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Assessment of the Ecological Status of OPA Reservoir, ILE IFE, Nigeria Based on a Comparative Study of its Planktonic Community and Water Quality Parameters

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Abstract

Study to determine the ecological status of Opa reservoir, Ile Ife Nigeria was conducted based on the plankton's diversity and physicochemical characteristics of the reservoir. Water samples for the analyses were collected from three established investigated stations on the reservoir for a period of one year between November 2012 and October 2013. Most of the physicochemical parameters' result were within recommended limits of the NESREA for aquatic life, but some heavy metals (Ni and Cr) were above permissible limits. One hundred and thirty-six (136) plankton species belonging to thirteen taxa were encountered whose total abundance and distribution were influenced greatly by dissolved oxygen, salinity and light obstruction parameters. Notable, recorded species at the riverine (Cryptomonas ovata, Branchionus angularis and Cyclops) revealed the unacceptable quality of the reservoir's influx. Besides, the observed low species diversity index, at all zones of the reservoir investigated, revealed dominance by few species that characterized eutrophicated waters. Furthermore, the presence of plankton pollution tolerant species (Anabaena sp., Navicula sp. and Peridinium sp.) also suggested a minimal level of organic pollution in the reservoir. The water qualities of Opa reservoir at the Lacustrine zone (76.14) and Transition zone (67.89) were of occasional threatened while Riverine zone (63.57) was frequently impaired according to the CCME Water Quality Index.

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Introduction

Lakes, rivers and reservoirs play vital roles in freshwater ecosystems for the sustenance of all life on earth [1]. This role is accomplished through the interactions of both the physical and chemical properties of water, which determine composition, distribution and abundance of aquatic organisms. Therefore, maintenance of healthy aquatic ecosystem is dependent upon the physicochemical properties and biological diversity of the water body [2]. The physicochemical properties affect the nutrient level, hence abundance and distribution of plankton [3-5]. The environmental factors such as water temperature affects growth, development and mortality as well as tolerance of the planktonic organisms to their environment [6-8] low pH as reported could led to reduction in abundance and decreased biodiversity of zooplanktonic organisms [9, 10] while alkaline condition would result in high primary productivity [11]. The effect of light, oxygen and nutrient level on the distribution (horizontal/vertical), abundance and mortality rate of these planktonic organisms could not also be overemphasized [12-14]. Assemblages of planktonic species in an ecological community could therefore be reflections of interactions between organisms and the abiotic environment as well as among organisms [15]; hence they are valuable indicators of environmental conditions [16, 17] of waterbodies.

Unfavourable significant changes in physicochemical parameters due to unchecked discharge into waterbodies as reported by Akinbuwa [18] and Adesakin, et al. [19] in Opa reservoir could affect planktonic abundance and biodiversity of the reservoir. This possibility necessitates the continuous bio-monitoring of water quality to protect the inhabiting aquatic life. In this study, the plankton community of Opa reservoir was evaluated for species composition, abundance and distribution in comparison with physicochemical parameters to assess the ecological status of the reservoir with the impacts of the uncontrolled influx in view.

2. Materials and Methods

2.1. Study Area

Opa reservoir, the investigated water body is located within the Obafemi Awolowo University, Ile-Ife, Nigeria. According to Akinbuwa and Adeniyi [20] Opa reservoir Figure 1 was established in 1978 by the impoundment of the Opa River, which has its source in Oke-Opa, a series of hills on the eastern side of the Ife-Ilesha road. A number of streams unite to form the Opa River, the major one being the Rivers Amuta, Obudu and Esinmirin. The surface area of the reservoir is about 0.95km^2 while the maximum capacity is about 675,000m^3 The minimum depth is 1.01m while the maximum depth is 6.01m, at this level storage is about 389,000m^3 The reservoir was primarily create to supply potable water to the University community hence fishing activities are permitted only for recreational and research purposes. It has a catchment area about 116km^2 extending in width from longitude 004°31 to 004° 39´E, and in length from latitude 07°21 to 7°35´N.

