EnvironmentAsia
The international journal by the Thai Society of Higher Education Institutes on Environment

EnvironmentAsia 18(2) 2025 144-154
DOI 10.14456/ea.2025.44
ISSN 1906-1714; ONLINE ISSN: 2586-8861

Spatiotemporal Analysis and Determination of Major Sources Affecting Water Quality of Oguta Lake by Principal Component Analysis

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Received: May 20, 2024; Revised: July 25, 2024; Accepted: February 4, 2025

Abstract

Assessment of spatial and temporal changes in surface water is an important aspect in the interpretation of physicochemical data. Sixteen physical and chemical parameters monitored at four sampling stations along Oguta Lake, Nigeria were analyzed during a one-year period. A total of 48 samples were collected from each station. The Principal Component Analysis (PCA) technique was used to evaluate the spatial and temporal relationships of the water quality parameters. The Water Quality Index (WQI) was calculated by using the procedure of a weighted arithmetic index method. Five principal components, accounting for 88.72% of the total variances of information contained in the original data set were obtained. The results revealed that water depth, conductivity, iron, calcium and nitrate-nitrogen were the most important variables contributing to water physicochemical properties of the lake. The calculated water quality index of Oguta lake was 2649.12 thus making Oguta Lake unsuitable for drinking. The structural factor loadings (eigenvectors) followed a decreasing order of organic matter and inorganic fertilizer (28.68%), dissolved pollutants and climatic factors (22.05%), industrial waste (16.57%), parent rock influence (11.13%) primary productivity (10.28%) as the major factors responsible for the modification of the surface water quality of the area. Principal component analysis reduces original dimensions to make multiple variables into a few comprehensive index.

Keywords: Oguta Lake; Physicochemical parameters; Principal component analysis; Water quality index

1. Introduction

The level of water quality is relatively determined by the content of physical, chemical and biological parameters present in it. Relationship between two parameters may also lead to increase or decrease in the concentration of others. The knowledge of this relationship or association is usually achieved using multivariate statistical techniques (Jaji *et al.,* 2007). This is because some analyses are primarily concerned with relationships between samples, while others are concerned largely with relationships between variables. According to Yerel (2010), many multivariate statistical techniques have the capacity to summarize large data by means of relatively few parameters. Nonetheless, the choice of using any of the multivariate statistical techniques lies in the nature of the data, problem, and objectives of the study (Ayeni and Soneye, 2013). In view of the fact that Oguta lake is associated with four major rivers and serves for the daily drinking and domestic water needs of the majority of residents in the area there is the need to understand the variables that control the variations in its quality. Principal Component Analysis (PCA) was therefore adopted for this study. Principal component analysis is one of the best multivariate techniques for extracting linear relationship among a set of variables (Udoinyang and Ukpatu, 2015). It is a multivariate eigenvector analytical technique used for the interpretation of the structure within the correlation matrix of variables (Gauch Jr., 2006). According to Praus (2005) PCA is used to search new abstract independent eigenvalues which explain most of the data varies in a new harmonized structure. Each principal component (PC) is a linear combination of the original variables and describes different source of information by eigenvalues based on the decomposition of the correlation matrix (Geladi and Kowalski, 1986). Therefore, PCA is designed to modify the observed variables into uncorrelated variables of linear combinations of the original variables called principal components (Yerel, 2010) as well as to investigate the factors which caused variations in the observed data sets (Mazlum *et al.,* 1999).

In recent years many studies have been done using principal component analysis in the interpretation of water quality parameters (Sukarma *et al.,* 2011). Lohani and Todino (1984) utilized principal components technique to provide a quick analytical method for the water quality of Chao Phraya river in Thailand. Shihab (1993) also used this technique in order to describe the variation in water quality in Saddam dam reservoir. Principal component analysis has also been successfully applied to sort out hydrogeological and hydrogeochemical processes from commonly collected ground water quality data (Olobaniyi and Owoyemi 2006; Moscow *et al.,* 2011). The principal component analysis therefore provides information for interpretation and better understanding of the most meaningful parameters which describes the whole data set through data reduction with a minimum loss of the original information.

