



# Environmental assessment of Esa-Odo reservoir based on water quality index and multivariate analysis

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## Abstract

Water quality is used to evaluate the overall health status of a particular water body. It can also be used to identify possible sources of pollution due to anthropogenic activities and develop strategies for improving the water body. It is a measure of the quality of water based on physical, chemical, and biological parameters. The water quality index considers several parameters, including pH, dissolved oxygen, temperature, alkalinity, acidity, and total dissolved solids. Esa-Odo reservoir serves both industrial and domestic purposes for the people. However, there is dearth of information on the quality of the waterbody. The study's objective was to use the water quality parameters to determine the reservoir's water quality index. Thirteen (13) water quality parameters were selected between October 2017 and September 2018 across the three zones of the reservoir, covering the dry and rainy seasons, using standard methods. The results of the water quality parameters revealed significant differences ( $p < 0.05$ ) in water temperature, alkalinity, sulphate and acidity. The correlation coefficient showed a strong correlation between K + and sulphate; conductivity and total dissolved solids. PCA and cluster analysis showed the importance of water quality properties and revealed a close relationship between transition and riverine zones when compared to the dam site. The water quality index (WQI) across the three zones indicated poor water quality that ranged between 75.8 and 77.9. Human activities such as farming along the shoreline could have contributed to the poor water quality of the reservoir. Regular monitoring of water quality status by the stakeholders in charge of water resources should be encouraged in order to protect the waterbody from further anthropogenic activities.

**Keywords** Reservoir · Water quality · Multivariate · Esa-Odo · Index

## Introduction

Water quality refers to the physical, chemical, and biological parameters. Other properties are radiological, and aesthetic parameters of its quality (Alobaidy et al. 2010; Ombaka and Gichumbi 2012). It could also mean the properties of water that influence its useful applications and an ecosystem's sustainability (Sudarshan et al. 2019). It is a vital factor for improving the level of public human health projects in an area (Qishlaqi et al. 2017). Any ecosystem's water quality provides important information on the resources available for sustaining life and whether they are suitable for human

use (Lianthuamluaia et al. 2013). Due to the high demand, contamination risk, and potential depletion of freshwater resources in developing countries, the evaluation of freshwater water quality is essential (Yan et al. 2015). A water quality index (WQI) evaluates the water quality state, which is single with no unit value derived from a complex mathematical measurement based on a lot of water quality parameters (Pesce and Wunderlin 2000). The water quality index (WQI) is one of the most important techniques for informing policymakers and community members about water quality (Toma 2012). It therefore becomes a significant tool for evaluating and sustaining inland waterbodies. Also, effective decision-making tools based on statistical techniques are applied to aspects that influence the evaluation of the water quality in multiparametric statistical analysis (Varol and Davraz 2015). Multivariable statistical tests such as principal component analysis (PCA) can be used to minimize data when a large amount of data is obtainable (Noori et al. 2010). Also, cluster analysis is one of the multivariable

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statistical analyses that is usually employed to estimate relative similarities in observed parameter uniformity (Shrestha and Kazama 2007). In Nigeria, several studies have been conducted on the water quality status of some bodies of water. Rabiou et al. (2018) assessed the water quality parameters of Watari Dam, Kano State. The authors analyzed water quality properties, which included conductivity, pH, oxygen, and nutrient parameters. These parameters in the water body were within the recommended limits but posed a threat of pollution due to some nutrient parameters. A previous study in the Ikpoba River, as reported by Okonofua et al. (2019) using the water quality index approach, showed that the multivariable statistical method of water quality properties revealed poor water quality in the water body. Reservoirs and other fresh waterbodies are the chief sources of water for household, agriculture, and industries (Shil et al. 2019) as they are the most important resources for life (Bouaroudj et al. 2019; Han et al. 2020; He et al. 2020). These water bodies are degraded mostly by natural activities and human processes such as waste from households, industries, and agricultural run-off into the waterbody (Singh and Kumar 2017). Other processes are geochemical influences, chemical properties of water bodies (Giridharan et al. 2010), and occurrences as a result of nature, such as water interaction with the earth's crust structure that the water body is flowing through (Şener et al. 2017; Subramani et al. 2010). Thus, making it unsuitable for agricultural usage, manufacturing, or other applications (Kazi et al. 2009; Sánchez et al. 2007). Contamination as a result of microplastics have been a major challenge in our water body in which it enters the environment through domestic and industrial activities and contain chemicals which can affect the quality of the water body (Kye et al. 2023). Similarly, the pollution of the environment through household chemicals particularly the water bodies could cause health hazards to man who depends on the water body for domestic purposes especially children (Khalil et al. 2022). Some materials such as fish bones have been documented to reduce the effect of Lead uptake by plants in soil contaminated with Lead-acid batteries thereby resulting in the decrease of Lead absorption in the plant shoots, roots, and grain (Tauqeer et al. 2022). Rasool et al. (2022) was of the opinion that soil contaminated with Lead-acid batteries endangers the environment including groundwater, soils, waterbodies and reduces plant therapeutic qualities through Lead transfer.

Hence, constant monitoring and assessment of water quality are crucial to preserve, regulate and manage waterbodies from degradation (Barakat et al. 2016). Esa-odo reservoir, which was dammed on the River Osun (a UNESCO-recognized site downstream of the reservoir), is an important reservoir in Osun State. It provides water for industrial activities and source of drinking. The study was conducted on the Esa-Odo reservoir because the river in which the reservoir

was dammed is of local and international importance with dearth of information on its quality of water and usefulness. For this reason, this study on the Esa-Odo reservoir has to be carried out.

The objectives of the study are to;

- (i) Evaluate the physicochemical parameters of the reservoir and,
- (ii) Assess the water quality of the reservoir based on multivariate analysis and through water quality index analysis.