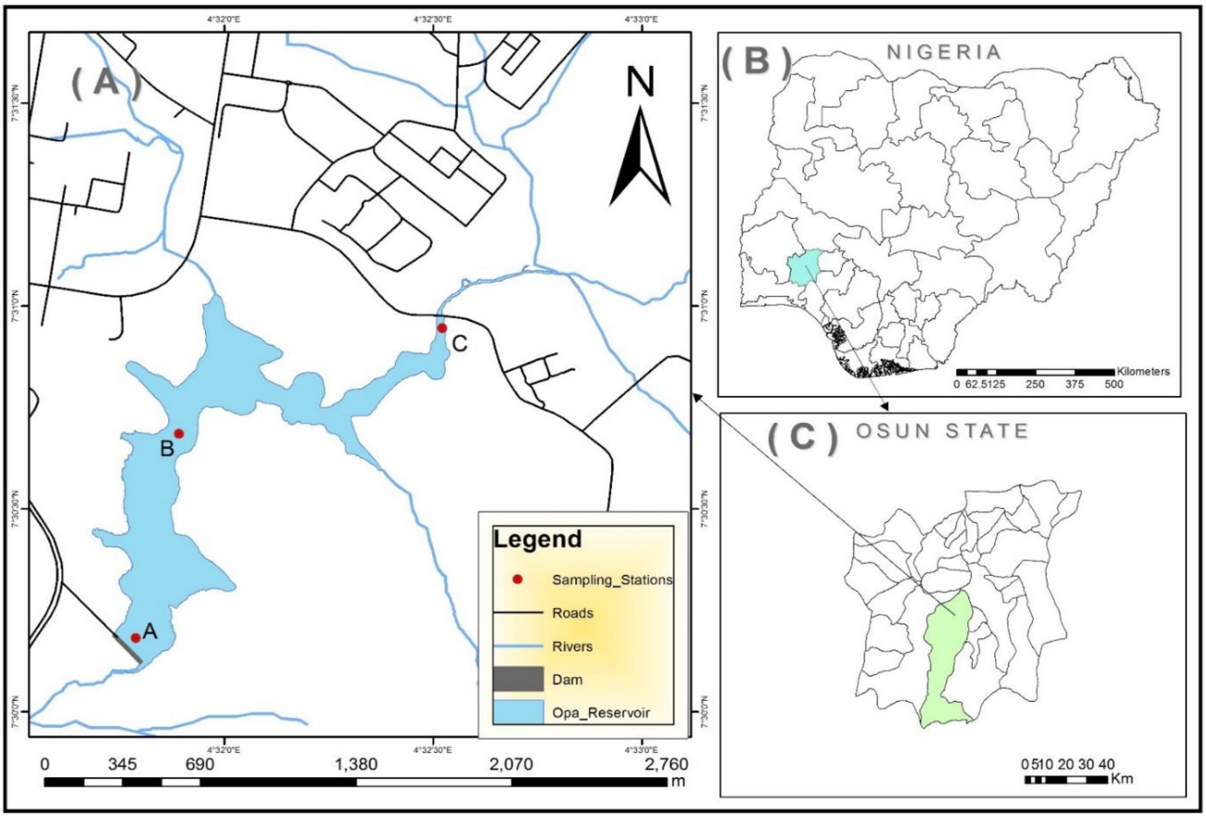

Figure-1. Map of Opa Reservoir showing the Investigated Sampling Stations (A), Nigeria (B) and Osun State (C).

2.2. The Sampling Procedure

Sampling stations were chosen after the preliminary survey of the reservoir based on average depth, volume of water, accessibility and the various activities taking place in and around the reservoir. Three sampling stations were established along the length of the reservoir such that location A for Lacustrine portion, close to the dam wall; location B at the mid-lake (Transition) and location C for the Riverine portion, towards the inflow to the lake. The coordinates and depths of the three sampling stations as well as their respective depths as depicted in Table 1. Samples were collected monthly from surface and bottom portion of these three sampling stations for a period of one year between November 2012 and October 2013 with a view of capturing various seasons during the period of study.

Table-1. Grid location of selected sampling stations.

Stations	Longitude	Latitude	Elevation (m)	Depth (m)
Lacustrine	07°30′13.0″ N	004°31′45.7″ E	240±10	6.01
Transition	07°30′284″ N	004°31′830″ E	245±07	4.99
Riverine	07°30′45.0″ N	004°31′10.5″ E	252±08	1.22

A total of thirty-six water samples (36) were collected from the reservoir for both physicochemical and plankton analyses in the laboratory. In the case of physicochemical analyses, samples were collected in 2L plastic containers, first washed with liquid detergent, and rinsed with distilled water severally. The plastic bottles meant for sampling were further rinsed thrice on-site with the reservoir water to be sampled. While the bottom water sample was taken using an improvised closing bottle sampler. The labelled samples were properly air tightened and transported to the laboratory where they were stored in refrigerators pending their analyses, which were carried out within their holding time.

The quantitative plankton samples were collected by straining a known volume of water sample (30 litres) through 55µm Hydrobio's plankton net to a concentrated volume of 30 ml. Each sampling bottle was properly label and preserved with 5 % formalin solution in specimen bottles and 3-5 drops of Lugol's solution was added to it depending upon the density observed. The preserved plankton bottles were left to stand for about 10-14 days so that the plankton content could settle down. The supernatant was then decanted carefully leaving about 3ml. The resultant, three (3) ml concentrated volume, which represents the plankton content of the original 30 litres of water was examined.

2.3. Qualitative Analysis of Planktons

An improvised Sedgewick rafter's counting chamber was filled with 1.5 ml of the sample using a stamped pipette until the chamber was completely filled without any air bubble. This was carefully placed on the light microscope stage and allowed to settle for 10 minutes to enable the plankton to settle at the bottom of the chamber. The enumerations of plankton were carried-out using OMAX binocular light compound microscope and their scaled pictures taken. The plankton were later identified to genus/species level based on the minute morphological details by observing them under the microscope using the taxonomic guide and standard identification key. The keys as described by Belcher and Swale [21]; Jeje and Fernando [22]; Fernando [23]; Kutikova [24]; Janse, et al. [25]; Brierly, et al. [26]; Yamaguchi and Gould [27]; Witty [28]; Suthers and Rissik [29]; Bellinger and Sigee [30]; Ekhator, et al. [31].

2.4. Physicochemical Analysis

The water depth was determined at specific points in the studied stations using a meter rule. Air and water temperatures were measured *in-situ* with mercury in glass thermometer, while a Secchi disc was used to measure water transparency. pH and conductivity of the water body were measured using electrode meter. The nutrient parameters were determined as follows: sulphate determined by the turbidimetric method [32] phosphate determined by colorimetric technique [33] while nitrate was determined by Brucine method [33]. The levels of Dissolved oxygen (DO) and Biological oxygen demand (BOD_5) were estimated using Winkler's method [34]. The determination of BOD_5 was done after 5 days incubation in the dark at 25°C. Alkalinity, acidity, chloride, magnesium and calcium were determined titrimetrically following the methods in APHA [35]. The concentrations of suspended and dissolved solids were determined using the gravimetric method [33]. The concentration of selected heavy metals namely chromium, copper, zinc, Iron, Nickel and cadmium in the water body were determined by Atomic Absorption Spectrophotometer. These metals were determined by preparing standard solutions of known metal concentrations from chemicals of AnalaR grade (BDH, England). Thereafter, the metal concentrations in the water samples were read against the prepared standard using spectrophotometer set at the normal wavelengths [35].

For the precision and accuracy of results, replicate analysis of blanks, standard, and samples were carried out and standard deviations were determined. Moreover, all chemicals used were of AnalaR grade (BDH, England).

2.5. Data Analysis

The species (N), dominance (D), Shannon diversity index (H), Margalef's index (d) and equitability (J) were calculated using [36]. The single-factor analysis of variance (ANOVA) was used to test for significant difference between stations [36] through the software package of SPSS 23 and PAST 2.7. The principal components (PCA) were determined using communalities extraction method. A total of 42 parameters were considered for WQI analysis, consisting of physicochemical, plankton abundance and diversity data collected from three sampling stations for the period of study.