Water Quality Index (WQI) summarizes numerically the information from multiple water quality parameters such as Dissolved Oxygen (DO), Electrical Conductivity (EC), pH, Biological Oxygen Demand (BOD), and Turbidity (TUR) into one single value (Kamran and Elnaz, 2017). This single value can be used to compare water quality conditions among sites and to investigate their trends over a given period of time. The objective of water quality index is to turn complex water quality data into information that is understandable and usable for common man (Inayathulla and Jai, 2013). It is a very important parameter that can provide a simple indicator of water quality trend in water bodies to water quality managers and gives the public general idea on possible problem with the water body (Boah *et al.,* 2015). In general, water quality indices use data from multiple water quality parameters into a mathematical equation that rates the health of a water body with numbers (Yogendra *et al.,* 2007) and provides a single numerical value that expresses overall water quality at a certain location and time based on several water quality parameters available (Otene and Nnadi, 2019).

The aim of this study is to apply the PCA technique to evaluate the spatiotemporal correlations of water physicochemical parameters and to extract those parameters that are most important in assessing variations of Oguta lake. Moreover, to provide information on the suitability of the lake for human consumption based on computed water quality index value.

2. Methodology

2.1 Study Area

Oguta lake (Figure 1) is located between Latitude 5° 41'– 5° 44' North of Equator and Longitude 6°56'– 6°45' East of Greenwich. This region is located within the equatorial rain forest belt with an average annual rainfall of 3,100 mm (Ahiarakwem and Onyekuru, 2011). Most parts of the shoreline are lined up by a community of bank macrophytes consisting of grasses such as Panicum senegalense and sparse population of floating macrophytes such as *Pistia stratiotes, Azollia africana, Salvinnia auriculata, Ceraphyllum demersum Ulyicularia inflexa* and water lilies- *Nymphyaea lotus* and *N. macrantha.* Plant life is poor and restricted to the littoral zone (< 1.5 m depth).

Four rivers (Njaba, Awbana, Utu and Orashi) are associated with Oguta Lake. The Njaba and Awbana discharge into the lake all the year round while Utu Stream flows in during the rainy season. The Orashi River flows past the lake in its southwestern portion. The total annual inflow from the rivers and stream is about 25,801.60 m^3 (Ahiarakwem, 2006; Umunnakwe, 2014). The rainy season period (April - September) is marked by moderate temperature and high relative humidity while the months of October to March (dry season) have scanty rainfall, higher temperatures and low relative humidity.

2.2 Sampling Locations

Four sampling stations were designated within the lake. Choices were made based on the four rivers associated with Oguta Lake.

(1) Utu Station: This is located at a point where Utu River enters Oguta Lake. From this station, farm lands and human settlements could be observed. Utu station has a mean depth of 5.63 ± 0.460 m.

