International Research Journal of Environmental Sciences ISSN 2319–1414
Vol. **11(2),** 13-24, April **(2022)** *Int. Res. J. Environmental Sci.*

Assessment of the Physico-chemical water quality of an Artificial Lake in Osun State, Nigeria, over time and space

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Available online at: www.isca.in, www.isca.me
Received 30th November 2021, revised 16th February 2022, accepted 18th March 2022

Abstract

This study investigated the variation in physico-chemical water quality of the Esa-Odo Reservoir over space and timefrom February 2017 to December 2018 at two months interval. To cover the whole reservoir zone, sampling points were chosen horizontally and vertically at marked out stations. Depth, transparency (using Secchi disc) and temperature (using mercury-in-glass bulb thermometer) were determined on field. Other physical and chemical parameters were evaluated using standard methods. The values obtainedrevealed Esa-Odo Reservoir as slightly buffered freshwater with cationic hierarchy of Na >Ca > Mg > K and anion hierarchy of HCO_3^- > Cl^- >SO_4^{2-}. Investigated physical parameters varied the most and were significant for two parameters (True Color and Total suspended solid) spatially. While vertically highly significant variation were observed for four (Temperature, Turbidity, Total suspended solid, apparent and true color) parameters. Seasonally, five of the investigated physical parameters (Turbidity, Total solid, Total suspended solid, apparent and true color) showed very highly significant variation. However, in terms of the chemical parameters investigated, only the salinity parameters showed significant vertical (pH and TDS) and highly significant seasonal (TDS, Alkalinity and Hardness) variations. Moreover, seasonally, the nutrient parameters recorded highly significant variation as well as all ions assessed except potassium. All monitored physico-chemical parameters were within the guide level range as of the World Health Organisation (WHO) for drinking water, therefore Esa odo Reservoir water can be classified as fairly clean, alkaline freshwater. However based on the significant seasonal variations in its water quality, regular proper monitoring of the reservoir is recommended.

Keywords: Reservoir, Physico-chemical, Vertical, Seasonal, Zones, Spatial.

Introduction

Reservoirs are vital biomes and nutrient sources to wide range of water species. Lake ecosystems, on the other hand, are delicate and susceptible to quick environmental changes, which can result in major reductions in their attractive, leisure, and aquaticfunctions[1]. Therefore, assessment of water quality and conservations of reservoir is very vital for its uses in diverse ways which includes irrigation, drinking and domestic purpose. Often times, its quality for best application is assessed using physico-chemical analysis[2]. These physico-chemical characteristics of waterbody vary depending on factors such as size, shape, topography, climatic, biological community and anthropogenic activity[3]. Also, temporal and spatial variation with the impact of seasons affect the status of physico-chemical parameters. Therefore, ensuring favorable existence of living organisms in the aquatic habitat, physico-chemical parameters should be regularly followed as activities of living things are affected by the changes in the temporal and daytime pattern of these parameters[4]. Variation in the physical and chemical factors may also affectaquaticlives favourably or adversely in some ways especially their survival, reproduction and growth rates. Adverse change in these physico-chemical parameters may eventually result in non-existence vital species [5]. Different studies have been conducted on physico-chemical water quality of an artificial lake in Nigeria but such information on Esa-Odo Reservoir were scarce. The only research of the lake's zooplankton population was a comparison with those of other lakes in the Osun River Basin. The study lasted only three months, and the sampling was limited to surface water and was done twice a month. This preliminary report is insufficient for planning and management purposes. Additionally, due to ongoing activity in and around the water body, the hydrology and other aspects of the lake have changed. As a result, this is the first comprehensive study of the lake since its impoundment (spanning two annual cycles).The primary goal of this study was to look into the variations in physico-chemical water quality in Esa-Odo Reservoir through time and space.

Materials and methods

Area of study: Esa Odo Reservoir, one of the major impoundments on Osun River (Figure 1.Map of Obokun Local Government Area (LGA) showing Esa-Odo) was impounded in[6]. The reservoir is located approximately on the geographical coordinates of Latitude 07° 35' to 07° 55' North of the Equator, and longitude 004° 30' to 004° 55'East of Greenwich Meridian on an altitude of about 350 m above mean sea level in Obokun

LGA, Osun State, Nigeria (Figure-1). The lake is around 30 kilometers east of Osogbo (the capital of Osun State), 20 kilometers north of Ilesa, 210 kilometers northeast of Lagos (Nigeria's largest commercial hub), and 330 kilometers southwest of Abuja (the Federal Capital Territory of Nigeria). The artificial lake was built to give drinkable water to the Obokun LGA's residents. The lake also serves as a source of raw water for the International Breweries in Ilesa, Nigeria. The reservoir provides potentials for fishery enterprise as well as tourism. The reservoir site is linked with motor-able roads to the state capital, Osogbo.