## Materials and methods

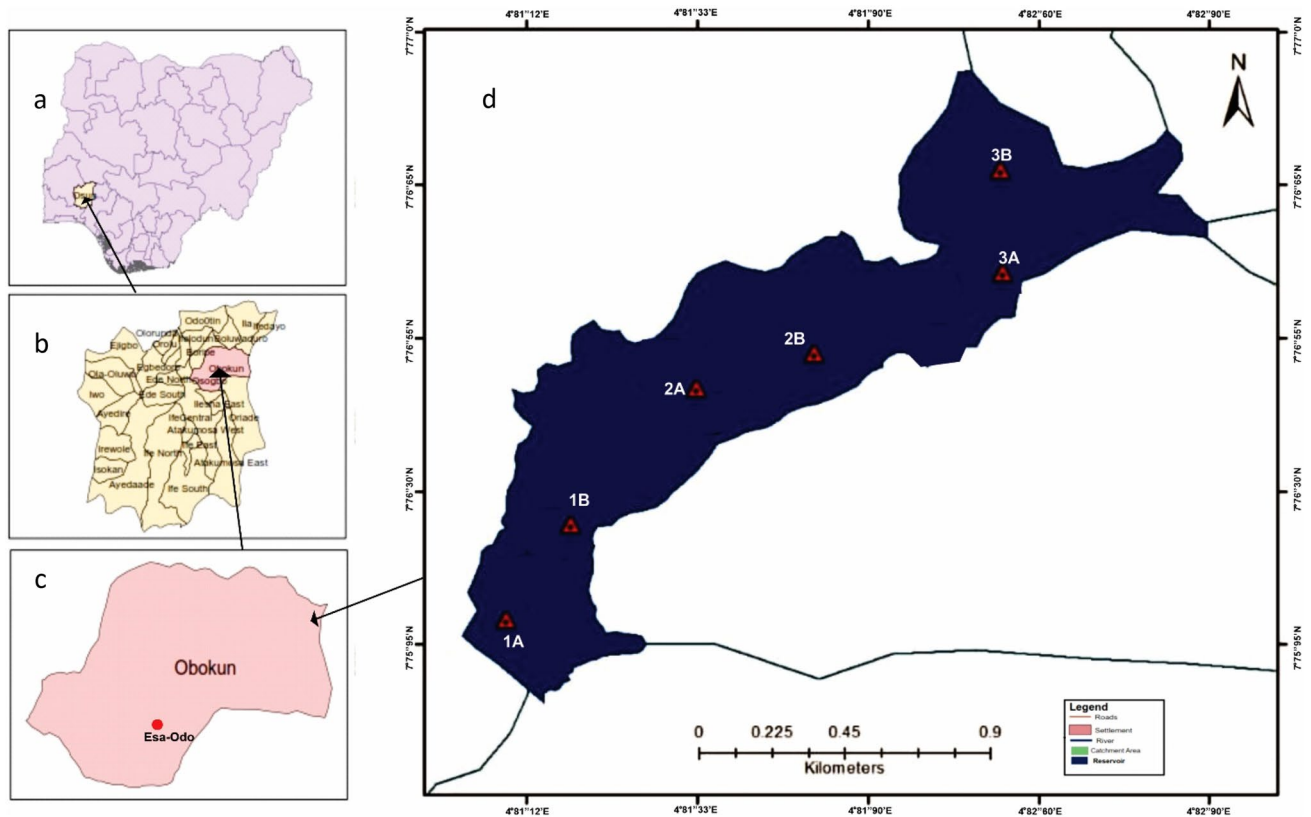
### Study area description

The study area is the Esa-Odo reservoir in the small community of Esa-Odo, Osun State. The area lies approximately on latitudes 007°75'0" N to 007°77'18" N and longitudes 04°81'0" E to 04°82'12". The reservoir was built on the Osun River, which took its source from Igede-Ekiti and flows through Osun State to the Lagos State lagoon. The area experienced dry season between November and February, and rainy season varied from March to October. The data collected were compared with published findings by other authors.

### Water sampling

Samples of water were collected for one annual cycle on monthly basis across three zones (Fig. 1) of the reservoir. The sampling was done in each of the sampling zones using GPS (Table 1) between October 2017 and September 2018. Most activities along the reservoir were cash crop farming and fishing, which some local fishermen do for a living. The water samples collected were preserved at 4 °C with immediate analysis according to (APHA 1999). Parameters such as water temperature was determined on the field using a mercury-in-glass thermometer; pH, conductivity, and total dissolved solids were analyzed using PCE-PHD Version 1.1 Model Q656697; dissolved oxygen and biochemical oxygen demand were analyzed using Winkler's reagents. In order to analyze other water quality parameters such as total suspended solids, total hardness, chloride, alkalinity, sulphate, nitrate, calcium, magnesium, phosphate, potassium, and acidity; water samples were analyzed based on suitable titrimetric or instrumentation method in the Hydrobiology Laboratory of the Department of Zoology, Obafemi Awolowo University, Ile-Ife.

Of the seventeen parameters selected for water analysis, only thirteen were used to calculate the water quality index. These are pH, conductivity, total dissolved solids,



**Fig. 1** a Map of Nigeria showing Osun state, b map of Osun state showing local government areas, c map of Obokun local government, d map of Esa-Odo reservoir showing six different stations covering three different zones

**Table 1** Grid co-ordinates and description of selected sampling stations

Sampling stations	Description of sampling points	Distance from dam axis (m)	Grid co-ordinates		Altitude (m)
			Latitude (N)	Longitude (E)	
1A	Dam site zone	200	07°75'0.9062"	004°81'0.1474"	346
1A	Dam site zone	255	07°76'0.0182"	004°81'0.2373"	346
2B	Transition zone	340	07°76'0.2090"	004°81'0.2607"	347
2B	Transition zone	400	07°76'0.4352"	004°81'0.4941"	351
3C	Riverine zone	525	07°76'0.5642"	004°81'0.7952"	350
3C	Riverine zone	580	07°76'0.6242"	004°81'0.9084"	349

total suspended solids, total hardness, chloride, DO, and BOD. Other physico-chemical parameters are alkalinity, sulphate, nitrate, calcium, and magnesium.

**Multivariate analysis**

Multivariate techniques have been broadly employed to analyze multiple data and variables under conditions that are interrelated (Ramos et al. 2022). It has also been used to analyze water quality characteristics (Nnorom et al. 2019). Water parameters were analyzed using SPSS software version 24 (SPSS, USA). ANOVA was used to determine the spatial differences, while the correlation

coefficient matrix was used to examine the relationship among the water parameters using PAST version 4.10. Principal components analysis (PCA) was used to analyze the relationship between water quality variables in the three zones of the reservoir, and a visual representation was done using graphs performed with PAST software version 2.12. Cluster analysis showed the relationship based on the clustering of different zones of the reservoir. The results of the physical and chemical properties of the water were expressed as a mean ± standard deviation. Also, Arc-Gis 10.8 software was used to create spatial map distribution of selected water quality parameters.