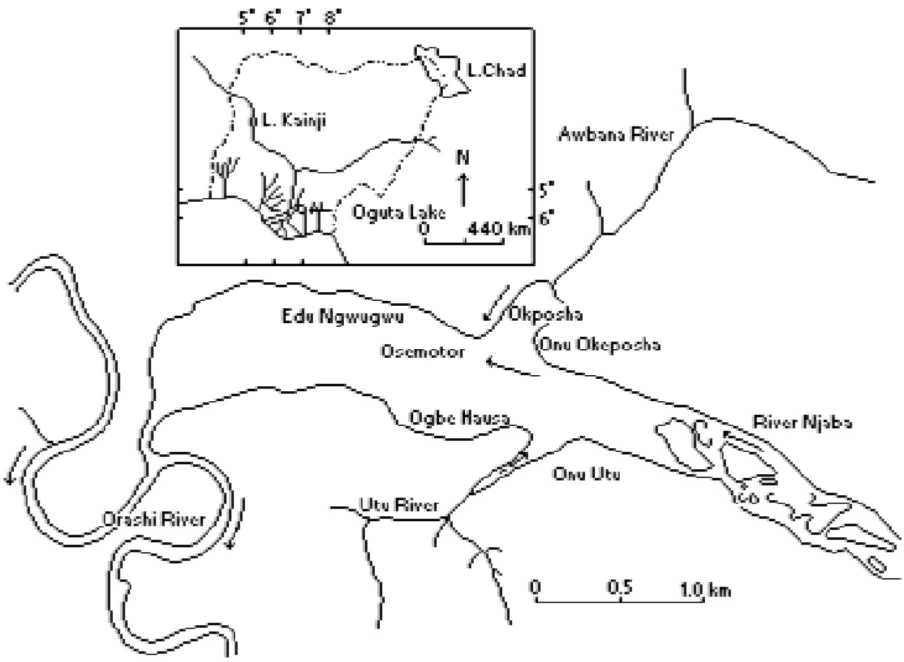

Figure 1. Map of Oguta Lake showing study locations

(2) Osemoto Station: This is located where Awbana River joins Oguta Lake. Anthropogenic activities like processing of cassava and breadfruit, refuse disposal and sewage disposal are predominant in this station. This station has a mean depth of 5.40 ± 0.732 m

(3) Njaba Station: This is where Njaba River joins Oguta Lake. Sand mining is done close to this station. The mean depth of this station is 5.42 ± 0.681 m

(4) Orashi Station: At this station Oguta Lake flows into Orashi River. A very serene environment and deeper than other stations with an average depth of 6.27 ± 0.630 m

2.3 Collection of water sample

Collection of water in this study was carried out over a period of 12 months from April 2017 to March 2018. This was done once a month and covered dry and rainy seasons. Samples were collected from the four stations on the same day between 9 a.m. and 10 a.m. Water samples were collected at depths of about 30 cm with 1 litre sterilized plastic containers, and taken to the laboratory for analysis.

2.4 Experimentation

pH and electrical conductivity (µs/cm) were determined using HANNA digital pH meter and EC multi meter Hi 98129. Water temperature (°C) was measured using mercury in glass thermometer, current (m/s), by the use of weighted cork, transparency (cm) measured by the visibility of a 25 cm (diameter) Secchi disc. Water depth (m) and dissolved oxygen (DO) (mg/L) were measured using adjustable meter rule and a field DO meter (Jenway, model 3050). The above parameters were recorded *in-situ.* Nitrate-nitrogen (NO_3-N) (mg/L), Phosphate-phosphorus (PO_4-P (mg/L), Alkalinity (mg/L), Hardness (mg/L), Total dissolved solids (TDS) (mg/L), Calcium (mg/L), Magnesium (mg/L), Sodium (mg/L) and Iron (mg/L), were determined *ex-situ* using standard methods for examination of water (APHA, 2005).

2.5 Water Quality Index (WQI) of Oguta Lake

The WQI was calculated by using the standards of drinking water quality recommended by World Health Organisation, (2011) and by the procedure of a weighted arithmetic index method (Brown *et al.,* 1972) in the following steps.

Calculation of sub index of quality rating (Qn)

The value of qn is calculated using the following expression

$$qn = 100(Vn-Vio)/(Sn-Vio)$$

Where,

qn = quality rating for the nth water quality parameter

Vn = observed value of the nth parameter

Sn = standard permissible value of nth parameter

Vio = ideal value of nth parameter in pure water

All the ideal values (Vio) are taken as zero for drinking water except for pH = 7.0, Dissolved Oxygen = 14.6 mg/L, and Fluoride = 1 mg/L (Inayathulla and Jai, 2013)

2.6 Calculation of unit weight (Wn)

Unit weight (Wn) for various water quality parameters are inversely proportional to the recommended standards for the corresponding parameters.

$$Wn = K/Sn$$

Where,

Wn = unit weight of nth parameters

Sn = standard value for nth parameters

K = constant for proportionality and is given as:

K = $1 / (1/V_{S1}+1/V_{S2}+\ldots\ldots\ldots+ 1/Vsn)$

2.7 Calculation of WQI

WQI is calculated from the following equation according to Srinivasa and Padaki (2012).

$$WQI = \sum qnWn / \sum Wn$$

Classification of water quality status is based on Water Quality Index as described by Bhaven *et al.* (2011).

< 50 Excellent, 50-100 Good Water, 100-200 Poor water, 200-300 Very poor water,

> 300 Water unsuitable for drinking

2.8 Statistical analysis

Using the standard statistical software SPSS version 23.0, significant principal components (PCs) with eigenvalues were extracted. The Varimax criterion, which provides maximum correlation of each parameter with a single PC, was applied for optimal rotation of the PCs.