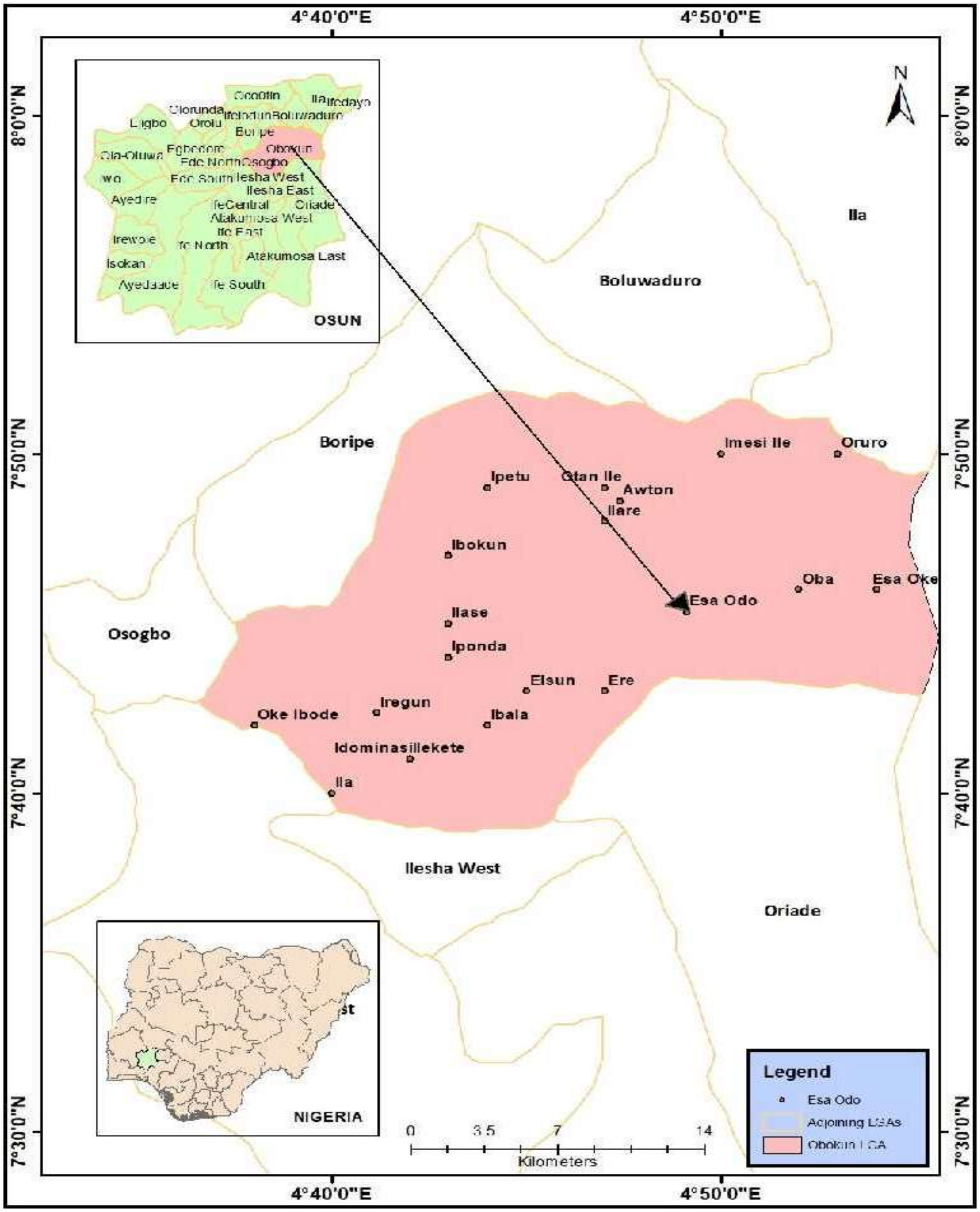


Figure-1: Map of Esa-Odoin Obokun Local Government Area.

Methodology: At various stations, sampling points were chosen horizontally (Lacustrine, Transition, and Riverine) and vertically (surface, mid-depth, and near to the bottom) to cover the reservoir's full zones (Figure-2. Map of Esa-Odo Reservoir showing the selected sampling stations). Only surface water samples were collected for physico-chemical analysis at shallow Stations while water samples were obtained from three levels across the reservoir's water column (surface, mid-depth, and close to the bottom) at other stations (1S 1B, 2S, 2M, 2B, 3S, 3M, 3B) using an improvised Meyer's water sampler (2.5 L capacity). Riverine stations (Inflow and station 1) were built near the inflow of the River Osun into the reservoir and a few meters distant, while a Transition station (station 2) was situated near the reservoir's open water section. Close to the dam region, a lacustrine station (station 3) was cited.In addition, stations 2L1, 2L2, 3L1 and 3L2 were established at the littoral zones of the transition and lacustrine stations of the reservoir.

The Physico-chemical water quality parameters presented in Table 3.5 weredetermined in this study. Air temperature (^oC), Water temperature (^oC), Transparency (cm) and Depth (m) were determined *in-situ* while water samples for the analysis of other physico-chemical factors were movedfor further analysis at the laboratory using standard methods. The water quality parameters were analysed using descriptive statistics (minimum, maximum, range, median, mode, mean, standard error, coefficient of variation); inferential statistics (Correlation, Regression analysis, Analysis of variance (ANOVA)) and multivariate statistics (Cluster analysis, Principal Component Analysis (PCA)) using PAST (Paleontological Statistics)[7] statistical software and Microsoft Excel.

Results and discussion

Physical Parameters of Water Quality: Table-1 shows the descriptive statistics for general physico-chemical water quality parameters evaluated in the thirteen (13) sites delineated on Esa-Odo Reservoir during the project. The horizontal changes in the mean of the physical parameters showed a substantial rise ($p \leq 0.05$) in true color and a non-significant drop in total solids from the lacustrine to the riverine region of the reservoir, respectively. while apparent colour had non-significant variations amongst the zones of the reservoir but had its highest mean at the transition zone along with temperature and turbidity (Table-2). The observed differences in water temperature were also non-significant with the highest mean value of 29.28 ± 0.3^{o}C recorded at the transition (Table-2). From the surface to the bottom, there was a very substantial decline ($p \leq 0.01$) in the mean values of water temperature, apparent color, and total solids (Table-2). On the other hand, total suspended solids exhibited very highly significant increase ($p \leq 0.001$) from the surface to the bottom water while turbidity and true colour were highest at mid-depth (Table-2). The colloidal parameters (turbidity, total solids (TS) and total suspended solids (TSS) had higher mean values during rainy season while colour parameters (apparent and true color) and water temperature were higher during dry season (Table-3).

Chemical parameters of water quality: *Salinity parameters:* Tables-1 shows descriptive statistics for the chemical characteristics of the Esa-Odo Reservoir.There exist no significant differences in the spatial variations of the salinity parameters both horizontally and vertically (Tables 2) with the exception of pH which had significant vertical variation ($p \leq 0.05$). pH, Conductivity and TDS had their highest mean of 7.07±0.1, 115.24±1.0 µScm^{-1}, 87.88±5.9 mg/L respectively at the lacustrine with TDS decreasing towards the riverine area. While an increase in alkalinity and water hardness was observed from lacustrine towards the riverine. Highest mean were also observed for pH and Conductivity at the lacustrine but had their lowest at the transition (Table-2) hence, the highest mean acidity recorded at the transition zone of the reservoir.

Vertically, the salinity parameters had highest mean at the surface water with reduction in concentrations observed towards the bottom except for conductivity whose highest mean was at the bottom water (Table-2). The only significant variation was observed for pH of the reservoir which was more acidic with depth. Temporally, all chemical parameters, with the exception of pH, exhibited higher mean values in the dry season (Table-3). And there exist very highly significant variations in the seasonal pattern of total dissolved solids, alkalinity and hardness.

Oxygen parameters: All the oxygen parameters had the maximum and minimum mean at the lacustrine and riverine zones respectively (Table-2). However, the horizontal variations of the oxygen parameters were statistically non-significant. There also exist no significant variations in the vertical concentrations of the oxygen parameters. Dissolved oxygen and Dissolved oxygen saturation had their highest and lowest mean values at the surface and mid-depth of the reservoir respectively (Table 2). While Biological Oxygen Demand (BOD_5) and Chemical Oxygen Demand (COD) were lowest at the surface water and increase in mean values down the column of the reservoir (Table-2).

Although the reservoir had more dissolved oxygen in rains than dry season, it was observed that saturation of the dissolved oxygen was higher in dry season (Table-3). Moreover, the observed seasonal variations in the oxygen parameters revealed a very highly significant difference ($p \leq 0.001$) in COD mean values with the higher value in the rainy season. While BOD_5 had higher mean values of 3.99 ± 0.3mg/l in the dry season (Table-3).