For the calculation of the water quality index, the CCME WQI was adopted which given by:

$$\text{CCME WQI} = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right)$$

The divisor 1.732 normalizes the resultant values to a range between 0 to 100, where 0 represents the "worst" water quality and 100 represents the "best" water quality [37].

F_1 represents *the percentage of parameters that do not meet their guidelines at least once* during the time period under consideration ("failed parameters"), relative to the total number of parameters measured. It is calculated as follows:

$$F_1 = \left(\frac{Number\ of\ failed\ parameters}{Total\ number\ of\ parameters}\right) \times 100 \quad (1)$$

F_2 represents frequency and refers to *the percentage of individual tests that do not meet guidelines ("failed tests")*. It is calculated as follows:

$$F_2 = \left(\frac{Number\ of\ failed\ Tests}{Total\ number\ of\ Tests}\right) \times 100 \quad (2)$$

F_3 represents amplitude and refers to the amount by which failed test values do not meet objectives. It is calculated in three steps:

a. Calculation excursion: Excursion is the number of times by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective.

This is calculated as follows:

When the test value must not exceed the objective:

$$Excursion_i = \left(\frac{Failed\ Test\ Value_i}{Objective_j}\right) - 1 \quad (3a)$$

For the cases in which the test value must not fail below the objective:

$$Excursion_i = \left(\frac{Objective_j}{Failed\ Test\ Value_i}\right) - 1 \quad (3b)$$

b. Summation of normative excursions: Normative sum of excursions (NSE) is the collective amount by which individual tests are out of compliance. This is calculated as follows:

$$nse = \frac{\sum_{i=1}^{n} Excursion_i}{Total\ number\ of\ Tests} \quad (4)$$

c. Calculation of amplitude: it is calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (nse) to yield a range between 0 and 100. This is calculated as follows:

$$F_3 = \left(\frac{nse}{0.01nse + 0.01}\right) \quad (5)$$

3. Results

3.1. Plankton

A hundred and thirty-six (136) plankton species (82 phytoplankton and 54 zooplankton) belonging to 22 classes was encountered in the Opa reservoir during the period of study. The highest number of species (92) was recorded from lacustrine and transition station while the least (81) was observed at the riverine station Table 2. Seasonally, species occurrence was higher by 30 species in the rainy season than dry season. The percentage occurrence revealed Bacillariophyta as the division with highest occurrence (37.80%) followed by cyanobacteria (18.29%) while cryptophyta (1.22%) had least occurrence Table 2 among the phytoplankton. The rotifera taxa recorded more than half of percentage of occurrence (57.41%) among the zooplankton followed by Arthropoda (33.33%).

The highest total plankton was recorded at the lacustrine station which was 59% and 71% greater than the total plankton recorded at transition and riverine respectively Table 3. The phytoplankton contributed more than 95% of the entire planktonic species recorded from these stations with Bacillariophyta having the highest percentage abundance for each station. Moreover, of note is the dominance of Bacillariophyta, which contributed 80.9% to the total planktonic abundance at the riverine station. However, the highest abundance (62,200,000 ind./L) of these groups of organisms was recorded at the Lacustrine Table 3. In all five (5) species recorded their highest abundance at the lacustrine, with six (6) species in transition and only two (2) species were most abundant in the Riverine zone of the reservoir Table 3. Significant spatial variation in total abundance was observed for Chlorophyta, rotifera and Arthropoda taxa Table 3.

3.2. Diversity Indices

The Simpson's dominance index (D) which was above 0.5 for many of the recorded taxa revealed prevalence of only one species for all except chlorophyta, cyanophyta, Myxozoa, Euglenophyta, rotifera and Arthropoda Table 4. While the complement of Simpson's dominance index $(\frac{1}{D})$ which ranged between 0.6 and 0.9 was recorded for chlorophyta, rotifer and Arthropoda. This implies a more stable population as further reflected in the number of very abundant species, which ranged from 3 (chlorophyta) to 10 (rotifer) Table 4. The estimated equitability index (J) was in addition more than 0.5 for chlorophyta, rotifer and Arthropoda. This signifies diversity in these taxa populations as compared to other recorded taxa that are characterized by dominance of few species Table 4.

Table-2. Outline classification and Taxa Composition of the plankton of Opa reservoir.

Division Phytoplankton	Class	Order	Family	Genus	Species	Percentage Occurrence
Cyanobacteria (Blue-Green Algae)	1	5	10	12	15	18.29
Chlorophyta (Green Algae)	2	5	6	8	12	14.63
Euglenophyta (Euglenoids)	1	1	2	3	8	9.76
Myzozoa	1	3	4	4	7	8.54
Cryptophyta	1	1	1	1	1	1.22
Ochrophyta	1	2	2	3	4	4.88
Charophyta	1	2	2	3	4	4.88
Bacillariophyta (Diatoms)	4	13	18	21	31	37.8
Total phytoplankton	12	32	45	55	82	
Zooplankton						
Protozoa	3	3	3	3	3	5.56
Cnidaria	1	1	1	1	1	1.85
Ciliophora	1	1	1	1	1	1.85
Rotifera	1	2	8	12	31	57.41
Arthropoda	4	6	11	18	18	33.33
Total zooplankton	10	13	24	35	54	
Lacustrine	12	41	68	84	120	88.24#
Transition	13	39	65	85	98	72.06#
Riverine	13	27	46	75	108	79.41#
Dry Season	13	33	54	70	93	68.38#
Rainy Season	12	37	62	60	123	90.44#

Note: NB: # Percentage occurrence based on the Total plankton recorded.