3. Results and Discussion

3.1 Principal components extracted

Table 1 shows variations in the values of the physicochemical parameters of Oguta Lake. The result of the principal components analysis (PCA) in Table 2 shows that out of the 16 parameters tested, all the parameters had initial communalities of 1.000 and a high extraction communality of 0.989 for current and 0.673 for sodium. After applying a PCA to the original sixteen (16) variables, several components were distinguished. Five principal components explaining 88.72% of the total variance were obtained. This reduced the complexity of the data set by using these components with only about a meagre 11.28% loss of information. The extraction sums of squared loadings revealed that PC1 contributed about 36.02% variance, PC2 contributing 19.17% variance, PC3 contributing 15.40% variance, PC4 contributing 10.23% variance while PC5 contributed 7.90% variance (Table 3). The extracted 5 components were subsequently rotated according to varimax rotation in order to make interpretation easier and show the fundamental significance of extracted components to the water quality status of Oguta Lake. The rotation maintained the cumulative percentage of variance (88.72%) explained by the extracted components. After the rotation, PC1 contributed 28.68% variance, PC2 contributing 22.05% variance, PC3 contributing 16.57% variance, PC4 contributing 11.13% variance while PC5 contributed 10.28% variance (Table 4)

Table 1. Variations of physicochemical parameters in Oguta Lake

Parameter	Minimum	Maximum	Annual mean
Temperature, °C.	27.00 ± 0.115	30.52 ± 0.240	28.77 ± 0.336
Current, m/s	0.24 ± 0.015	0.29 ± 0.010	0.27 ± 0.005
Depth, m	4.80 ± 0.100	6.90 ± 0.029	5.68 ± 0.234
Transparency, m	1.12 ± 0.019	1.41 ± 0.031	1.28 ± 0.028
pH	6.20 ± 0.265	8.00 ± 0.100	6.69 ± 0.161
Total dissolved solid, mg/L	3.24 ± 0.051	18.20 ± 1.489	7.55 ± 1.358
Conductivity, µS/cm	5.00 ± 0.577	26.00 ± 1.332	10.58 ± 1.959
Dissolved oxygen, mg/L	1.40 ± 0.153	6.70 ± 0.433	3.34 ± 0.653
Alkalinity, mg/L	59.00 ± 2.082	98.00 ± 1.527	81.5 ± 3.702
Total hardness, mg/L	12.19 ± 1.014	43.90 ± 1.418	25.19 ± 2.685
Calcium, mg/L	1.68 ± 0.468	7.57 ± 1.973	3.68 ± 0.435
Magnesium, mg/L	1.58 ± 0.221	8.13 ± 1.417	3.66 ± 0.738
Nitrate-nitrogen, mg/L	2.40 ± 0.643	26.40 ± 3.429	10.73 ± 2.265
Phosphate-phosphorus, mg/L	0.16 ± 0.031	13.40 ± 0.817	3.24 ± 1.345
Sodium, mg/L	0.01 ± 0.006	4.25 ± 0.579	1.09 ± 0.328
Iron, mg/L	0.01 ± 0.005	0.52 ± 0.335	0.16 ± 0.042

Table 2. Principal components analysis (PCA) output

Parameter	Communalities Initial	Extraction
Temperature	1.000	0.743
Current	1.000	0.989
Depth	1.000	0.936
Transparency	1.000	0.938
pH	1.000	0.767
TDS	1.000	0.907
Conductivity	1.000	0.943
DO	1.000	0.907
Alkalinity	1.000	0.866
Total Hardness	1.000	0.926
Calcium	1.000	0.907
Magnesium	1.000	0.924
NO_3-N	1.000	0.988
PO_4-P	1.000	0.885
Sodium	1.000	0.673
Iron	1.000	0.895

Table 3. Extraction sums of squared loadings of the principal components (PCs)

Component	Total	% of Variance	Cumulative %
1	5.763	36.022	36.022
2	3.067	19.168	55.190
3	2.464	15.400	70.591
4	1.636	10.226	80.817
5	1.264	7.899	88.715

Table 4. Rotation sums of squared loadings of the principal components (PCs)

Component	Total	% of Variance	Cumulative %
1	4.589	28.684	28.684
2	3.528	22.049	50.733
3	2.651	16.570	67.303
4	1.781	11.130	78.433
5	1.645	10.283	88.715

According to Carlos *et al.* (2017), the eigenvalues of the main components are a measure of their associated variances and the sum of them coincides with the total number of variables. The scree plot (Figure 2) represents the Eigenvalues of each component in the initial solution. The extracted components are on the steep slope while the components on the shallow slope contributed very little, that is, 11.28% to the solution. The last big drop occurred between the fifth and sixth components.