Major ions: The anion parameters of the water quality did not show any regular pattern of horizontal variation with only chloride showing significant difference in spatial concentration at $p \leq 0.05$. Bicarbonate decreased in concentration from riverine to lacustrine while sulphate and chloride had their highest concentration at the transition zone with lowest mean at lacustrine and riverine respectively (Table-2). Vertically, the differences in anion concentrations were not statistically significant (Table-2). Chloride increased from surface to the bottom of the reservoir while Bicarbonate and Sulphate had highest and lowest mean values at the surface and mid-depth of the reservoir respectively. Very highly significant seasonal variations ($P<0.001$) were observed in the concentration of anions (Table-3). The reservoir had higher mean concentration of chloride in the dry season, while the mean concentrations of bicarbonate and sulphate were higher in the rainy season.

The horizontal variations of the cation parameters revealed an increase in potassium and sodium concentration from riverine through the transition to lacustrine (Table-2). However, the hardness cations (Calcium and Magnesium) had their maximum concentration at the transitional zone and did not show any definite pattern. These spatial variations were statistically non-significant. Moreover, the vertical differences in cation concentration of the reservoir were also non-significant. All the cations with the exception of potassium increased from surface water to the bottom with potassium having its maximum concentration at the mid-depth (Table-2). Likewise, the seasonal variations were statistically significant for all the cations of Esa-Odo Reservoir except potassium. Calcium and magnesium had higher mean values of 4.93 ± 0.7 mg/L, and 0.39 ± 0.2 mg/L respectively during the dry season while potassium and sodium had the higher mean values of 3.09 ± 5.6 mg/L and 7.03 ± 6.7 mg/L, respectively in the rainy season (Table-3).

Figure-3 (Piper Diagram showing variations in cations and anions of Esa-Odo Reservoir)conveniently shows the similarities and differences among sampled stations based on the ions investigated. On the left triangle, cations are represented, while anions are plotted on the right triangle. The core diamond-shaped area is then projected with these two triangles.For all water samples, the cation ternary diagram shows the dominance of $Na^{+} + K^{+}$ ions as compared to $Ca^{2+}$and Mg^{2+} ions, exhibiting $Na^{+} + K^{+}$ type. On the anion ternary diagram, most samples collected from the Esa-Odo Reservoir contain more HCO_3^- than SO_4^{2-} and Cl^- ions, reflecting water characterized by HCO_3^- type.

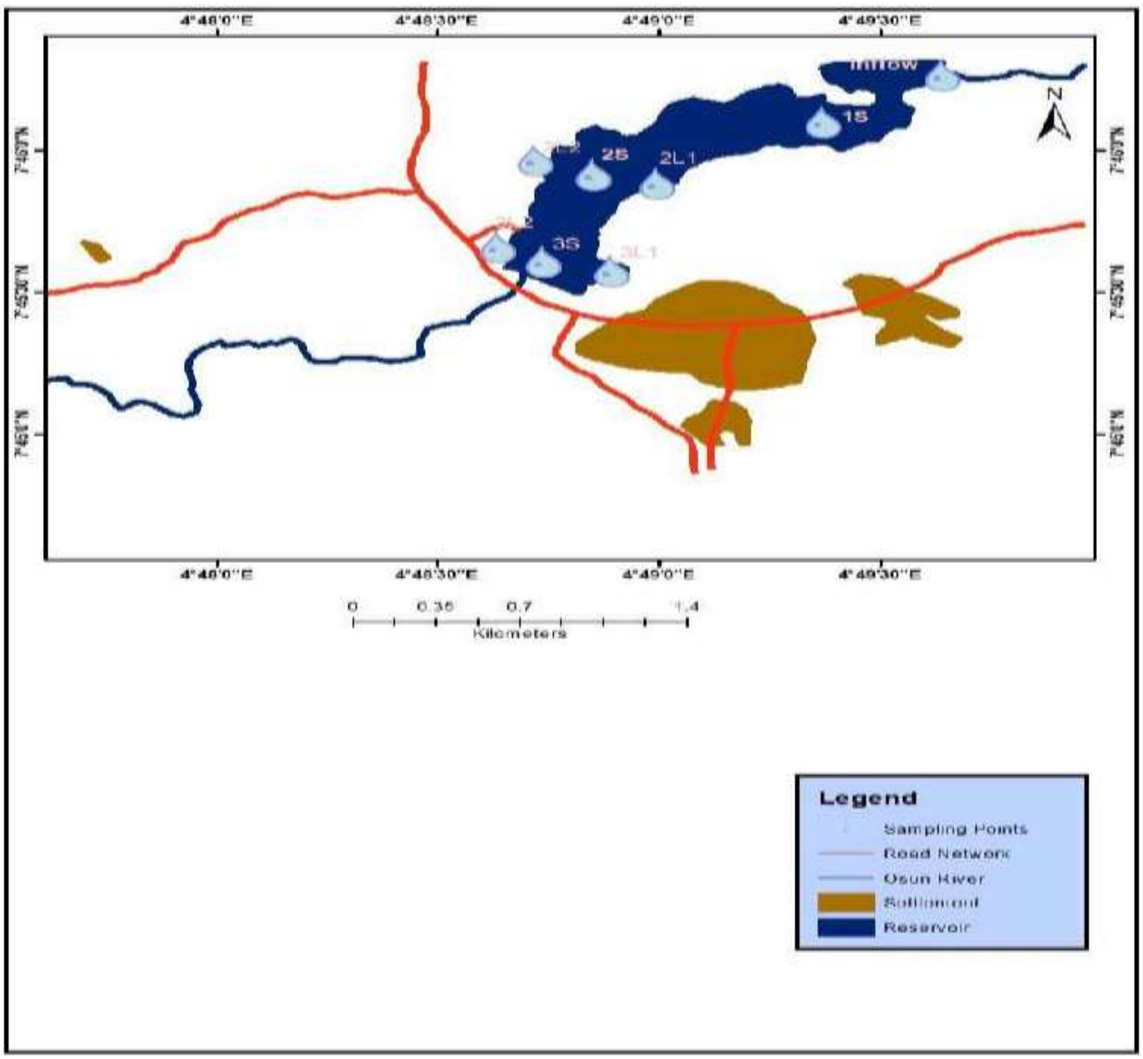


Figure-2: Map of Esa-Odo Reservoir showing the selected sampling stations.

Table-1: Descriptive statistics of the physico-chemical parameters of Esa-Odo Reservoir.