Species richness was greater among the zooplankton taxa than phytoplankton as deduced from the calculated value of Menhinick index of richness. The recorded higher Shannon index values for zooplankton taxa, especially rotifera and Arthropoda (2.010 and 2.627 respectively) also suggested that these taxa were well distributed in terms of the individual species recorded; as compared to phytoplankton taxa whose Shannon's index values ranged between 0.002 and 1.309 Table 4. The estimated Sheldon's evenness index for documented taxa revealed uneven distribution of the encountered organisms in the reservoir with all the taxa having less than 0.5 evenness except for taxa with single species (crytophyta, cnidarian and ciliophora). The most abundant taxa (bacillariophyta) had the highest inequitable distribution of species with Sheldon's evenness index value of 0.033.

Table-3. Mean abundance of plankton composition along horizontal axis of Opa reservoir.

Taxa	Station						ANOVA	
	Lacustrine	Percentage Abundance (%)	Transition	Percentage Abundance (%)	Riverine	Percentage Abundance (%)	F	P
	Sum (Mean ± SD)		Sum (Mean ± SD)		Sum (Mean ± SD)			
Bacillariophyta	62,126,850 (1002046±6048190)	69.90	21,385,500 (344927.4±1876845)	61.63	51,821,250 (835826.6±4733705)	95.13	0.35	0.687
Chlorophyta	599,850 (24993.75±50915.66)	0.67	323,550 (13481.25±29846.98)	0.93	147,300 (6404.35±15699.36)	0.27	3.65	0.012*
Cyanobacteria	8,584,650 (286155±1031621)	9.66	8,487,600 (282920±1209435)	24.46	1,045,500 (34850±99308.09)	1.92	0.74	0.480
Myzozoa	2,878,500 (205607.1±486675.2)	3.24	3,399,600 (242828.6±890692.4)	9.79	102,900 (7350±14099.14)	0.19	0.65	0.530
Cryptophta	30,150 (15075±3075.91)	0.03	17,250 (8625±742.46)	0.05	76,050 (38025±44865.93)	0.14	0.71	0.560
Ochrophyta	30,750 (5125±10006.89)	0.03	120,450 (20075±48953.2)	0.35	0 (0±0)	0	0.54	0.480
Charophyta	14,013,300 (2802660±5946900)	15.77	193,500 (24187.5±51394.63)	0.56	349,950 (58325±55144.18)	0.64	1.59	0.230
Euglenophyta	84,750 (6053.57±9277.94)	0.10	58,500 (3656.25±8246.25)	0.17	58,050 (3628.13±1938.68)	0.11	0.40	0.670
Rotifera	359,700 (5801.61±14043.01)	0.41	419,700 (6769.36±14086.69)	1.21	383,050 (6178.23±10505.43)	0.70	4.87	0.015*
Protozoa	31,800 (5300±6520.89)	0.04	27,450 (4575±10113.94)	0.08	133,350 (22225±45211.74)	0.25	2.82	0.056
Ciliophora	150 (75±106.07)	0.01	1,200 (600±212.13)	0.01	0 (0±0)	0	1.98	0.080
Cnidaria	0 (0±0)	0	3,150 (1575±2015.25)	0.01	150 (75±106.07)	0.01	1.11	0.405
Arthropoda	138,900 (3307.143±6467.46)	0.16	263,850 (6282.14±14523.19)	0.76	357,450 (8510.71±14032.12)	0.67	5.91	0.015*
Total phytoplankton	88,348,800	99.40	33,985,950	97.94	53,601,000	98.40		
Phytoplankton Mean ± SD	1,244,349.30 ± 7,532,335.31		666,391.18 ± 3,096,211.22		893,350.00 ± 6,663,733.82			
Phytoplankton diversity Mean ± SD (Range)	22.58 ± 5.32 (11 - 31)		19.08 ± 4.03 (13 – 26)		16.75 ± 4.09 (14 – 21)			
Total zooplankton	530,550	0.60	715,350	2.06	874,000.00	1.60		

Zooplankton Mean ± SD	10,827.55 ± 20889.61		15,220.21 ± 20,991.31		18,208.33 ± 27,362.54			
Zooplankton Diversity Mean ± SD (Range)	19.42 ± 5.42 (9 – 26)		18.00 ± 5.10 (9 – 27)		18.42± 5.62 (9 – 26)			
Total plankton	88,879,350		34,701,300		54,475,000			

Table-4. Diversity indices among the taxonomic groups of plankton at Opa reservoir during study period.

	Bacillariophyta	**Chlorophyta**	**Cyanophyta**	**Myzozoa**	**Cryptophyta**	**Ochrophyta**	**Charophyta**	**Euglenophyta**	**Protozoa**	**Cnidaria**	**Ciliophora**	**Rotifera**	**Arthropoda**
Taxa (S)	31	12	15	7	1	4	4	8	3	1	1	31	21
Individuals (org/m^3)	135,333,600	1,070,700	18,117,750	6,381,000	123,450	151200	14,556,750	201,300	192,600	3,300	1,350	1,162,450	760,200
Dominance (D)	0.994	0.352	0.595	0.493	1.000	0.989	1.000	0.508	0.921	1.000	1.000	0.091	0.231
Simpson (1/D)	0.006	0.648	0.405	0.507	0.000	0.011	0.0003	0.492	0.079	0.000	0.000	0.909	0.769
Shannon (H)	0.028	1.309	0.720	0.760	0.000	0.041	0.002	0.975	0.199	0.000	0.000	2.627	2.010
Evenness (e^H/S)	0.033	0.309	0.137	0.305	1.000	0.260	0.251	0.301	0.407	1.000	1.000	0.446	0.355
Menhinick's richness index (R2)	0.003	0.011	0.004	0.002	0.003	0.010	0.001	0.011	0.025	0.017	0.027	0.028	0.019
Equitability (J)	0.008	0.527	0.266	0.391	0.000	0.029	0.001	0.469	0.181	0.000	0.000	0.765	0.660
Hill's first diversity number (N1)	1.040	3.909	2.053	1.344	1.000	1.043	1.002	2.990	1.180	1.000	1.000	12.572	9.945
Hill's Second diversity number (N2)	1.010	3.142	1.676	1.136	1.000	1.012	1.000	2.184	1.079	1.000	1.000	10.308	7.519