### Water quality index

The water quality index is the most simple and widely employed water index for determining the total quality of water bodies (Gad et al. 2021; Ma et al. 2020). It involves the use of the weighted index method, in which the estimated unit weight assigned to each of the physicochemical parameters of water was considered for the calculation. Therefore, by assigning unit weights, all the selected water properties of different units and dimensions were changed to a common scale. The equation for WQI in this study was based on modified version of several equations that has been in use since its first proposal by Horton (1965).

The water quality index in this study was calculated mathematically as

$$WQI = \frac{\sum W_i Q_i}{\sum W_i}$$

$$Quality\ rating\ (Q_i) = 100 \times \frac{V_i - V_o}{S_i - V_o}$$

where  $Q_i$  is the quality rating scale for  $i^{th}$  parameter,  $V_i$  is the estimated concentration of  $i^{th}$  parameter in the scale,  $S_i$  is the recommended standard value for  $i^{th}$  parameter and  $V_o$  is the

ideal value of the  $i^{th}$  parameter. Here, for all the parameters ideal value,  $V_o$  is taken as zero except for pH, which is 7.0 while DO and BOD is 14.6 (Khan and Tahsin 2020).

$$Unit\ Weight\ for\ Each\ Parameter\ (W_i) = \frac{K}{S_i}$$

where  $W_i$  = unit weight for  $i^{th}$  Parameter and  $K$  = proportionality constant =  $\frac{1}{\sum \frac{1}{S_i}}$

(Khan and Tahsin 2020) The obtained value of the water quality index determines the quality of the water, which can be very excellent (WQI=0–25), good (WQI=26–50), poor (WQI=51–75), very poor (WQI=76–100) or unsuitable (WQI=above 100) (Sudarshan et al. 2019).

### Results

#### Water quality parameters

The summary of environmental parameters of water samples collected at different zones of the reservoir is presented in Table 2. The water quality showed that the highest mean water temperature was observed at the riverine when compared with the other zones, with a significant

**Table 2** Summary of environmental water quality parameters of the reservoir

Parameters	Zones			ANOVA		Seasonal variation		T-test	
	Dam site	Transition	Riverine	F-ratio	p-value	Rainy	Dry	t	p-value
	Mean ± S.D	Mean ± S.D	Mean ± S.D			Mean ± S.E	Mean ± S.E		
Water temperature (°C)	25.7 ± 0.93	25.8 ± 0.79	26 ± 0.71	0.94	0.38	25.5 ± 0.19	26.1 ± 0.07	3.16	0.00*
pH	7.08 ± 0.20	7.11 ± 0.19	7.09 ± 0.14	0.13	0.88	7.09 ± 0.027	7.11 ± 0.03	- 0.47	0.64
Conductivity (µS/cm)	119 ± 10.6	122 ± 9.37	121 ± 10.1	0.31	0.73	120 ± 1.72	121 ± 1.47	- 0.13	0.90
Total dissolved solid (mg/L)	79.8 ± 7.92	81 ± 7.92	81.1 ± 7.78	0.22	0.81	80.2 ± 1.44	81.1 ± 0.90	- 0.52	0.61
Total suspended solid (mg/L)	28.3 ± 5.25	29.3 ± 4.75	29.7 ± 4.35	0.53	0.59	29.8 ± 0.86	28.2 ± 0.59	1.50	0.14
Total hardness (CaCO <sub>3</sub> mg/L)	59.3 ± 10.3	58 ± 9.04	59.5 ± 9.40	0.16	0.85	58.4 ± 1.25	59.6 ± 2.05	- 0.52	0.61
Chloride (mg/L)	7.35 ± 2.25	7.63 ± 2.10	8.40 ± 2.79	1.22	0.30	7.68 ± 0.39	7.95 ± 0.41	- 0.48	0.63
Dissolved oxygen (mg/L)	4.99 ± 1.60	5.04 ± 1.61	5.35 ± 1.27	0.41	0.66	4.95 ± 0.22	5.37 ± 0.27	- 1.19	0.24
Biochemical oxygen demand (mg/L)	2.71 ± 1.24	2.72 ± 1.09	2.85 ± 1.03	0.12	0.88	2.72 ± 0.18	2.82 ± 0.20	- 0.35	0.73
Alkalinity (CaCO <sub>3</sub> mg/L)	45 ± 7.52	46.4 ± 8.73	47.5 ± 8.27	0.54	0.59	49.3 ± 1.17	42.2 ± 1.31	4.01	0.00*
Sulphate (mg/L)	3.85 ± 1.17	3.85 ± 0.91	3.46 ± 1.25	0.99	0.38	3.44 ± 0.14	4.11 ± 0.23	- 2.48	0.02*
Nitrate (mg/L)	1.56 ± 0.53	1.73 ± 0.63	1.68 ± 0.58	0.46	0.62	1.73 ± 0.09	1.55 ± 0.1	1.31	0.19
Calcium (mg/L)	16 ± 3.19	16.4 ± 3.40	16 ± 0.84	0.15	0.86	16.5 ± 0.47	15.7 ± 0.58	0.99	0.33
Magnesium (mg/L)	4.69 ± 1.75	4.10 ± 1.56	4.75 ± 1.63	1.36	0.33	4.20 ± 0.22	4.95 ± 0.34	- 1.83	0.07
Potassium (mg/L)	6.69 ± 1.50	6.59 ± 1.26	5.97 ± 1.35	1.94	0.15	6 ± 0.15	7 ± 0.30	- 2.98	5.00
Phosphate (mg/L)	1.33 ± 0.73	1.24 ± 0.70	1 ± 0.59	1.47	0.24	1.05 ± 0.07	1.39 ± 0.16	- 1.93	0.06
Acidity (mg/L)	11.33 ± 3.83	12.29 ± 3.97	12.30 ± 4.99	0.40	0.67	13 ± 0.51	10.5 ± 0.92	2.37	0.02*

\*Significant (p ≤ 0.05)

\*\*Highly significant (p ≤ 0.01)