Parameter	Min	Max	Mean	Std. error	Stand. dev	Median	Skewness	Kurtosis	Geom. mean	Coeff. var
Water temp (^oC)	22.8	33.4	25.9	0.19	0.67	25.9	-0.24	0.09	25.9	2.6
Turbidity (NTU)	25.23	27.02	26.03	0.16	0.59	25.78	0.30	-1.23	26.03	2.26
App colour (Pt-Co)	149	244.62	196.56	3.12	11.27	199.15	-1.06	-0.12	196.24	2.98
True colour (Pt-Co)	136.89	234.74	182.68	2.44	8.78	182.60	-0.17	-1.27	181.95	2.44
TS (mg/L)	77.48	84.35	81.06	0.57	2.07	81.18	-0.08	-0.74	81.04	2.55
TSS (mg/L)	18.86	39.58	27.75	1.36	4.90	27.28	0.78	2.50	27.36	17.65
pH	6.2	7.60	6.95	0.09	0.33	7.05	-3.25	11.19	6.94	4.68
Conductivity μScm^{-1}	110.63	116.37	114.27	0.55	1.99	115.35	-0.72	-0.94	114.26	1.74
TDS (mg/L)	77.48	84.35	81.06	0.57	2.07	81.18	-0.08	-0.74	81.04	2.55
Alkalinity mg$CaCO_3$/L	45.00	56.42	51.54	0.97	3.49	51.75	-0.65	0.13	51.43	6.77
Acidity mg$CaCO_3$/L	15.67	23.50	18.57	0.54	1.94	18.33	1.20	2.80	18.48	10.46
Hardness mg$CaCO_3$/L	41.19	54.18	46.53	1.12	4.04	45.11	0.95	0.06	46.38	8.69
DO (mg/L)	5.48	7.92	6.69	0.22	0.78	6.63	0.23	-1.03	6.64	11.67
DO SAT. (mg/L)	66.08	102.88	82.18	2.98	10.73	79.95	0.50	-0.50	81.55	13.05
BOD_5 (mg/L)	2.92	4.88	3.76	0.17	0.62	3.59	0.55	-0.76	3.71	16.58
COD(mg/L)	9.58	15.64	13.22	0.44	1.58	13.23	-0.84	1.31	13.13	11.92
Chloride Cl^- (mg/L)	6.63	8.04	7.33	0.12	0.44	7.41	-0.15	-1.04	7.32	6.06
Sulphate SO_4^{2-} (mg/L)	3.80	6.76	5.49	0.22	0.78	5.53	-0.24	1.03	5.43	14.16
Bicarbonate HCO_3^- (mg/L)	27.67	28.56	27.98	0.07	0.25	27.88	1.35	1.07	27.97	-
Calcium Ca^{2+} (mg/L)	3.87	5.07	4.72	0.10	0.36	4.75	-1.16	1.21	4.71	-
Magnesium Mg^{2+} (mg/L)	0.36	0.67	0.50	0.03	0.09	0.48	0.80	0.43	0.49	-
Potassium K^+(mg/L)	1.71	3.23	2.21	0.12	0.44	2.21	1.04	1.02	2.17	-
Sodium Na^+ (mg/L)	6.14	6.88	6.59	0.05	0.19	6.60	-0.94	1.68	6.58	-
TOC (mg/L)	3.69	6.04	5.09	0.19	0.67	5.07	-0.39	-0.09	5.05	-
OM(mg/L)	6.08	10.15	8.60	0.32	1.15	8.54	-0.57	0.52	8.52	-
Nitrate (mg/L)	1.04	1.49	1.26	0.03	0.11	1.24	0.18	1.34	1.26	-
Phosphate(mg/L)	0.57	1.14	0.83	0.05	0.17	0.83	0.21	-0.76	0.81	-

Table-2: ANOVA Statistics showing the spatial variation in the physico-chemical parameters of Esa-Odo Reservoir.

	Horizontal variation					Vertical variation				
Parameters	Lacustrine Mean ± SE (n = 36)	Transition Mean ± SE (n = 60)	Riverine Mean ± SE ((n = 60)	F	P	Surface Mean ± SE (n = 96)	Mid Depth Mean ± SE (n = 24)	Bottom Mean ± SE (n = 36)	F-ratio	Prob.
Air temperature	25.69±0.18	26.52±0.2	25.48±0.3	5.964	0.019	27.07±0.32	21.29±4.0	27.55±0.72	10.160	0.000
Water temperature (^{o}C)	25.83±0.23	29.28±0.3	28.91±0.3	0.670	0.535	29.59±0.40	25.90±0.4	25.04±0.38	8.086	0.002
Transparency	0.88±0.3	0.72±0.15	0.76±0.2	0.187	0.832	0.7275±0.1	0.35±0.01	0.83±0.08	8.336	0.002
Depth	2.0±1.0	1.91±0.52	2.43±0.6	0.176	0.841	1.74±0.5	1.52±0.04	2.75±0.33	2.621	0.096
Turbidity (NTU)	61.03±3.6	63.50±2.5	60.62±1.6	0.461	0.644	65.04±3.32	76.56±7.5	73.35±5.49	5.072	0.016
App colour (Pt-Co)	177.07±1.9	192.56±0.96	169.18±0.8	0.332	0.725	196.55±0.57	195.20±0.2	185.41±0.73	8.623	0.002
True colour (Pt-Co)	138.68±0.7	143.19±0.7	160.94±0.8	5.136	0.029	162.93±0.86	186.40±0.7	177.23±1.26	8.484	0.002
App colour (Pt-Co)	33.02±3.46	24.65±1.6	27.69±1.3	4.181	0.048	35.64±3.74	31.86±3.5	36.40±13.88	6.010	0.009
True colour (Pt-Co)	87.88±5.9	79.02±3.1	53.85±0.9	0.290	0.754	84.01±2.4	74.02±6.7	82.12±2.0	1.861	0.206
pH	7.07±0.1	6.83±0.2	7.00±00	0.554	0.591	7.05±0.03	7.02 ±0.5	6.43±0.5	5.024	0.031
Conductivity μScm^{-1}	115.24±1.0	113.41±1.0	114.56±0.9	0.857	0.453	114.25±0.8	113.85±0.04	114.61±1.5	0.075	0.929
TDS (mg/L)	57.20±1.49	54.37±1.6	53.85±0.9	1.427	0.285	62.88±1.84	60.39±3.1	60.59±4.02	8.745	0.002
Alkalinity mg$CaCO_3$/L	48.72±1.8	51.36±1.8	53.42±1.1	1.150	0.355	53.01±0.9	51.38±0.04	47.75±2.5	1.349	0.303
Acidity mg$CaCO_3$/L	16.55±0.5	18.75±0.4	13.81±0.5	1.986	0.188	18.96±0.8	18.04±0.29	17.89±0.7	3.521	0.070
Hardness mg$CaCO_3$/L	43.70±1.3	48.12±1.9	57.76±1.2	3.215	0.083	47.92±1.7	43.57±0.7	44.82±0.2	0.373	0.698
DO (mg/L)	7.28±0.5	6.13±0.3	6.89±0.2	3.157	0.087	7.57±0.1	6.20±0.3	6.45±0.3	3.628	0.065
DOSAT (mg/L)	90.43±7.9	75.11±4.1	84.30±3.1	2.634	0.121	93.03±1.6	76.07±3.7	79.64±3.9	2.655	0.119
BOD_5(mg/L)	4.15±0.38	3.39±0.2	3.89±0.3	1.799	0.215	3.59±0.2	3.82±0.9	4.17±0.1	0.975	0.410
COD(mg/L)	13.34±0.8	12.57±0.9	13.81±0.5	0.749	0.498	12.81±0.2	13.55±0.3	14.11±0.4	0.770	0.489
Chloride Cl^- (mg/L)	7.34±0.2	7.67±0.1	6.99±0.2	4.765	0.035	7.23±0.1	7.34±0.7	7.44±0.5	0.797	0.478
Bicarbonate HCO_3^- (mg/L)	28.20±3.4	28.38±1.8	28.76±1.2	2.530	0.129	28.56±1.2	28.08±2.7	28.16±1.7	0.131	0.879
Sulphate SO_4^{2-} (mg/L)	5.11±0.7	6.03±0.3	5.16±0.1	0.280	0.762	6.76±5.6	5.19±0.01	5.28±0.03	0.157	0.857
Potassium K^+(mg/L)	2.77±0.03	2.76±0.1	2.73±0.1	0.700	0.519	1.73±0.02	2.83±0.07	2.76±0.1	0.797	0.478
Sodium Na^+(mg/L)	6.71±0.1	6.55±0.1	6.56±0.1	0.468	0.639	6.65±0.03	6.37±0.2	6.66±0.1	1.857	0.206
Calcium $Ca^{2+(}$mg/L)	3.83±0.75	4.66±0.9	3.83±0.4	0.462	0.643	4.08±0.0	4.40±0.5	4.42±0.6	0.071	0.932
Magnesium Mg^{2+}(mg/L)	0.54±0.4	0.66±0.2	0.62±0.3	0.468	0.639	0.52±0.3	0.57±0.1	0.67±0.4	0.157	0.857
TOC (mg/L)	5.23±0.3	4.74±0.3	5.35±0.3	1.113	0.366	4.99±0.3	4.64±0.1	5.66±0.2	1.823	0.211
OM(mg/L)	8.71±0.6	8.11±0.6	9.01±0.5	2.934	0.099	8.32±0.5	8.35±0.4	9.49±0.4	1.257	0.326
Nitrate (mg/L)	0.65±0.1	0.88±0.1	0.89±0.1	0.768	0.490	0.88±0.1	0.76±0.1	0.72±0.03	1.147	0.356
Phosphate(mg/L)	1 \11.47±0.1	1.46±0.1	1.48±0.05	0.235	0.795	1.47±0.04	1.49±0.01	1.45±0.1	0.071	0.932

