in a bar chart

Table 5. Agglomeration Schedule for Heavy Metals Composition in Ero Dam.

Stage	Cluster Combined		Coefficients	Stage Cluster First Appears		Next Stage
	Cluster 1	Cluster 2		Cluster 1	Cluster 2	
1	1	2	0.002	0	0	3
2	3	4	0.016	0	0	3
3	1	3	0.178	1	2	4
4	1	5	142.857	3	0	0

IV. DISCUSSION

Physicochemical investigation of the Ero Dam water sampled in January, March, and June 2025 showed seasonal changes in most parameters that are important in determining the quality of the water, which in turn influences its suitability for domestic and environmental use. While the overall water quality picture was acceptable, the high levels of some different heavy metals, especially lead (Pb) and cadmium (Cd), were of concern due to the toxicological implications of these elements.

Temperature did not vary significantly across all the sampling months, falling within the limits of WHO guidelines and suitable for aquatic life, which is similar to those obtained from other surface waters in Nigeria (Adeogun *et al.*, 2021).

pH values ranged from slightly acidic to near neutral values, with January recording 5.4, which was below the recommended value of 6.5-8.5 by WHO, possibly due to acid rain or leaching from the neighbouring agricultural fields (Nong *et al.*, 2021; Olalekan *et al.*, 2023). Such acidity causes an increase in metal solubility, leading to an increase in the bioavailability and toxicity of metals such as Pb and Cd (Edokpayi *et al.*, 2020).

Dissolved oxygen (DO) levels were good, with aeration conditions, but slight reductions were noted in June, coinciding with the onset of the rainy season (Kannel *et al.*, 2007). This reduction is due to increased biochemical oxygen demand (BOD) and chemical oxygen demand (COD), which peaked in June, which could be attributed to increased microbial activity and runoff input of organic matter (a seasonal variation, consistent with other dams in Nigeria, Omotosho *et al*., 2020b; Adesakin *et al*., 2022b).

Electrical conductivity (EC) and total dissolved solids (TDS) revealed an increasing trend between January and June owing to the influx of ions and sediments in runoff during the early part of the rainy season, conforming with the pattern observed across the tropics (Akinbile *et al*., 2019). While TDS levels were below WHO limits (<1000 mg/L), continued observation of the condition is recommended because of possible anthropogenic pressures.

Turbidity levels were low for all samples, which either indicated very little suspended particles or good natural filtration. Total hardness, as well as the concentration of magnesium and calcium, were found to have seasonal variations but were still within the permissible limits and thus indicate geological controls and weathering processes (Olalekan *et al*., 2023).

Nutrient concentrations such as nitrate and phosphate were minimal, suggesting limited agricultural run-off or efficient natural attenuation processes. This is consistent with results from other surface waters in areas where there are low-intensity farming practices (Ishaku *et al*., 2019).

Heavy metal analysis showed extremely high levels of Pb and Cd for all sampling months. The Pb concentrations were higher than the WHO guidelines (> 0.01 mg/L), and there is a risk of neurological, renal, and cardiovascular damage (WHO, 2017; Ayenimo *et al*., 2021). Cd levels were also above safe levels (> 0.003 mg/L), indicating persistent inputs from agrochemical residues or improper disposal of used batteries, as was also found in southwestern Nigeria (Edokpayi *et al*., 2020; Oluyemi *et al*., 2022). The bioaccumulation and biomagnification potential of these metals are large hazards to human health and aquatic ecosystems.

In contrast, Cu, Zn, and Cr concentrations were within the tolerable WHO range. Though Cu and Zn concentrations slightly decreased between Jan-Dec-Jun, their moderate concentrations are most likely due to leaching from plumbing fixtures and natural geochemical weathering (Ugbaja *et al*., 2022). Despite being known to be essential micronutrients, a high level may still be toxic and require continuous monitoring.

The results of hierarchical cluster analysis based on the average linkage were useful to understand the relationships between these parameters. This method of grouping was effective in highlighting natural groupings and helped in environmental assessments where latent patterns in multivariate data sets were being retrieved (Han *et al*., 2011; Liu *et al*., 2023). The parameters were clustered on the basis of their seasonal co-variation in the dendrogram, which gave clear indications about the pollution source and geochemical processes (Giri and Qiu, 2016). For example, Cd and Cr were close to each other, showing common sources like industrial effluents and phosphate fertilizer (Li *et al*., 2023; Singh *et al*., 2022). Their similar responses in terms of seasonal occurrence show that hydrological changes, such as changes in runoff during rain events, influence their mobility in a similar way (Okoye *et al*., 2022; Adeola *et al*., 2022). Cu and Pb occurred in another cluster, indicating possible inputs from plumbing corrosion, vehicular emissions, and waste dumpsites (Adekola *et al*., 2015; Adeleye *et al*., 2021). Zn, however, remained distinguished, mixing with other metals at a greater rescaled distance that formulated its geogenic origin (not coming from seasonal anthropogenic activities) and its relative independence on them (Al-Khashman, 2023).

Such clustering results tend to show the importance of targeted management of water quality. Toxic metals, such as Cd and Pb, have to be given priority in monitoring because of public health risks (WHO, 2017; USEPA, 2022). Differentiation of metal sources enables the formulation of adequate pollution control strategies, i.e., targeting industrial discharge and agricultural runoff for Cd and Cr, whereas urban and vehicular pollution sources for Pb and Cu.

Furthermore, these insights have policy implications which can guide the sustainable dam catchment management and inform interventions sensitive to changes in the hydrology seasonally, as that affects contaminant mobility (Ali *et al*., 2024). Overall, cluster analysis proved instrumental in evaluating the Ero Dam water quality, providing a framework of evidence to ensure the protection of the environment and/or public safety in terms of health.

V. CONCLUSIONS

The results of the physicochemical assessment of Ero Dam water samples in the period of January, March, and June 2025 showed that although most of the parameters are within the limit set by WHO, some of the heavy metals, especially cadmium (Cd) and lead (Pb), regularly exceed the guideline values and create a high risk to the health and ecosystem. Seasonal trends revealed an increase in parameters (TDS, EC, BOD, and COD) in the rainy season due to runoff from surrounding agricultural and urban areas. Cluster analysis also showed relationships between parameters, where Cd and Cr showed similar seasonality, probably owing to their common anthropogenic origin, but Zn was found to be different, indicating predominant geogenic origins. These insights highlight the complex interaction between natural processes and human inputs in water quality dynamics in Ero Dam.

Overall, the results highlight the need for integrated water quality management that is urgently needed. The existence level of toxic metals such as Pb and Cd demands a proactive mitigation to ensure public health and consistency in the aquatic ecosystem, which is in line with the global water safety standards (WHO, 2017; USEPA, 2022). It is recommended that heavy metal monitoring be intensified, season-specific pollution control measures be taken, integrated catchment management approaches be promoted, awareness of communities on water safety be improved, more research on the bioavailability of metals be carried out, and policies on water quality be reviewed and effectively enforced to ensure sustainable water resources management.

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