\*\*\*Very highly significant (p ≤ 0.001)

difference ( $p < 0.05$ ) between the rainy and dry seasons. The mean level of pH in the reservoir was higher in the dry season ( $7.11 \pm 0.03$ ) than  $7.09 \pm 0.027$  recorded in the rainy season. Also, the mean conductivity of the reservoir varied from  $119 \pm 10.6$   $\mu\text{S}/\text{cm}$  at the dam site to  $122 \pm 9.37$   $\mu\text{S}/\text{cm}$  at the transition zone. On the other hand, TDS had the highest mean value of  $81.1 \pm 0.90$  mg/L during the dry season and  $80.2 \pm 1.44$  mg/L in the rainy season, with no significant difference ( $p > 0.05$ ) between the seasons. In this study, the highest mean TSS concentration ( $29.7 \pm 4.35$  mg/L) was recorded at the riverine, and the lowest value ( $28.3 \pm 5.25$  mg/L) was observed at the dam site. The total hardness of the Esa-Odo reservoir was higher during the dry season with a mean concentration of  $59.6 \pm 2.05$   $\text{CaCO}_3/\text{mg}/\text{L}$  while the mean value of  $58.4 \pm 1.25$   $\text{CaCO}_3/\text{mg}/\text{L}$  recorded in the rainy season. Chloride levels in the reservoir water had a mean value of  $7.35 \pm 2.25$  mg/L,  $7.63 \pm 2.10$  mg/L and  $8.40 \pm 2.79$  mg/L for dam site, transition and riverine zones, respectively. A higher mean DO value of  $5.37 \pm 0.27$  mg/L was recorded during the dry season when compared with  $4.95 \pm 0.22$  mg/L observed in the rainy season, with no significant difference ( $p > 0.05$ ) between the seasons. The BOD of the reservoir was highest at the riverine ( $2.85 \pm 1.03$  mg/L) than  $2.71 \pm 1.24$  mg/L recorded at the dam site. Also, the highest mean alkalinity of  $49.3 \pm 1.17$   $\text{CaCO}_3/\text{mg}/\text{L}$  was observed during the rainy season while  $42.2 \pm 1.31$   $\text{CaCO}_3/\text{mg}/\text{L}$  was recorded during the dry season, with a significant difference ( $p < 0.05$ ) between the two seasons. The mean sulphate level of the reservoir varied from  $3.46 \pm 1.25$  mg/L at the riverine to  $3.85 \pm 1.17$  mg/L and  $3.85 \pm 0.91$  mg/L at both the transition and dam sites respectively. A high mean nitrate value of  $1.73 \pm 0.63$  mg/L was recorded at the transition zone while the lowest value of  $1.56 \pm 0.53$  mg/L was observed at the dam site during this study. The mean level of calcium in the reservoir was higher in the rainy season ( $16.5 \pm 0.47$  mg/L) than  $15.7 \pm 0.58$  mg/L recorded during the dry season. Maximum potassium value was observed at the riverine, and there was no significant difference ( $p > 0.05$ ) between the seasons. The mean levels of phosphate across the zone differ significantly and the highest mean concentration was recorded at the dam site. Acidity had the highest mean concentration of  $13 \pm 0.51$  mg/L in the rainy season, while the dry season recorded a value of  $10.5 \pm 0.92$  mg/L with a significant difference ( $p < 0.05$ ) between the seasons. ANOVA showed that there was no significant difference ( $p > 0.05$ ) among the water parameters across the zones.

### Multivariate analysis of the water quality

The correlation matrix table was used to describe the inter-relationship between different water quality parameters of the reservoir. The result of this study showed that there was

a strong correlation between the water quality parameters of the reservoir (Table 3). Conductivity showed a highly significant correlation ( $p < 0.01$ ) with TDS. However, a negative correlation was recorded between water temperature and magnesium. Potassium and sulphate revealed a strong positive correlation. Also, both TDS and calcium, as well as conductivity, showed a similar positive correlation. The component analysis showed the water quality parameters had more influence in different zones of the reservoir. It revealed water quality parameters that clustered with different reservoir zones (Fig. 2). It also revealed differences between the riverine, transition, and dam sites. The variables showed that there was a close relationship between acidity, alkalinity, and TSS, which clustered at both the riverine and transition zones, while magnesium, conductivity, pH, DO, BOD, TDS, sulphate, nitrate, chloride, water temperature, potassium, phosphate, and calcium are related at the dam site and clustered together. The water variables showed good clustering of physicochemical parameters at the dam site while water hardness showed not too close clustering with the dam site when compared with riverine and transition zones.

The clustering of the water qualities based on the zone is presented in Fig. 3. The similarity among each of the zones in the clusters recorded from cluster analysis was the result of correlation and autocorrelation among the water quality properties of the reservoir. As shown in Fig. 3, two clusters were extracted based on the distance. The first cluster combined the transition and riverine zones, while the second cluster was that of the dam site. Figure 4 showed the spatial map distribution of selected water quality parameters of the reservoir. The water quality parameters were illustrated by different colour combinations for their respective concentration ranges.

### Water quality index

The calculation of WQI was based on an estimate of the unit weight assigned to each physicochemical parameter taken into consideration for the mathematical calculation; the weighted arithmetic index technique was used. A minimum weight of 0.0033  $W_n$  was assigned to TDS, TSS, and hardness, while a maximum weight of 0.3317  $W_n$  was assigned to both DO and BOD. Therefore, indicating the key importance of these properties in water quality evaluation of the environment and their significant influence on the water index. Thirteen (13) water quality parameters were carefully selected. The result of the WQI obtained from all the sampling zones and seasons is shown in Table 4. The transition zone recorded the highest value of WQI (77.3), while the lowest WQI (75.8) was observed in the riverine zone. The values of WQI increased considerably from one zone to another and improved considerably at the dam site. Seasonally, the dry season recorded the