*significant = $p \leq 0.05$ **highly significant = $p \leq 0.01$ ***Very highly significant = $p \leq 0.001$

Table-3: ANOVA Statistics of the seasonal variation in the physico-chemical parameters of Esa-Odo Reservoir.

Parameter	Dry Season			Rainy Season			T-test	Prob
	Min	Max	Mean ± SE (n=78)	Min	Max	Mean ± SE (n=78)		
Air temperature (^{o}C)	20.5	36.5	26.1±0.2	22.00	30.00	27.00±0.4	25.84	0.000
Water temp (^{o}C)	22.8	33.4	29.19±0.3	23.00	30.80	26.89±0.2	0.756	0.393
Depth	0.88	4.45	2.80±0.2	1.10	5.70	3.88±0.13	0.55	0.865
Transparency	0.4	1.96	0.80±0.1	0.30	1.29	0.37±0.1	1.16	0.327
Turbidity (NTU)	52.64	74.65	61.09±1.2	60.15	144.11	68.73±2.8	6.312	0.019
App colour (Pt-Co)	163.08	239.68	180.38±0.8	170.25	247.08	195.82±0.4	19.280	0.000
True colour (Pt-Co)	108.65	187.79	143.19±0.4	136.89	244.62	160.94±0.7	27.570	0.000
TSS (mg/L)	11.2	95.1	23.60±0.5	12	98	31.90±2.8	8.315	0.008
TS (mg/L)	20.2	63.6	73.84±0.3	32.0	87.10	93.44±2.9	46.540	0.000
pH	6.3	7.7	6.79±0.18	6.4	7.6	7.11±0.0	3.014	0.095
Conductivity μScm^{-1}	80	135.7	114.18±3.3	82	125.1	111.45±0.9	0.640	0.430
TDS (mg/L)	72	164	59.29±1.6	61.7	81.5	50.36±0.9	27.220	0.000
Alkalinity $mgCaCO_3/L$	26	103	55.17±2.2	22	69	46.42±0.7	14.710	0.000
Acidity $mgCaCO_3/L$	10	36	18.57±0.8	8	38	18.50±0.5	0.006	0.935
Hardness $mgCaCO_3/L$	34.0	89.88	54.11±2.4	17.04	66.71	37.32±0.9	44.300	0.000
DO (mg/L)	1.6	11.6	6.57±0.4	4.4	10.8	7.11±0.0	0.267	0.610
DOSAT (mg/L)	15.15	180.6	82.20±5.3	35.49	135.17	111.45±0.9	0.00002	0.996
BOD_5(mg/L)	0.8	11.2	3.99±0.3	0.4	13.6	50.36±0.9	1.620	0.215
COD(mg/L)	0.31	27.11	11.28±0.6	3.17	44.34	46.42±0.7	20.940	0.0001
Chloride Cl^- (mg/L)	4.89	5.13	7.84±02	4.40	6.80	6.68±0.1	2.94	0.000
Bicarbonate HCO_3^- (mg/L)	27.2	28.4	4.50±0.4	27.61	33.10	6.87±0.2	7.10	2.47E-19
Sulphate SO_4^{2-} (mg/L)	2.66	8.65	28.05±2.6	0.87	5.45	28.42±1.1	1.69	2.32E-12
Potassium K^+(mg/L)	1.07	3.97	2.56±0.2	1.01	3.95	3.09±5.6	4.35E-29	1.000
Sodium Na^+(mg/L)	3.53	8.02	6.28±0.2	2.23	7.92	7.03±6.7	4.80	0.038
Calcium $Ca^{2+(}$mg/L)	2.19	5.98	4.93±0.7	2.18	7.91	4.06±0.3	39.03	0.000
Magnesium Mg^{2+}(mg/L)	0.19	0.83	0.39±0.2	0.11	0.99	0.37±0.1	2.54	0.000
TOC (mg/L)	0.35	11.18	4.66±0.2	0.88	18.26	5.52±0.3	5.75	0.025
OM(mg/L)	0.20	16.74	7.59±0.4	1.51	31.46	9.48±0.5	9.55	0.005
Nitrate (mg/L)	0.04	3.28	0.93±0.1	0.68	1.69	1.09±0.7	6.11	0.021
Phosphate(mg/L)	0.16	2.60	1.20±0.1	0.02	1.79	1.49±0.2	4.43	0.000

*significant = $p \leq 0.05$ **highly significant = $p \leq 0.01$ ***Very highly significant = $p \leq 0.001$.