Spatially, the Menhinick's index showed that species richness was highest for zooplankton (0.048) and phytoplankton (0.017) at lacustrine and transition zone respectively; with zooplankton having higher species richness than phytoplankton in all investigated zones of the reservoir Table 5. The dominance of approximately 0.1 recorded for total zooplankton recorded at all the zones of the reservoir revealed that the recorded individual species were more equally represented than the phytoplankton species Table 5. There exists the dominance of only one species among the phytoplankton taxa, especially at the lacustrine and riverine zone of the reservoir with Simpson's dominance (D) value above 0.5 Table 5. The complement of Simpson's index value ($\frac{1}{D}$) which was also greater than 0.6 for total zooplankton in all the stations investigated Table 5. This implies that the recorded zooplankton taxa had a more established community than phytoplankton taxa, which was stable only at the transition zone. The stability and maturity of the zooplankton community were also revealed in the Shannon's equitability index (J) which was extremely close to 1 as well as the number of very abundant species, which was greater than 10 species for all the investigated stations. The Shannon's index was highest for both zooplankton and phytoplankton taxa at the transition zone thus indicating equal representation of all species in this zone Table 5. The spatially distribution evenness of recorded taxa as measured by Sheldon's evenness index was greater than 0.5 for total zooplankton in transition and riverine zone signifying more even distribution of zooplankton taxa as compared to phytoplankton with Sheldon's index value of 0.024 to 0.090.

Table-5. Diversity indices of total phytoplankton and total zooplankton of Opa reservoir based on their spatial distribution during study period.

Diversity indices	Lacustrine		Transition		Riverine	
	Total Phytoplankton	Total Zooplankton	Total phytoplankton	Total zooplankton	Total phytoplankton	Total zooplankton
Taxa (S)	71	49	51	47	60	48
Individuals (Org/m^3)	**88,348,800**	530,550	**33,985,950**	715,350	53,601,000	**874,000**
Dominance (D)	0.648	0.113	0.339	0.060	0.770	0.091
Simpson's index (1/D)	0.352	0.887	0.661	0.940	0.230	0.910
Shannon index (H)	0.929	2.566	1.851	2.948	0.670	2.661
Evenness (e^H/S)	0.037	0.420	0.090	0.707	0.029	0.572
Menhinick's richness index (R2)	0.009	0.048	0.017	0.031	0.014	0.030
Equitability (J)	0.219	0.747	0.434	0.895	0.159	0.827
Hill's first diversity number (N1)	2.807	16.644	3.411	21.998	1.270	19.648
Hill's Second diversity number (N2)	1.912	10.546	2.301	16.424	1.077	14.948

Source: Constructed from data trough biodiversity index analysis.

3.3. Water Quality

The variations in the annual mean values for most of the water-quality parameters among the investigated zones of the reservoir were statistically insignificant except for transparency, depth and nitrate. The effect of the municipal run off / discharge entering the reservoir was observed in 17 out of the 36 analyzed water quality parameters which had highest mean values in the Riverine zone. These include hydro-physical conditions (water temperature, Apparent and True Color, TS, TDS and TSS); major anions (Cl^-, CO_3^{2-}, SO_4^{2-}, HCO_3^-; oxygen parameters (DO and BOD) as well as 4 out of the 7 assessed heavy metals (Cd, Cr, Fe and Ni) Table 6. In the Lacustrine zone, the highest annual mean was recorded for ten (10) water quality parameters, which were mostly salinity parameters (conductivity, Alkalinity, acidity, total hardness and COD) as well as main cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^+) and only one heavy metal (Cu) Table 6. While notable water quality parameters that had their maximum mean at the transition zone were the plant nutrient (NO_3^-, PO_4^{3-}, and organic matter). The water-quality index values ranged from 63.57 at Riverine zone to 76.14 as deduced for lacustrine zone revealing a marginal to fair classification of the reservoir.

Table-6. Physicochemical parameters of Opa reservoir.

