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Water Quality Monitoring of a Tropical Lake and Associated Rivers: A Case Study of Oguta Lake and Its Tributaries, Niger Delta Basin, Southeastern Nigeria

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Abstract: Water quality monitoring of Oguta Lake and associated rivers (Utu, Awbana, Orashi and Njaba Rivers) over a one year period was conducted to ascertain the variability of the surface water bodies with respect to biochemical constituents. A total of 30 water samples collected from Oguta Lake and 24 water samples from the associated rivers were analyzed using the AAS (atomic absorption spectrophotometer), digital meters and membrane filters. Results of the analyses showed that the pH of Oguta Lake water varied from 5.1 to 6.5 with a mean value of 5.92, while the mean pH value of Rivers Utu, Awbana, Orashi and Njaba was 6.35, 6.30, 6.20 and 6.40, respectively. The DO (dissolved oxygen) values of Oguta Lake water ranged from 5.6 to 8.0 mg/L with a mean value of 7.01 mg/L, while the BOD (biochemical oxygen demand) ranged from 1.6 to 3.0 mg/L with a mean value of 2.95 mg/L. The mean values of DO for Rivers Utu, Awbana, Orashi and Njaba were 6.87, 7.20, 7.40 and 8.10 mg/L, respectively, and the mean BOD values were 0.75, 0.70, 0.66 and 1.33 mg/L, respectively. Mean *SAR* (sodium adsorption ratio) of the Oguta Lake was 0.58 while those of Rivers Utu, Awbana, Orashi and Njaba were 0.77, 0.81, 0.72 and 0.64, respectively. The relative abundance of major cations in the Oguta Lake water and its associated rivers followed the trend of $Na^+ > Ca^{2+} > K^+ > Mg^{2+}$ while the major anions followed the trend $HCO_3^- > SO_4^{2-} > Cl^- > NO_3^-$. Piper Trilinear Plots showed that the lake and associated rivers plotted on the potable water zone. The Piper Trilinear and Stiff Diagrams indicated strong positive chemical relationship between the lake and associated rivers. Except for low pH and high counts of microbial constituents in both the lake waters and the associated rivers, measured chemical parameters were in conformity with the WHO (World Health Organization, 2006) standard for safe drinking water. The Oguta Lake and associated rivers waters can be described as soft, fresh and suitable for domestic purposes (if treated for pH and bacteria). The lake and associated rivers are, however, excellent for irrigation purposes based on their *SAR* values.

Key words: Water quality, biochemistry, microbiology, safe, irrigation.

1. Introduction

Water is essential for economic, social, and environmental development. Global water resources are vulnerable to pollution due to increasing demands related to population growth, pollution potential and climate change. Competition for water between different sectors is increasing and in order to meet this trend, the use of proper water management strategies has been advocated worldwide.

Water quality assessment of the Oguta Lake and its associated rivers is in focus. Oguta Lake is the largest fresh water system in southeastern Nigeria [1]. The lake is linear in shape and is precisely located within latitudes 5°41′ and 5°44′ north and longitudes 6°45′ and 6°50′ east (Fig. 1). The surface areas of the lake during the dry and wet seasons are about 1.8 km^2 and 2.48 km^2, respectively, while the length of its shoreline is about 10 km. Maximum depth of the lake