Classifying the component loadings according to Liu *et al.* (2003), the loading values greater than 0.75 signifies "strong", the loading with absolute values between 0.75 and 0.50 indicate "moderate" while loading values between 0.50 and 0.30 denote as "weak". Based on the component loadings, the variables are grouped accordingly with their designated components as follows:

Component 1: Water depth, PO_4-P, Mg, Total Hardness and Transparency

Component 2: Conductivity, TDS, DO, pH, Temperature and Current

Component 3: Fe, Na and Alkalinity

Component 4: Ca, Temperature and Current

Component 5: NO_3-N

The rotated component matrix (Table 5) shows that PC1 was most highly correlated with water depth (0.960) and also has high loadings for phosphate-phosphorus (0.899), magnesium (0.892), total hardness (0.825) and transparency (-0.875). The second PC, (PC2) was most highly correlated with conductivity (0.928) and also has strong loadings for total dissolved solids (0.855), moderate loading for dissolved oxygen (0.742), pH (0.723), temperature (0.505) and current (-0.577). PC3 was most highly correlated with iron (0.913) with high loadings for sodium (0.777) and alkalinity (0.689). PC4 was most highly correlated with calcium (0.925) and also had high loadings with temperature (-0.582) and current (-0.550) while PC5 was most highly correlated with nitrate-nitrogen (0.861).

Components loading (correlation coefficients) measures the degree of closeness between the variables and the Principal Components (Taboada-Castro *et al.,* 2007; Sukarma *et al.,* 2011). The largest loading is either positive or negative, and suggest the meaning of the dimensions. Positive loading indicates that the contribution of the variables increases with the increasing loading in dimension and negative loading indicates a decrease.

An interpretation of the rotated 5 principal components was made by examining the component loadings noting the relationship to the original variables. Component 1 gives information about the variations in Water