**Table 3** Correlation matrix table showing the relationship between environmental parameters

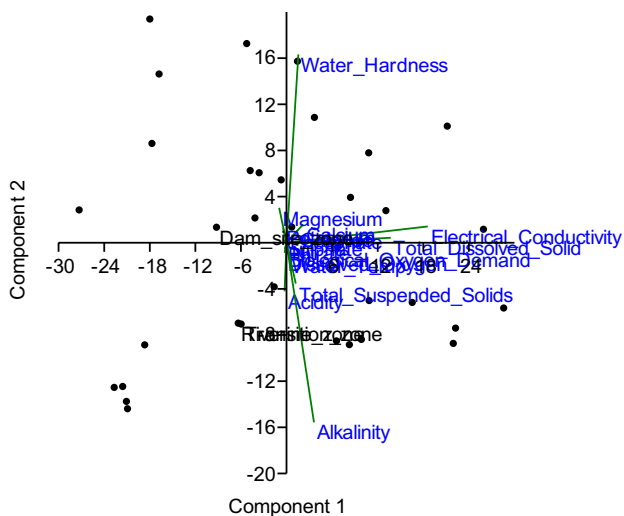
	Water temp	DO	BOD	pH	EC	TDS	Chloride	Acidity	Alkalinity	Ca <sup>2+</sup>	Mg <sup>2+</sup>	K <sup>+</sup>	WH	Nitrate	Sulphate	Phosphate	TSS
Water temp	0.000																
DO	0.128	0.000															
BOD	0.166	0.872***	0.000														
pH	0.024	0.115	0.042	0.000													
EC	0.172	-0.141	-0.158	-0.390	0.000												
TDS	0.193	-0.118	-0.131	-0.296	0.987***	0.000											
Chloride	-0.069	-0.073	0.036	-0.159	0.451	0.464	0.000										
Acidity	-0.121	0.071	0.109	0.258	-0.087	-0.025	0.008	0.000									
Alkalinity	0.450	0.154	0.066	-0.069	0.260	0.291	-0.014	0.350	0.000								
Ca <sup>2+</sup>	0.082	-0.060	-0.018	-0.331	0.636*	0.627*	0.238	-0.117	0.015	0.000							
Mg <sup>2+</sup>	-0.515*	-0.209	-0.194	0.099	-0.341	-0.342	0.144	-0.042	-0.542	-0.367	0.000						
K <sup>+</sup>	-0.278	-0.207	-0.176	-0.160	-0.165	-0.168	-0.206	-0.082	-0.363	-0.158	0.319	0.000					
WH	-0.445	-0.253	-0.204	-0.162	0.151	0.142	0.330	-0.133	-0.521	0.397	0.708**	0.200	0.000				
Nitrate	-0.149	0.168	0.324	-0.092	0.337	0.369	0.449	0.284	0.049	0.160	0.024	-0.183	0.154	0.000			
Sulphate	-0.106	-0.251	-0.207	0.034	-0.243	-0.212	-0.090	-0.056	-0.156	-0.300	0.230	0.868***	0.004	-0.288	0.000		
Phosphate	-0.382	0.004	-0.008	-0.378	0.074	0.015	-0.264	-0.074	-0.470	0.183	0.257	0.561	0.396	0.112	0.077	0.000	
TSS	0.000	-0.042	0.159	-0.062	0.112	0.110	0.421	0.389	0.177	0.022	-0.099	-0.349	-0.078	0.273	-0.209	-0.352	0.000

\*Significant (p ≤ 0.05)

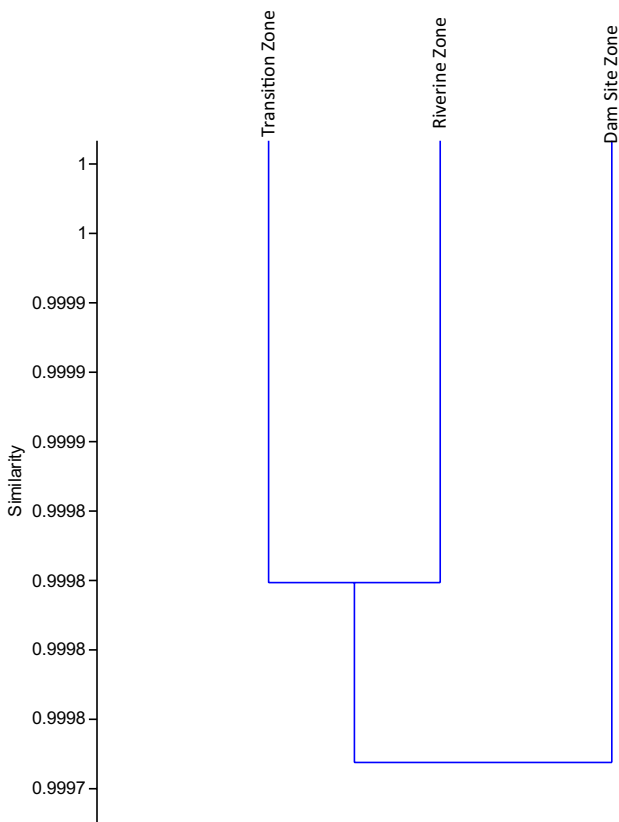
\*\*Highly significant (p ≤ 0.01)

\*\*\*Very highly significant (p ≤ 0.001)





**Fig. 2** Principal component analysis (PCA) showing relationship between water quality parameters



**Fig. 3** Cluster analysis of the study area showing clustering zones

highest WQI value of 77.9 when compared with the rainy season, which recorded 76.4 as its WQI value. Irrespective of the zones and seasons, the values recorded indicated poor water quality based on the drinking water index.

A comparison of the water quality index with other inland water bodies is presented in Table 5. The WQI recorded in this study was between 75.8 and 77.9. It showed a lower value in comparison with Beheshtabad River, the Adolfo López Mateos Dam, and the Ogbese River which recorded 62.2–71, 73.5 and 44.9–46.6 respectively. However, Hebbal Lake and the Mahananda River revealed WQI values higher than those in the Esa-Odo reservoir.