Parameter	Stations			ANOVA		Drinking water Standards
	Lacustrine	Transition	Riverine	F	P	
	Mean ± S.D	Mean ± S.D	Mean ± S.D			
Water temperature (°C)	28.58 ±1.34	28.29 ±2.50	29.01 ±2.05	1.166	0.324	20-30*
Transparency (m)	0.57 ±0.21	0.84 ±0.39	0.52 ±0.23	4.476	0.019**	30-45*
Depth (m)	1.01 ±0.19	4.99 ±0.57	1.23 ±0.29	405.5	0.000***	-
Apparent colour (Pt.Co.)	315.87±440	241.23±363.64	326.53±339.29	1.08	0.345	0-15+
True colour (Pt.Co.)	70.02±39.97	123.93 ±177.05	178.26 ±264.51	1.188	0.311	0-2+
Total solid (mg/L)	159.42±53.27	150.33±29.08	176.00±92.21	1.976	0.146	-
TSS (mg/L)	61.71 ± 49.88	93.13 ± 79.13	106.20 ± 105.28	1.89	0.159	500+
Turbidity (NTU)	19.24 ±36.64	23.98 ±38.58	20.89 ±26.10	1.162	0.319	5+
pH	7.28 ±0.42	7.46 ±0.37	7.34 ±0.43	0.706	0.497	6.5-8.5+
Conductivity (µS/cm)	175.34 ±29.19	174.23 ±21.35	170.45 ±21.72	0.059	0.943	1000*
Alkalinity $CaCO_3$mg/L)	72.37 ±10.36	69.54 ±11.69	71.96 ±13.08	0.407	0.668	120+
Acidity ($CaCO_3$mg/L)	12.75±5.51	11.46±5.98	11.42±4.27	0.35	0.706	-
TDS (mg/L)	107.33 ±17.34	105.42 ±13.29	110.42 ±26.60	0.074	0.929	600+
Total hardness ($CaCO_3$mg/L)	96.63 ±22.78	89.18 ±21.51	90.74 ±21.49	0.099	0.906	100-500+
Calcium (mg/L)	21.82 ± 5.12	21.58 ±4.86	20.81 ±6.03	0.622	0.54	75-200+
Magnesium (mg/L)	11.84 ±9.29	10.33 ± 8.18	11.01 ±9.29	0.046	0.956	30+
Sodium (mg/L)	2.47 ± 2.41	1.81 ± 1.69	1.60 ±1.13	0.749	0.497	200+
Potassium (mg/L)	0.70 ±0.37	0.64 ±0.39	0.53 ±0.21	0.037	0.964	20+
Chloride (mg/L)	9.09 ±2.00	9.19 ±3.11	9.21 ±2.78	0.345	0.709	250**
Carbonate (mg/L)	43.43± 6.22	41.72± 7.03	44.68± 9.64	0.878	0.42	120
Bicarbonate (mg/L)	86.80 ±12.89	85.00 ±12.80	88.20 ±15.46	0.389	0.679	120
Sulphate (mg/L)	2.16 ±4.12	3.14 ±5.12	4.12 ±6.13	0.178	0.838	250**
Nitrate (mg/L)	0.21 ±0.12	0.29 ±0.16	0.19 ±0.20	4.159	0.020*	10-50+
Organic matter (mg/L)	14.19±7.89	16.01±12.96	14.63±6.04	0.055	0.947	-
Total organic carbon (mg/L)	1.86±0.90	2.11±1.18	2.17±1.75	0.068	0.935	5+
Phosphate (mg/L)	2.44 ±1.85	2.56 ±1.53	2.47 ±1.89	0.068	0.93	0.02-0.2
DO (mg/L)	5.11 ± 2.73	6.29 ± 1.63	7.06 ± 2.46	1.398	0.254	≥5
BOD (mg/L)	2.46 ± 1.79	3.33 ± 2.34	4.35 ± 1.75	1.108	0.336	5
COD (mg/L)	6.57 ±5.16	5.89 ±4.03	6.55 ±4.89	0.2	0.819	40+
Cadmium (mg/L)	0.028±0.004	0.029±0.004	0.034±0.005	0.3984	0.6729	0.03+
Chromium (mg/L)	0.025±0.003	0.022±0.003	0.047±0.020	1.339	0.2689	0.03**
Iron (mg/L)	0.162±0.026	0.174±0.027	0.193±0.026	0.3574	0.7008	0.3**
Copper (mg/L)	0.556±0.087	0.463±0.078	0.503±0.078	0.3288	0.7209	2**
Lead (mg/L)	0.004±0.001	0.008±0.001	0.004±0.000	0.7311	0.4851	0.01+
Nickel (mg/L)	0.899±0.033	0.905±0.032	0.911±0.032	0.0296	0.9709	0.02+
Zinc (mg/L)	0.050±0.009	0.087±0.019	0.086±0.016	1.849	0.1651	3+
WQI	76.14	67.89	63.57			

Note: **= NIS, 2007 (Maximum permitted)
+ = WHO, 2011
*= Health Canada, 2012
Bolded values do not meet the objective.

3.4. Interrelationship between Planktonic Abundance and the Investigated Water Quality Parameters

The correlation between the physicochemical parameters (Independent variables) and total phytoplankton and zooplankton (dependent variable) is shown in Table 7. The correlation matrix showed notable correlation between planktonic organisms' abundance, and six (6) of the thirty-one (31) investigated water-quality parameters (pH, magnesium, dissolved oxygen, copper, Iron and lead). Dissolved oxygen and pH showed a significant to very highly significant positive correlation with abundance of both zooplanktonic and phytoplanktonic organisms at all the investigated stations. While Iron (Fe) showed negative correlation with the planktonic abundance which was significant for total phytoplankton at lacustrine and riverine zone but insignificant for zooplankton at all stations except the Lacustrine. Moreover, at the Lacustrine zone, magnesium concentration of the reservoir had significant positive correlation with phytoplankton while copper and lead concentration had positive correlation with zooplankton abundance at the transition zone of the reservoir.

Table-7. Correlation coefficient (r) values of the total phytoplankton, total zooplankton and physicochemical parameters of opa reservoir during the period of study.

Parameter	Lacustrine		Transition		Riverine	
	Total phytoplankton	Total zooplankton	Total phytoplankton	Total zooplankton	Total phytoplankton	Total zooplankton
True_colour	-0.09684	-0.07379	-0.10845	-0.0779	-0.10447	-0.07072
Turbidity	-0.14343	-0.12916	-0.13563	-0.12617	-0.1299	-0.1194
Apparent_colour	-0.12529	-0.12625	-0.12437	-0.12533	-0.11619	-0.11878
Total_solids	-0.16879	-0.13813	-0.18125	-0.1254	-0.17997	-0.12076
Total_suspended_ solid	-0.10929	-0.09905	-0.12794	-0.08913	-0.1251	-0.08611
pH	0.16781	0.35827**	0.32116**	0.369***	0.28981*	0.35167**
Conductivity	-0.12413	-0.02819	-0.04385	-0.03491	-0.05019	-0.02985
Alkalinity	-0.14433	0.018742	-0.05465	0.010969	-0.07634	0.018781
Acidity	-0.02719	-0.04442	-0.08484	-0.05559	-0.11436	-0.04805
Total_hardness	0.090805	-0.01795	-0.00075	-0.00748	-0.00524	-0.01314
Total_dissolved_ solid	-0.1342	-0.05451	-0.07419	-0.05792	-0.07486	-0.05249
Calcium	-0.07667	0.13737	-0.16732	0.17281	-0.15731	0.17427
Magnesium	0.26218*	-0.07201	0.079508	-0.06086	0.063316	-0.07563
Sodium	-0.02936	0.063612	0.075157	0.054675	0.030887	0.044805
Chloride	-0.04906	-0.02113	-0.09009	-0.00266	-0.08804	0.002148
Sulphate	-0.12321	-0.11029	-0.13397	-0.10291	-0.12109	-0.09762
Bicarbonate	0.035543	0.01745	-0.04543	0.010099	-0.05108	0.017523
Nitrate	-0.03469	0.021293	-0.0914	0.068434	-0.00181	0.065772
Phosphate	0.14587	-0.01397	-0.0961	0.013126	-0.04394	0.014204
Organic_matter	-0.04304	-0.03637	-0.02906	-0.03868	-0.0501	-0.04105
Total_organic_ carbon	-0.04592	-0.03981	-0.03283	-0.04189	-0.05276	-0.04401
Dissolved_ oxygen	0.059476	0.38428***	0.43489***	0.31263**	0.22624*	0.30936**
Biochemical_ oxygen_demand	-0.14987	0.036467	0.14897	-0.05117	-0.07407	-0.04107
Chemical_ oxygen_ demand	-0.04189	-0.03606	-0.0305	-0.03769	-0.04783	-0.03943
Cd	-0.09981	-0.10311	-0.19692	-0.09193	-0.19012	-0.08016
Cr	0.047911	-0.0423	-0.01795	-0.01329	-0.0229	-0.02461
Cu	0.15734	0.19032	0.041811	0.24391*	0.032621	0.22032
Fe	-0.24033*	-0.23808*	-0.28513	-0.22154	-0.26104*	-0.21095
Pb	0.17056	0.14645	0.080334	0.26471*	0.18942	0.22539*
Ni	-0.01247	0.05241	-0.13495	0.063429	-0.18578	0.075485
Zn	-0.10933	-0.11706	-0.12296	-0.11039	-0.09909	-0.1053