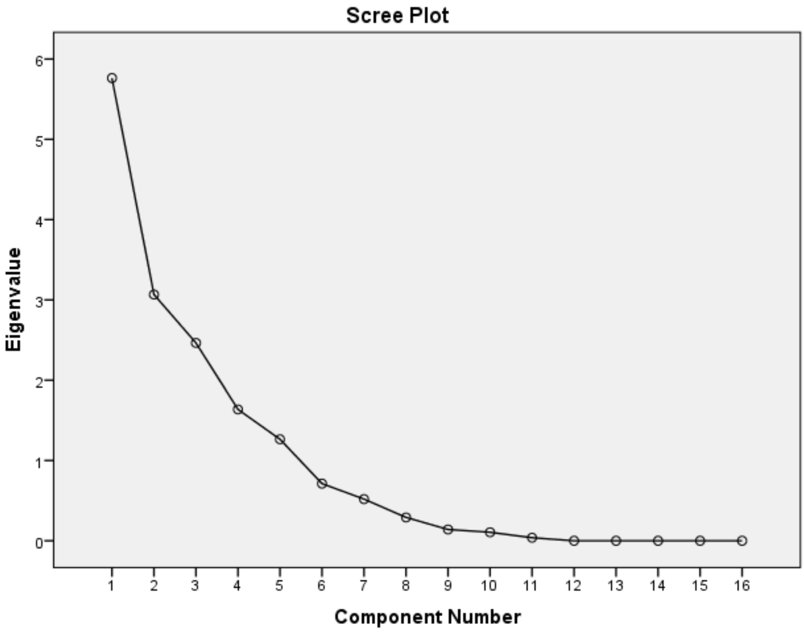

Figure 2. Scree plot of Eigenvalues by Component Numbers of the PCs

Table 5. Rotated component matrix

	Component				
Parameter	1	2	3	4	5
Temperature	-0.126	0.505	-0.365	-0.582	0.014
Current	-0.067	-0.577	0.353	-0.550	0.474
Depth	0.960	0.055	0.063	0.083	-0.010
Transparency	-0.875	-0.015	-0.282	-0.197	-0.233
pH	0.148	0.723	-0.314	-0.021	0.351
TDS	0.164	0.855	0.330	0.149	-0.137
Conductivity	0.027	0.928	0.273	0.086	0.023
DO	0.380	0.742	-0.303	-0.211	0.274
Alkalinity	0.494	0.302	0.689	0.237	0.029
Total Hardness	0.825	-0.072	-0.148	0.126	0.450
Calcium	-0.005	0.117	0.003	0.925	0.194
Magnesium	0.892	0.252	0.037	-0.126	0.220
NO_3-N	0.390	0.206	0.015	0.229	0.861
PO_4-P	0.899	0.217	0.031	-0.115	-0.126
Sodium	0.078	-0.084	0.777	-0.079	-0.224
Iron	-0.048	0.054	0.913	0.060	0.230

depth, Phosphate-phosphorus, Magnesium, Total hardness and Transparency. In this component, loading indicates that organic matter and inorganic fertilizer which could be attributed to various anthropogenic activities, agricultural farming and geological formation or composition of the area greatly influenced the quality of Oguta lake. Variation in hardness of Oguta lake is probably due to regular addition of sewage and detergents due to large human presence and activities. The second PC was highly correlated with Electrical conductivity, Total dissolved solids (TDS), Dissolved oxygen, pH, Temperature and Current but its eigenvalue and total variance is quite lower when compared with component 1. This loading indicates that the lake has presence of dissolved pollutants such as NO_3^-, PO_4^{3-}, Cl^-, SO_4^{2-}, Na^+ and K^+. Anthropogenic activities and sediment composition may have contributed to this situation. Climatic conditions such as increased evapotranspiration rate especially during the dry season may also be responsible for the increased concentration of these pollutants in water. Component 3 explained information about Fe, Na and Alkalinity. This component represents pollution from domestic and possibly industrial waste as well as the geological composition of the area. The high alkalinity value could be due to large scale use of the lake bank as open latrine and consequent washing of excreta into the lake (Sukarma *et al.,* 2011). Industrial waste in this study is highlighted by the presence of Iron. In component 4, (Ca, Temperature and Current), Ca presence is an indication of the parent rock influence. The significance of Nitrate (NO_3^-) in component 5 indicates that nitrification is taking place in the lake. Nitrate is the main form of nitrogen found in waters, as it is a major source for primary producers. When in high concentrations, its oxidation can consume a lot of oxygen, stimulating the growth of algae (Carlos *et al.,* 2017).

In figure 3, the component plot in rotated space of the physicochemical parameters revealed that transparency, iron and sodium were more closely associated with each other than with the other variables in space.

3.2 Water Quality Evaluation

The result of the water quality index (WQI) of Oguta Lake is presented in Table 6. From the calculated WQI only Magnesium exceeded WHO permissible limit of 0.1 mg/L. According to William and Onisogen (2013), the lower the value of a parameter the better in terms of water quality. Similar result was