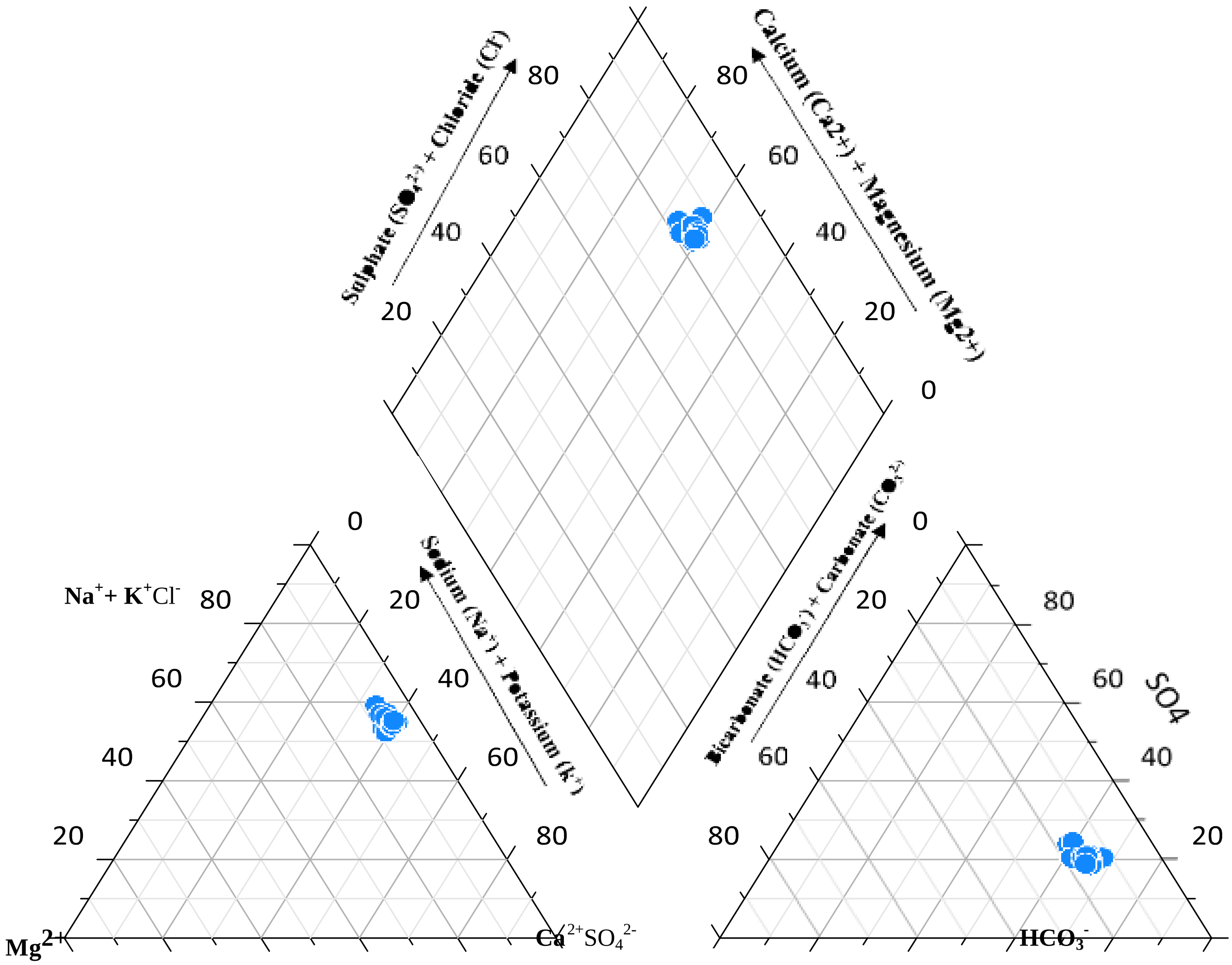
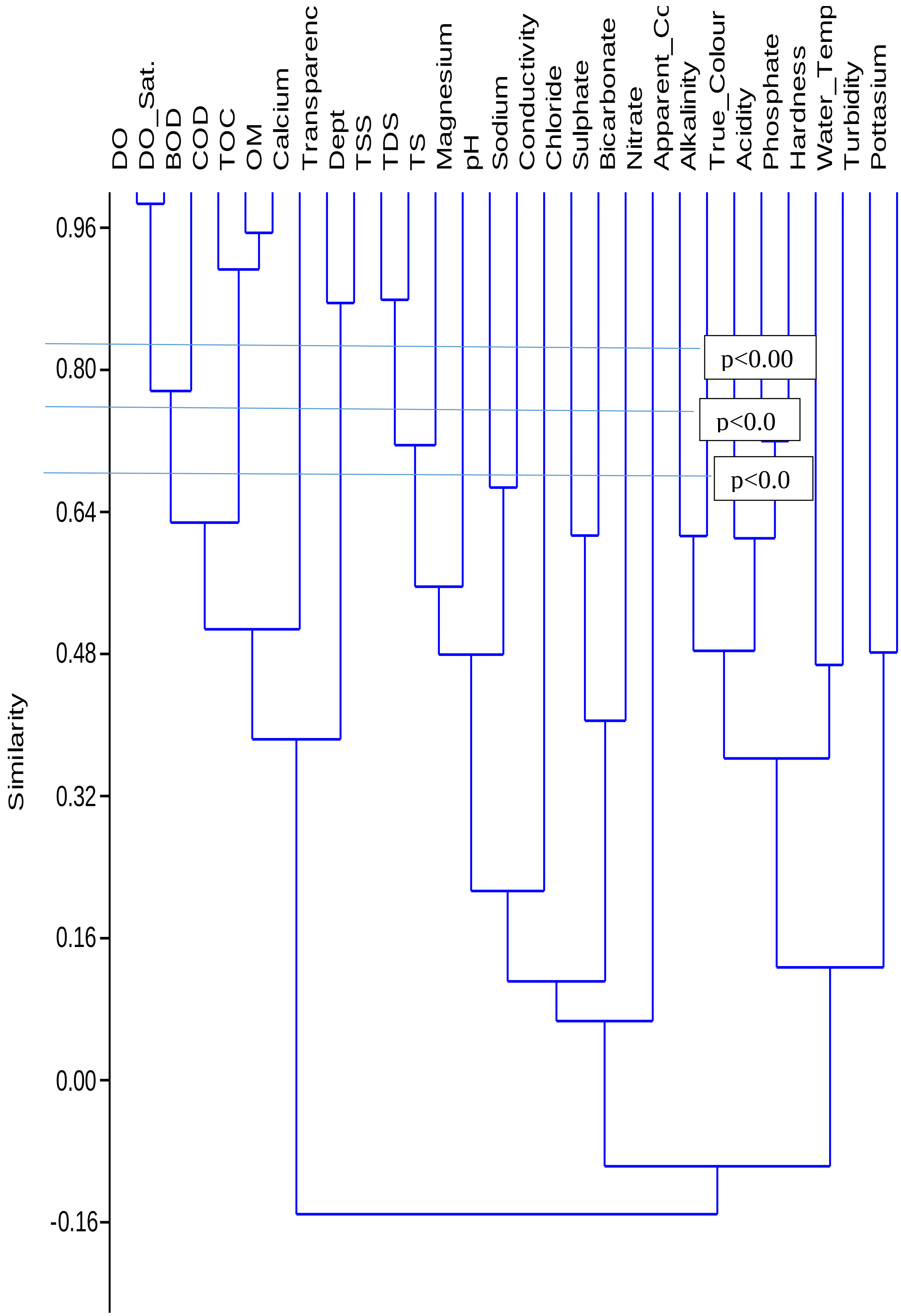