Note: *=significant ($p<0.05$)
**= highly significant ($p<0.01$)
***= very highly significant ($p<0.001$).

Principal components' analysis was used to identify the different groups of the investigated physicochemical water quality parameters and planktonic taxa contributing strongly to the differences observed among the zones of the reservoir. A total of five (5) PCs with eigenvalue above 1 which explained 97.12% of the entire variance was obtained Table 8. The first component that accounted for 77.3% of the whole variance showed strong positive loadings for True Color, Apparent Color, Total solids, conductivity total hardness, Total dissolved solids and bicarbonate. While second component which accounted for 11.7% further revealed the correlation between True Color and Apparent Color. The third component (3.1%) isolated some of the phytoplankton taxa, mainly bacillariophyta, cyanobacteria, myxozoa and Charophyta Table 8. The fourth component (2.8%) showed a correlation between baccilariophyta abundance and True Color, Conductivity, Total Hardness and Total Dissolved Solid. Moreover, the correlation between True Color and Total Solid/Suspended solid was further established by the fifth component which accounted for just 2.1% of the whole variance.

Table-8. Principal analysis component between the plankton groups and water quality parameters of Opa Reservoir.

	PCA1	PCA2	PCA3	PCA4	PCA5	PCA6
Eigenvalue	55.6828	8.45489	2.21233	2.02868	1.52709	0.759867
% variance	77.337	11.743	3.0727	2.8176	2.121	1.0554
Cummulative	77.37	89.11	92.18	95	97.12	98.18
Bacillariophyta	-0.51935	0.29911	4.7648	0.52321	0.48458	0.083332
Chlorophyta	-0.48849	0.1902	-0.2509	-0.05772	-0.14614	-0.06435
Cyanobacteria	-0.49983	0.22895	1.4826	0.14264	0.069542	-0.01358
Myzozoa	-0.50898	0.26151	3.0134	0.32022	0.26418	0.04004
Cryptophyta	-0.48949	0.19403	-0.05608	-0.03499	-0.12059	-0.05586
Ochrophyta	-0.48809	0.18877	-0.31634	-0.06529	-0.15433	-0.06583
Charophyta	-0.50353	0.24157	1.9205	0.19198	0.1137	-0.05199
Euglenophyta	-0.48784	0.18798	-0.34973	-0.06914	-0.1584	-0.06689
Protozoa	-0.48762	0.18719	-0.38667	-0.07342	-0.16308	-0.06809
Cnidaria	-0.48765	0.18729	-0.38237	-0.07292	-0.16254	-0.06792
Ciliophora	-0.48762	0.18719	-0.3869	-0.07345	-0.16311	-0.06808
Rotifera	-0.48811	0.18892	-0.30552	-0.06401	-0.15277	-0.06528
Arthropoda	-0.48872	0.19108	-0.20377	-0.0522	-0.13981	-0.06153
True_colour	1.1977	0.85772	-1.0386	4.0828	4.6759	0.31141
Turbidity	-0.1367	0.43253	-0.37868	-0.19627	-0.02344	-0.37093
Apparent_colour	4.2925	4.517	0.20582	-0.50237	-1.6538	0.008085
Total_solids	2.3833	-2.0849	0.37389	-1.977	1.3469	-1.2043
Total_suspended_solid	0.69394	-0.20264	-0.0378	-4.3796	3.4454	0.95451
pH	-0.36691	0.060142	-0.36335	-0.02138	-0.18244	-0.09528
Conductivity	2.4123	-2.8438	0.31847	1.0754	-1.147	-1.4138
Alkalinity	0.67929	-0.95118	-0.15536	0.42067	-0.16496	-0.72649
Acidity	-0.28546	0.049228	-0.34197	-0.07509	-0.20628	-0.06972
Total_hardness	1.1071	-1.5633	-0.01659	0.52561	-1.0551	6.0183
Total_dissolved_solid	1.2906	-1.6685	0.036355	0.76188	-0.77802	-1.0054
Calcium	-0.12169	-0.22486	-0.30895	0.15196	-0.29389	-0.10738
Magnesium	-0.30969	0.009835	-0.34954	-0.01936	-0.20782	0.22885
Sodium	-0.45027	0.1353	-0.3787	-0.06237	-0.20063	0.14431
Chloride	-0.32386	0.016356	-0.34909	-0.02226	-0.21677	-0.12203
Sulphate	-0.4281	0.097175	-0.37296	-0.04256	-0.1663	-0.16419
Bicarbonate	0.99005	-1.4267	-0.02227	0.44994	-0.66918	-0.55029
Nitrate	-0.48351	0.1832	-0.38945	-0.06986	-0.16141	-0.06669
Phosphate	-0.44391	0.14585	-0.38091	-0.06049	-0.16606	-0.05414
Organic_matter	-0.22135	-0.04267	-0.35651	-0.05959	0.040037	-0.2367
Total_organic_carbon	-0.45151	0.1626	-0.38768	-0.04536	-0.13611	-0.08837
Dissolve_oxygen	-0.39035	0.072379	-0.36832	-0.00058	-0.20097	-0.12849
Biochemical_oxygen_demand	-0.43178	0.13637	-0.37398	-0.04256	-0.21503	-0.14266
Chemical_oxygen_demand	-0.39256	0.12312	-0.38482	-0.00228	-0.08104	-0.11468
Cd	-0.48714	0.18688	-0.38977	-0.07377	-0.16364	-0.06864
Cr	-0.48715	0.18682	-0.38972	-0.07387	-0.16391	-0.06804
Cu	-0.47862	0.17405	-0.38733	-0.06947	-0.1691	-0.06353
Fe	-0.48486	0.18559	-0.38932	-0.07351	-0.16336	-0.07234
Pb	-0.48753	0.18705	-0.38985	-0.07377	-0.16352	-0.06821
Ni	-0.47209	0.16964	-0.38638	-0.06701	-0.16589	-0.06895
Zn	-0.48645	0.18587	-0.38968	-0.07286	-0.16362	-0.06834