### Discussion

The water temperature in this study area varied from one zone to another. The mean temperature varied from 25.7 °C to 26 °C with higher water temperature recorded during the dry season. The rainy season had a mean temperature of  $25.5 \pm 0.19$  °C while the dry season recorded a mean value of  $26.1 \pm 0.07$  °C and this variation could be due to the weather conditions that usually occurred in the two seasons. The temperatures recorded were within the recommended limit (WHO 2004) and the observation was similar to the results recorded by Omoboye et al. (2022) in Owalla Reservoir. The findings of pH during the dry season were higher than the value recorded in the rainy season. Also, the mean value varied from 7.08 at the dam site to 7.11 at the transition zone. The values of pH recorded were above the values of FAO (2012), and it was slightly neutral. In comparison with other inland waters, this finding was lower than the pH values recorded at Oyan Dam by Osibona and Ayoola (2020). Also, this was consistent with the results of Onwugbuta-Enyi et al. (2008) in Bodo Creek in the Lower Niger Delta Basin. Electrical conductivity (EC) is the ability of water to conduct current; it also serves as a tool to determine the number of dissolved salts or ions in the solution (Pal et al. 2015). The mean conductivity values across the zones varied from 119 to 122  $\mu\text{S}/\text{cm}$  with  $120 \pm 1.72$  and  $121 \pm 1.47$   $\mu\text{S}/\text{cm}$  recorded during the rainy and dry seasons respectively. These findings were similar to the reports of Eneogwe et al. (2022) that recorded conductivity values which ranged between 21.5 and 156.4  $\mu\text{S}/\text{cm}$ . However, the mean conductivity values recorded in this study were below the 86.3  $\mu\text{S}/\text{cm}$  reported by Atwebembeire et al. (2018). Higher conductivity in the dry season could probably be due to the reduced volume of the water and the increase in temperature that is associated with ionization (Chikogu et al. 2012). TDS had a mean value of  $80.2 \pm 1.44$  mg/L in the rainy season and  $81.1 \pm 0.90$  mg/L during the dry season. The concentration of TDS was below the WHO (2004) concentration of 250 mg/L and the FAO (2012) concentration of 2000 mg/L. The result of the mean TSS value of  $29.8 \pm 0.86$  mg/L recorded in the dry season was higher than the value of  $28.2 \pm 0.59$  mg/L during the rainy season. The increased water flow that might carry more suspended

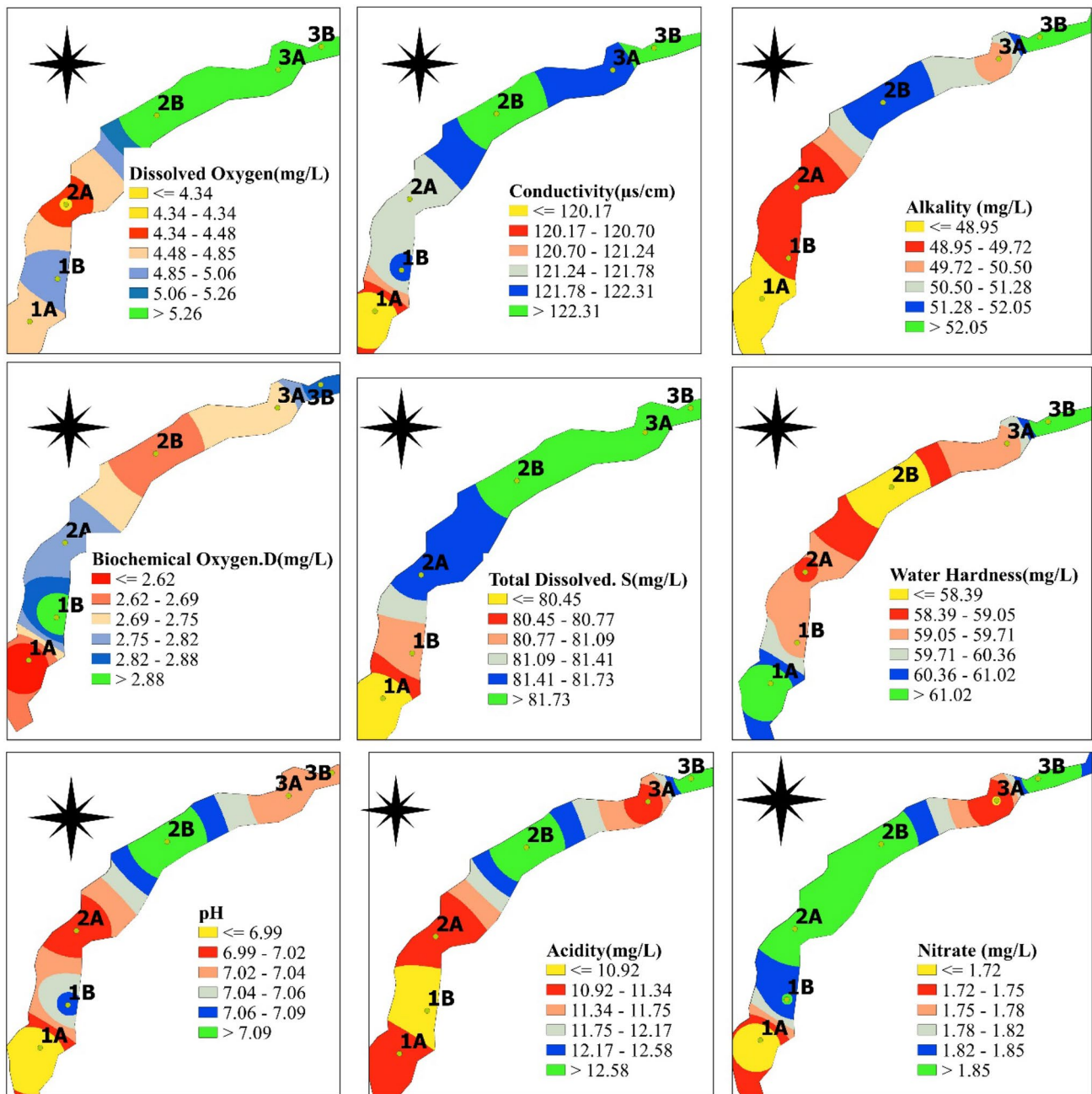


Fig. 4 Spatial distribution of selected water quality parameters

particles was responsible for the higher results during the rainy season (Kitonga et al. 2018). The total hardness had a mean value that varied from 58.0 CaCO<sub>3</sub>mg/L at the transition zone to 59.5 CaCO<sub>3</sub>mg/L at the riverine zone; the values across the zones were below the mean value of 33.7 CaCO<sub>3</sub>mg/L recorded in Bontanga Reservoir.