Figure-3: Piper Diagram showing variations in cations and anions of Esa-Odo Reservoir.

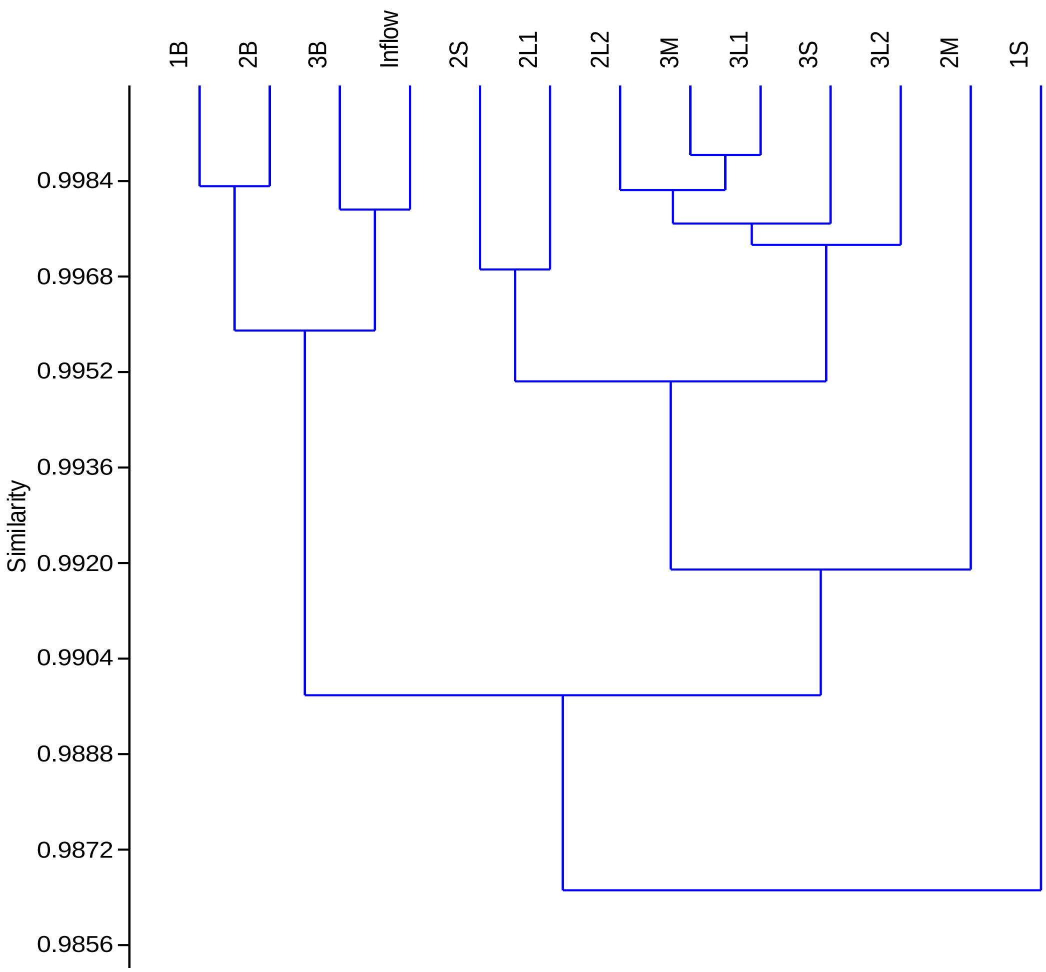
Nutrients parameters of water quality: All the nutrient parameters had the highest concentration at the riverine with no definite pattern of variation except for nitrate which decreased from riverine to lacustrine zone (Table-2). However, none of these variations was statistically significant. The vertical variations in the nutrient parameters were also non-significant. The mean values of organic matter increased from the surface to the bottom of the reservoir, while nitrate showed a reversed pattern as its mean concentration decreased to the bottom of the reservoir (Table-2). The lowest and highest mean concentrations of total organic carbon and phosphate, respectively were observed at the mid-depth. Seasonally, all the nutrient parameters had higher mean values during the rainy season with the differences in concentration been high to very highly statistically significant ($0.05 \geq p \leq 0.001$) (Table-3).

The relationship among the physico-chemical parameters: Cluster analysis (CA) of the physicochemical parameters was done to illustrate the grouping of the parameters (Figure-4). Cluster analysis showing the relationship between the investigated physico-chemical parameters). The parameters were grouped into three significant clusters. Cluster 1 comprises mostly oxygen parameters (DO, DO Saturation, BOD, COD), TOC, OM, calcium, transparency and depth. The second cluster composed of TSS, TDS, TS, magnesium, pH, sodium, conductivity, chloride, sulphate, bicarbonate, and nitrate having most of the major ions dominating the group. Also, the third cluster is made up mostly of colour, physical and salinity parameters (apparent colour, true colour, acidity, alkalinity hardness) with water temperature, turbidity and potassium, phosphate as well. Cluster analysis was also used to explore the spatial variation in Esa-Odo Reservoir (Figure-5). Cluster analysis showing relationship among sampling stations). All the stations were group into one statistically significant cluster at P = 0.001 (Figure-5).



n = 28, n = number of parameters, P ≤ 0.05, r = 0.3610, P ≤ 0.01, r = 0.4629, P ≤ 0.001, r = 0.5703

Figure-4: Cluster analysis showing the relationship between the investigated physico-chemical parameters.



n = 13, n = number of stations, $P \leq 0.05$, r = 0.5140, $P \leq 0.01$, r = 0.6411, $P \leq 0.001$, r = 0.7604.