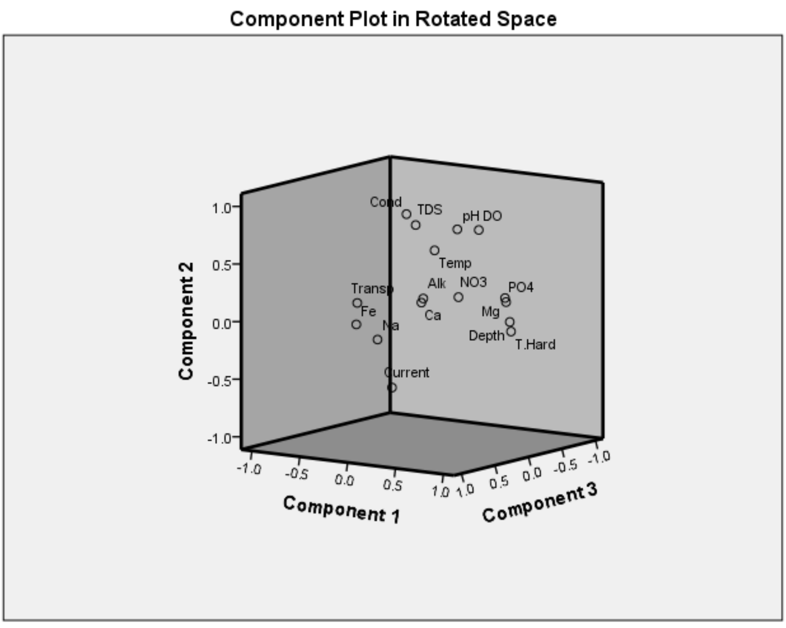

Figure 3. Component plot in rotated space of the physicochemical parameters

also obtained by Akindele *et al.* (2012). pH value which is a very significant indicator that determines the suitability of water for various purposes (Yogendra and Puttaiah, 2008; Venkatesharaju *et al.,* 2010) falls within the acceptable range of 6.5 - 8.5. Other observed parameters were below the WHO permissible limit but higher than the ideal values except dissolved oxygen (3.34 mg/L) that was lower than the ideal values. The higher the dissolved oxygen (DO) in water, the clearer the water (Ashwani and Anish, 2009). The mean value of DO in Oguta lake is lower than 5 mg/L (Table 6) which shows that the lake is not free from impurities. The low value of dissolved oxygen is probably due to discharge of industrial or domestic waste containing high concentration of organic matter and nutrients (Ahaneku and Animashaun, 2013).

The nutrient parameters are quite low but of high pollution potential. This can be due to anthropogenic inputs and other natural causes associated with Oguta lake. Manila and Tamuno-Adoki (2007) and Emovin *et al.,* (2006) recorded similar observations. The value obtained from the WQI of Oguta lake is greater than 300, which shows that the lake is unsuitable for human consumption (Bhaven *et al.,* 2011).

4. Conclusion

This study presents the usefulness of Principal Component Analyses in identifying the factors responsible for physicochemical variations in Oguta Lake. The result revealed that the percentages of the total variance of the 5 extracted components when added account for 88.72% of the total variance of the observed variables. A varimax rotation of these PCs revealed that water depth, conductivity, iron, calcium and nitrate-nitrogen were the most important variables contributing to water physicochemical properties of the lake. The variation in components 1 and 2 loadings indicates that organic matter, agricultural farming and geological formation could greatly influence the quality of the lake. Component 3 and 4 is mainly due to anthropogenic activities and sediment composition of the lake while component 5 could be attributed to human waste input into the lake. The result of the water quality index has given credence that Oguta lake has high loadings of organic matter which may have resulted from anthropogenic activities, agricultural farming etc. and must be treated before use to avoid water related diseases. To this end measures such as sewage disposal and open defecation on the banks of the lake should be avoided. This will reduce nutrients and organic loads into the water to contain an emerging eutrophication process of Oguta Lake.

Acknowledgement

Mr Johnson Clement of New Concepts Analytical Laboratory and Environmental Services LTD; Owerri, is acknowledged for his contributions during field and laboratory analysis.

Table 6. Calculation of water quality index of Oguta Lake

Parameter	WHO permissible limit (Sn)	Ideal values	Observed values	Quality rating (Qn)	1/Sn	Unit weight (Wn)	Wn.Qn
pH	6.5-8.5	7.0	6.69	-20.67	0.118	0.0085	-0.1757
TDS, mg/L	500	0	7.55	1.51	0.002	0.00014	0.00022
Conductivity, µS/cm	1000	0	10.58	1.058	0.001	0.00007	0.000076
DO, mg/L	5	14.6	3.34	117.29	0.2	0.0144	1.6889
Alkalinity mg/L	200	0	81.5	40.75	0.005	0.00036	0.01467
Total hardness, mg/L	150	0	25.19	16.79	0.0067	0.00048	0.00805
Calcium, mg/L	200	0	3.68	1.84	0.005	0.00036	0.00066
Magnesium, mg/L	0.1	0	3.66	3660.0	10	0.72	2635.2
NO_3-N mg/L	50	0	10.73	21.46	0.02	0.00144	0.0309
PO_4-P, mg/L	5.0	0	3.24	64.8	0.2	0.0144	0.933
Sodium, mg/L	200	0	1.09	0.545	0.005	0.00036	0.000196
Iron, mg/L	0.30	0	0.16	53.33	3.33	0.24	12.799
Total	2318.90			3958.70	13.893	1.00052	2650.499
K = 0.0719	**Water Quality Index** = 2649.12						

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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