4. Discussion

The annual mean concentrations of most investigated water quality parameters were within the permissible range for aquatic life except apparent color, true color, turbidity, phosphate, dissolved oxygen, chromium and nickel in all the zones of the reservoir. This revealed the effect of discharge / inflow received from the catchment area of the reservoir. The number of parameters (17 out of 36 studied) with highest annual mean values at the riverine further established the fact that inflow is having a negative impact on the lake. Furthermore, the deduced Canadian Council of Ministers of the Environment WQI of 63.57 connotes the riverine zone as a frequently threatened zone whose water quality is often more departed from natural or desirable level.

The resultant effect of the level of pollution in the riverine zone of the reservoir was observed in the lowest occurrence (species richness) and highest mean concentration of four (4) of the seven (7) detected heavy metals. This observation has been connected with the quality of the influx and shallowness of this region of the reservoir. The most abundant phytoplankton species (*Cryptomonas ovata)* is a known bio-indicator of eutrophicated waters [38]. Moreover, the observed maxima abundance of zooplankton, with the dominance of rotifers (*Brachionus angularis*) and arthropods (Cyclops), at the riverine also confirmed its eutrophic conditions [39]. The quantitative richness of zooplankton at the zone could be as a result of the influx that either introduced or caused dislodgement of many species from river bed and littoral zone [40, 41].

The second most abundant taxa (Charophyta) at the lacustrine have been linked with salinity and clarity of water [42]. The maxima annual mean concentration of salinity parameters at the zone confirmed the charophytes as good indicators of salinity while the lowest plant nutrient concentration and total organic carbon revealed these taxa's ability to remove nutrient and carbon from the water body to build biomasses [42]. The clarity resulted in the growth and dominance of phytoplankton at the zone with the maxima abundance of 90,500,000 ind./m^3 which could be linked to availability and absorption of light. While obstruction of light depicted by maxima turbidity at the transition led to reduction in growth and minima phytoplankton abundance recorded at the zone. Moreover, the highest phytoplankton abundance recorded from the lacustrine might be as a result of less turbulence and more restricted movement unlike riverine, which is the inflow, characterized by very high turbulence [43].

Notable is the positive correlation that phytoplankton abundance had with magnesium concentration at the lacustrine endorsing the important role magnesium plays in plant metabolism and growth, supply of carbon and limitation of chlorophyll formation [44]. Another limiting element, iron had negative correlation with phytoplankton abundance at both lacustrine and riverine zone thus revealing the unfavorable effect that iron concentration, which was beyond the permissible limit of 0.1 mg/l [44] had on the growth of the phytoplankton population of the reservoir. However, the maxima phytoplankton population recorded at the zones could be as a result of inferred low level of potential environmental risk that iron concentration had in the reservoir during the study period [45].

Furthermore, the Principal Component Analysis (PCA) revealed that salinity (conductivity, total hardness, bicarbonate and TDS) and light (True and apparent color, Total Solid) parameters contributed mostly to the community structure of the reservoir. These parameters as established by PCA affected the abundance of the first four the most populated taxa (Bacillariophyta, Cyanophyta, Myxozoa and Charophyta) thus strongly influencing the community distribution of micro-biota of the reservoir. Conversely, these phytoplankton were dominated by only one species and uneven distribution, which could be due to tolerance level of recorded species and low species diversity (resultant effect of eutrophication of lakes [40]. The deduced highest phytoplankton species richness (Menhinick's index) at the transition zone could, nevertheless, be linked to availability of plant nutrient and longer retention time. The retention time, in connection with Nickel concentration which was above the permissible limit of 0.02 mg/l [44] explains the 62% decrease in phytoplankton abundance recorded at the transitional zone as compared to the lacustrine. This is since unacceptable nickel concentration could have negative effect on phytoplankton growth [46] and their photosynthetic system [47].

In conclusion, although most of the water-quality parameters investigated had statistically insignificant variation among the zones studied, their concentration reflected the unsuitable state of the reservoir as established by CCME Water Quality Index. These physico-chemical parameters had strong influence on the community structure of the micro-biota. The Principal component analysis and Correlation analysis inferred that dissolved oxygen, salinity parameters (Magnesium, pH, conductivity, total hardness, total dissolved solid, bicarbonate) and light obstruction parameters (true and apparent color, Total Solid and total suspended solid) were the main contributing factors to planktonic abundance and distribution in the Opa reservoir. However, recorded metal concentrations (Fe and Ni) which were above the permissible limits had a negative effect on the micro-biota structure. Biologically, the diversity index revealed dominance by few tolerant species characterized of eutrophicated waters. Therefore, special attention should be given to the management of the Opa reservoir's influx in order to sustain good water quality and healthy aquatic ecosystem.

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