Figure-5: Cluster analysis showing the relationship among the sampling stations

Discussion: The results showed that the physical aspect of water quality compared well with other tropical lakes. The water temperature in Esa-Odo Reservoir at this study period ranged from 22.80 °C to 33.40 °C, with an overall mean ± s.e.m. of 25.93 ± 0.19 °C. Both water temperature mean and range values compare well with the known values for some lakes in the tropics as sited by[8] who reported temperature range of 23.1 °C - 29.6°C from Oyun Reservoir while Onyema and Ojo [9] reported a range of 27 ºC and 31 ºC from Lagos Creek. The range of temperature is important to animal distribution as aquatic organisms require certain temperature range for optimal growth[10]. It was also within the range of 25°C to 35°C recommended for best yield in warm water fishery as earlier reported by Boyd and Lichtkoppler (1979)[11] and corroborated byGupta and Gupta, (2006) [12]. Water temperature in Esa-Odo Reservoir showed a decrease from surface towards the bottom in all the stations. Thus, exhibited the usual direct thermal stratification pattern of tropical lakes where the bottom is characterised by low oxygen[13]. The highest mean water temperature recorded at dry season may be attributed to high intensity of sunshine and air temperature at this period. This is a phenomenon common to most tropical waters according to the works of Ayodele and Adeniyi, 2006[6], on Esa-Odo Reservoir, Omoboye, 2015 [14]on Owalla Reservoir, alsoEgboge, 1981 [15]on Asejire Reservoir.The vertical variation in the turbidity and total suspended solids were characterized by decrease from the surface toward the bottom. On the other hand, total solids increase downwardly. Seasonally, turbidity, total suspended solids and total solids showed a higher mean values during the rainy season. This was more obvious in the transparency and water colour which had the same pattern. The high values of turbidity, TSS and TS may arise from the influx of allochtonous particles washed into river basin by rain[16].

Esa-Odo Reservoir hydrogen ion concentration (pH) showed that it was slightly acidic (pH 6.20 to 7.60). The value of pH increase upwardly through the water column. This is common to most water bodies in Nigeria and other tropical countries as this compares well with the work of Adedeji et al., 2011[16] on Opa Reservoir and Aduwo 2008 [17] on Obafemi Awolowo University Teaching and Research Farm Lake. This is due to the fact that photosynthetic activities which uses up CO_2 occur at the water surface, while decaying organic material releases $CO_2$to the bottom[8]. The decrease in the mean pH at wet season had been explained to be due to acidic rain water washed into the reservoir and the up-turning of the bottommost sediments at rainy season [18]. The conductivity of the reservoir ranged from 110.63 μScm^{-1} to 116.37 μScm^{-1} with the mean value 114.27 ± 0.55 μScm^{-1}. These values are low compared to the conductivity mean value reported by Akin-Oriola [19]from Awoba reservoir (239.65 ± 74.31 μScm^{-1}) which was regarded as being intermediate. This class of water could be classified as diluted (conductivity less than 600 μScm^{-1}) and will support diverse species of organism [20]. The lower value of conductivity recorded during the rainy season has been reported to be due to the diluting effect of rain on the nutrients in the reservoir as suggested by Atobatele and Ugwumba[21].

The range of the total alkalinity obtained in the present study of (45 $mgCaCO_3/L$ to 56.42 $mgCaCO_3/L$) compare well with the range given for lakes and reservoirs by FEPA [22]. Moreover, alkalinities at or above 20 $mgCaCO_3/L$ trap free CO_2 and increase the concentrations available for photosynthesis. Therefore, the alkalinity range recorded during the study period can adequately support phytoplankton productivity (pond fertility). This high rate of photosynthesis also resulted to the noticed high level of DO [12]. The DO range of 5.48 to 7.92 mg/L as well as mean of 6.69 ± 0.22mg/L suggested that the reservoir was well oxygenated during the study period. The higher photosynthetic activity at the surface of the reservoir accounts for the increase in DO at surface of the reservoir as compared to bottom waters.

The mean BOD_5 value (3.76 ± 0.17mg/L) of the reservoir suggested that the water may be considered as fairly clean following the classification of Moore and Moore[23] (cited by Abowei and George[24]). According to the classification, waters with BOD_5 values between 1.0 and 2.0mg/L is measured clean, 3.0mg/L as fair, 5.0 as mg/L unsure and 10.0mg/L as polluted.During the rainy season, dissolved oxygen and biochemical oxygen demand were higher than during the dry season.Such seasonal changes in oxygen condition of freshwater lakes have been found to be due to the effect of rainfall and its influences on the amount of discharge into the lake[25].

The cationic hierarchy of the reservoir (Na >Ca > Mg > K) was in line with the work of Aduwo, 2008[17]on O.A.U. Teaching and Research farm lake but contrast that of the standard freshwater of Ca>Na>Mg>K [26]. The difference recorded may be due to the fact that cation hierarchy varies from one water body to another as observed byTimms (1986) [27] The higher Na concentration reported during the period of study may be due to the combination of Ca and Mg with carbonate and bicarbonate ions to increase the alkalinity of the reservoir[17,27]. The anion hierarchy ($HCO_3^- > Cl^- > SO_4^2$) was the same with general freshwater system hierarchy for freshwater[26]. In addition, the higher concentration of Ca and Na suggest that the reservoir water is soft as this attribute is common to general soft waterbodies [12]hence will support fish growth[28].

The organic matter and organic carbon range of 6.08 to 10.15 mg/L and 3.69 and 6.04 mg/L observed during the sampling period was far below the 100 mg/L reported for polluted water but high enough for biological activities and productivity in the reservoir[29]. The decrease in the nitrate value down the reservoir column was in contrast to the observation of Akinbuwa (1988)[30] on Opa Reservoir, and Aduwo, 2008[17] on O.A.U. Teaching and Research Farm Lake. The highest value recorded at the surface may be due to the release of nitrogenous substance like faecal matter into the surface water which was generally observed during the sampling period.

Conclusion

The reservoir, based on the physico-chemical parameter ranges recordedcan be classified as fairly clean. However, regular and proper monitoring should be carried out because of the likely effect of some human activities (like open space defaecation, washing and bathing with detergents and soaps and grazing of cows around the water shed) observed during the study. Such activities may cause deterioration of water quality.

Acknowledgement

The authors appreciate the Hydrobiology Unit, Department of Zoology, Faculty of Science, Obafemi Awolowo University, Nigeria, for the provision of equipment and chemicals for this study.

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