The mean chloride of 7.68 ± 0.39 mg/L reported in the rainy season was lower than the level observed during the dry season (7.95 ± 0.41 mg/L). Low chloride contents in this study indicated low pollution level around the reservoir

(Kumari et al. 2019). The mean DO varied from 4.99 mg/L at the dam site to 5.35 mg/L at the riverine zone. This agreed with the study of Iliya et al. (2019) in the Gurara River. DO values recorded in this study were below the (NSDWQ 2007; WHO 2004) recommended limit of 10 mg/L. Reduced DO during the rainy season may be caused by a significant influx of waste, which would also reduce the reservoir’s biological life, in accordance with the findings of Hassan et al. (2013). This showed that the water might be unsuitable for domestic purposes and reduced the activities of aquatic organisms



**Table 4** Water quality index for zones and seasons of the reservoir

Parameters	Zones			Seasons		Overall
	Dam site	Transition	Riverine	Rainy	Dry	
pH	0.32	0.75	0.33	0.87	− 0.09	0.47
Conductivity (µS/cm)	0.23	0.23	0.23	0.23	0.23	0.23
Total dissolved solid (mg/L)	0.05	0.05	0.05	0.05	0.05	0.05
Total suspended solid (mg/L)	0.02	0.02	0.02	0.02	0.02	0.02
Total hardness (CaCO <sub>3</sub> mg/L)	0.04	0.04	0.04	0.04	0.04	0.04
Chloride (mg/L)	0.02	0.02	0.02	0.02	0.02	0.02
Dissolved oxygen (mg/L)	33.9	33.9	32.4	32.9	34.1	33.4
Biochemical oxygen demand (mg/L)	41.20	41.4	41.1	40.7	42	41.2
Alkalinity (CaCO <sub>3</sub> mg/L)	0.56	0.58	0.60	0.63	0.51	0.58
Sulphate (mg/L)	0.03	0.03	0.03	0.03	0.03	0.03
Nitrate (mg/L)	0.12	0.13	0.12	0.13	0.11	0.12
Calcium (mg/L)	0.48	0.49	0.48	0.48	0.49	0.49
Magnesium (mg/L)	0.32	0.27	0.33	0.26	0.37	0.31
<b>∑Wiqi</b>	<b>77.3</b>	<b>77.9</b>	<b>75.8</b>	<b>76.4</b>	<b>77.9</b>	<b>77</b>

∑Wiqi = summation of water quality index (in bold)

**Table 5** Comparison of water quality index with other Inland waterbodies

Waterbodies	WQI	Study
Esa-Odo	75.8–77.9	This study
Beheshtabad river	62.2–71	(Fathi et al. 2018)
Hebbal lake	92.2–102	(Sudarshan et al. 2019)
Ogbese river	44.9–46.6	(Akinbile and Omoniyi 2018)
Adolfo López Mateos dam	73.5	(Quevedo-Castro et al. 2018)
Mahananda river	17.6–94.5	(Shil et al. 2019)

in the reservoir. BOD is the level of oxygen necessary for the biological oxidation of organic materials in water. The mean BOD values in the dry season ( $4.95 \pm 0.22$  mg/L) were slightly lower than  $5.37 \pm 0.27$  mg/L recorded during the rainy season. The result of this current study was in contrast with the findings of Akaahan and Azua (2016), who recorded BOD values that ranged between 1.21 and 2.18 mg/L. The low amount of BOD in the reservoir could probably be a result of low levels of organic matter and pollution. High levels of BOD during the rainy season might be due to runoff and organic materials.

The result of alkalinity during the rainy season with a value of 49.3 CaCO<sub>3</sub>mg/L was higher than the value recorded in the dry season (42.2 CaCO<sub>3</sub>mg/L). The mean value varied from 45 CaCO<sub>3</sub>mg/L at the dam site to 47.5 CaCO<sub>3</sub>mg/L at the riverine zone. The values of alkalinity recorded in Esa-Odo were above the values of FAO (2012). Similar findings were observed by Aliu et al. (2020) in the Obudu River, where the alkalinity level was 44.2 CaCO<sub>3</sub>mg/L. Also, this was consistent with the findings of Hyeladi and

Nwagilari (2013) that reported an alkalinity level of 36–72 CaCO<sub>3</sub>mg/L in Alau Dam. Sulphate naturally occurs in groundwater as a result of sulfides, such as pyrite, being dissolved by percolating water, which releases sulphate ions from the interstratified minerals (Olobaniyi and Owoyemi 2010). In this study, sulphate (SO<sub>4</sub><sup>2-</sup>) levels ranged from  $3.46 \pm 1.25$  mg/L in the riverine to  $3.85 \pm 1.17$  mg/L at the dam site. The nitrate level in the reservoir could be due to infiltration from farmland as a result of fertilizer application to the farm. Nitrate had a mean value of  $1.73 \pm 0.09$  mg/L in the rainy season and  $1.55 \pm 0.1$  mg/L during the dry season. The nitrate levels in this current study were below (WHO 2004) concentration of 50 mg/L and (FAO 2012) level of 10 mg/L. These findings were in contrast with the results of Adedeji et al. (2020) that recorded nitrate levels between 0.19 and 0.22 mg/L in the Opa reservoir. High nitrate water consumption results in birth disorders of the central nervous system, diabetes, stomach carcinomas, methemoglobinemia illness, aberrant pain, and gastric cancers in infants (Varol and Davraz 2015; Vasanthavigar et al. 2010).

The growth and metabolism of aquatic organisms are significantly influenced by the hardness of the calcium (Vankar et al. 2019). The result of mean calcium of  $16.5 \pm 0.47$  mg/L observed in the rainy season was higher than the level of  $15.7 \pm 0.58$  mg/L in the dry season. All the levels of calcium across the zones were within the recommended limits for drinking water (WHO 2011). Similar observations were reported by Adesakin et al. (2016) and Olanrewaju et al. (2017) in the Opa and Eleyele reservoirs respectively. The magnesium values recorded in this study had a mean value that varied from  $4.10 \pm 1.56$  mg/L at the transition zone to  $4.75 \pm 1.63$  mg/L at the riverine zone; the values across the zones were consistent with the values recorded

by (Pulugandi 2014) who recorded magnesium values that ranged between 5.3 and 11.2 mg/L in Vembakottai reservoir. Despite its abundance in nature, potassium is only found in trace amounts in the majority of natural fluids, owing to weathering, which converts it into secondary minerals that are insoluble (Mallick 2017). The mean potassium in Esa-Odo varied between 5.97 mg/L at the riverine site and 6.69 mg/L at the dam site. This was in agreement with the findings of Saxena (2012), who reported potassium levels that varied from 4.25 to 7.53 mg/L and a mean concentration of  $5.93 \pm 0.23$  mg/L at Raipur reservoir. Potassium values recorded in this study were below (BIS 2003) permissible limit of 10 mg/L. The mean phosphate value in the dry season ( $1.39 \pm 0.16$  mg/L) were higher than  $1.05 \pm 0.07$  mg/L reported in the rainy season. Increased level of phosphates in the dry season was similar to the study by Lanmandjèkpogni et al. (2018). Phosphates may be associated with buffer zones' influence on phosphorus retention in the waterbody and run-off infiltration of water trapped at the sediments of the reservoir. The mean acidity varied from 11.33 mg/L at the dam site to 12.30 mg/L at the riverine zone. This result was higher than the concentrations recorded by Hameed et al. (2019) at Ifewara Reservoir.

The water quality index (WQI) of Esa-Odo reservoir was determined mathematically using Khan and Tahsin (2020) methods from thirteen water quality parameters for rainy and dry seasons. Parameters such as pH, conductivity, TDS, TSS, total hardness, chloride, DO and BOD were determined for WQI. Other parameters namely alkalinity, sulphate, nitrate, calcium and magnesium, were also considered for estimating the WQI value for the seasons and zones. In order to determine the unit weights, the minimum and maximum weights for each parameters due to the vital significance of these properties in water quality were used in water quality index evaluation. Total dissolved solids, total suspended solid and total hardness had the least unit weight of 0.0033 while dissolved oxygen and biochemical oxygen demand recorded maximum unit weights of 0.3338. The WQI varied from 75.8 at the riverine to 77.9 at the transition zone. Hence, the WQI of the dam site was of better quality when compared to the riverine and transition zones. This could be due to reduced anthropogenic activities at the dam site. High WQI recorded at the transition zone was as a result of intense fishing activities at the open water part of the reservoir. The finding in this study was similar to the observation of Aigberua and Tarawou (2019) at the inland freshwaters of Taylor Creek. The WQI ranged between 75.8 and 77.9 recorded in Esa-Odo reservoir could be compared with other waterbodies. The WQI was higher in comparison with the findings of Fathi et al. (2018) at Beheshtabad River; Akinbile and Omoniyi (2018) at Ogbese River and Quevedo-Castro et al. (2018) at Adolfo López Mateos Dam. However, the WQI of these

current findings was lower than the concentration recorded by Sudarshan et al. (2019) at Hebbal Lake and Shil et al. (2019) at Mahananda River. The overall WQI of Esa-Odo reservoir could be classified as of poor quality. Seasonally, the WQI value of 77.9 recorded during the dry season was higher than the 76.4 observed in the rainy season. The reduction in WQI in the rainy season could probably be as a result of high humidity since it increases the amount of water entering the reservoir, this was also the view of Sánchez et al. (2007) and significant level of pollution in the rainy season when compared to the dry season.

Also, similar findings were recorded by Aliu et al. (2020) in the Obudu River, where the alkalinity level was 44.2  $\text{CaCO}_3$ mg/L. Also, the results of this study was consistent with the findings of Hyeladi and Nwagilari (2013) that reported an alkalinity level of 36–72  $\text{CaCO}_3$ mg/L in Alau Dam. Sulphate naturally occurs in groundwater as a result of sulfides, such as pyrite, being dissolved by percolating water, which releases sulphate ions from the interstratified minerals (Olobaniyi and Owoyemi 2010). In this study, the mean sulphate ( $\text{SO}_4^{2-}$ ) level ranged from  $3.46 \pm 1.25$  mg/L in the riverine to  $3.85 \pm 1.17$  mg/L at the dam site. The nitrate level in the reservoir could be due to infiltration from farmland as a result of fertilizer application to the farm. Nitrate had a mean value of  $1.73 \pm 0.09$  mg/L in the rainy season and  $1.55 \pm 0.1$  mg/L during the dry season. The levels were below the WHO (2004) concentration of 50 mg/L and the FAO (2012) level of 10 mg/L. These findings were in contrast with the results of Adedeji et al. (2020) that recorded nitrate levels between 0.19 and 0.22 mg/L in the Opa reservoir. Birth disorders of the central nervous system, diabetes, stomach carcinomas, methemoglobinemia illness, aberrant pain, and gastric cancers in infants are all associated with high nitrate water consumption (Varol and Davraz 2015; Vasanthavigar et al. 2010).

The growth and metabolism of aquatic organisms are significantly influenced by the hardness of calcium (Vankar et al. 2019). The results of the mean calcium level of  $16.5 \pm 0.47$  mg/L observed in the rainy season was higher than the level of  $15.7 \pm 0.58$  mg/L in the dry season. All the levels of calcium across the zones were within the recommended limits for drinking water (WHO 2011). Similar observations were reported by Adesakin et al. (2016) and Olanrewaju et al. (2017) in the Opa and Eleyele reservoirs respectively. The magnesium values recorded in this study had a mean value that varied from  $4.10 \pm 1.56$  mg/L at the transition zone to  $4.75 \pm 1.63$  mg/L at the riverine zone; the values across the zones were consistent with the values recorded by Pulugandi (2014), who recorded magnesium values that ranged between 5.3 and 11.2 mg/L in Vembakottai reservoir. Government at all levels especially the state government should give maximum attention to the reservoir by regulating human activities around the reservoir such as

mining of fine sediments and disposal of palm oil effluents by the locals and regulating the use of chemicals by farmers along the shoreline of the reservoir. Also, regular monitoring of the health status of Esa-Odo reservoir and its tributaries through deployment of new technologies.

## Conclusion

The evaluation of the water quality index of the Esa-Odo reservoir revealed that the water quality was poor and unfit for domestic use if not appropriately treated. The application of WQI to the reservoir indicated the significance of this index in classifying the reservoir under study. As a result, the reservoir's water quality was observed to be influenced by anthropogenic activities, with the dry season having the highest WQI. Pollution along the shoreline of the reservoir could have contributed to the physico-chemical parameters and quality of the reservoir. Also, human activities such as farming along the shoreline could have deteriorated the water quality of the Esa-Odo reservoir. Therefore, periodic protection actions relating to the use of the reservoir water should be encouraged. It is recommended for all stakeholders involve in the management of the reservoir to intensify their efforts in monitoring of the quality of the reservoir water through constant investigation of the reservoir and reducing human activities around the reservoir.

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**Data availability** The data of this study will be available based on a request from the corresponding author.

## Declarations

**Conflict of interest** The authors declare no conflict of interest.

**Informed consent** Not applicable.

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