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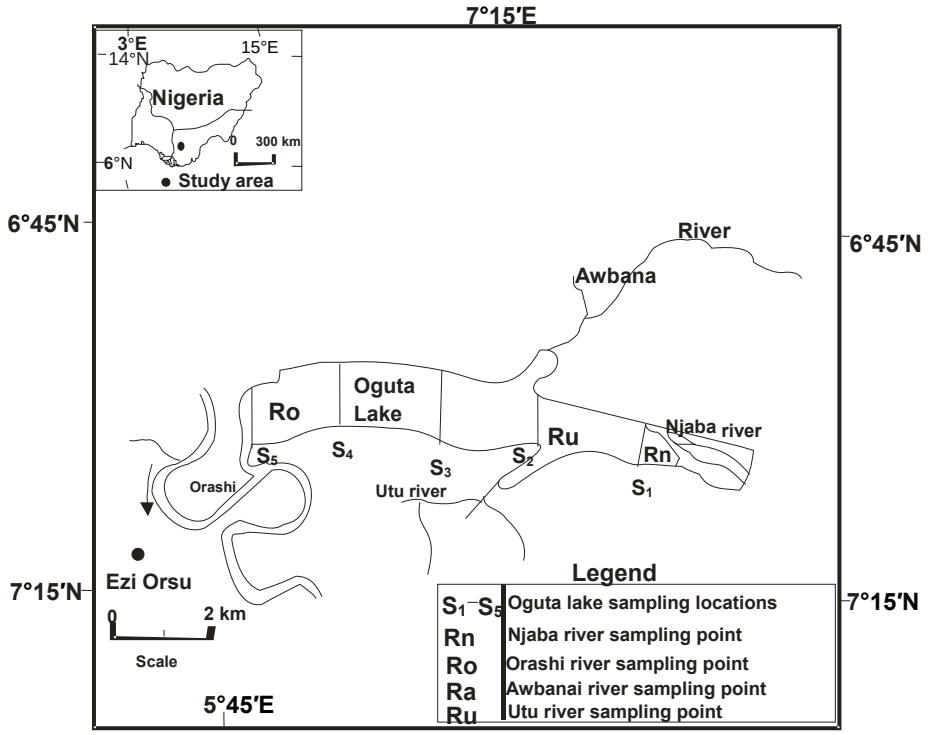

Fig. 1 Map of study area showing the sampling locations.

is about 8.0 m with a mean depth of about 5.5 m [1]. The lake is of strategic importance both to the local population and Imo State government. To the latter it constitutes a focal point for sporting activity, transport and tourism development. To the former, it serves as the major source of domestic water supply, fishing and other economic activities such as sand mining.

Environmental degradation and unethical human intervention in the natural systems (i.e., Oguta Lake and associated rivers) have increased the concern for the betterment of healthy living in and within the watershed of the water bodies. The deterioration of aquatic systems is commonplace in the developing world [2]. Surface water resources are more vulnerable to pollution than groundwater resources [3]. This trend is a combined result of inadequate and improper planning observed in many countries around the world, including Nigeria, which have led to indiscriminate actions including the dumping of wastes into rivers, streams, road sides, which through runoff can easily contaminate the surface water bodies. Also, the uncontrolled industrial resolution in Nigeria has created a lot of water pollution problems through discharge of potentially toxic substances and other harmful materials into water [4]. It is therefore obvious that human and even natural activities within and around Oguta Lake and the associated rivers have the potential to impact on the lake's biochemical characteristics and thus alter its resource status and usefulness. This concern becomes grave as the biochemical constituents of the Oguta Lake water would very likely reflect the degradation in and around the lake and the associated rivers that recharge it.

One important approach towards maintaining the resource status and usefulness of Oguta Lake is by developing and implementing appropriate pollution preventive and mitigation strategies. This can be achieved with proper management strategies, including constant water quality assessment and monitoring of the lake water and the associated rivers for proper pollution control and the sustainable development of Oguta Lake.

2. Climatic Conditions

Oguta Lake is located within the equatorial belt of Nigeria with mean monthly temperature in the range of 25 to 28.5 ^{o}C. Mean annual rainfall is about 2,500 mm, most of which fall between the months of May and October [5]. The lake is thermally stratified with the upper parts being relatively warmer during the dry season (due to increased solar radiation) than during the rainy season. The rainy period (May-October) is characterized by moderate temperature and high relative humidity. The months of November to April have scanty rainfall, higher temperatures and low relative humidity [6].

3. Geology and Hydrology

The study area is underlain by the Benin Formation which is the major stratigraphic unit in the Niger Delta Basin (Fig. 2). The Benin Formation (Pliocene to Miocene in age) consists of friable sands with intercalations of shale/clay lenses. The formation also contains some isolated units of gravels, conglomerates, very coarse sands [7]. The study of the geology of Oguta area using road cuttings and exposures from hills identified superficial deposits like ferruginized sands, occasionally massively bedded and pebbly [6].

Oguta Lake is fed by Rivers Njaba and Awbana; the third (River Utu) flows into the lake during the rainy season. A fourth associated River, Orashi flows past the lake at its southwestern end (Fig. 1). Orashi River is a major river of the lower Niger Basin. Apart from the rivers that feed the lake, there is also input from precipitation during the rainy season.

4. Materials and Methods

Surface water samples were obtained at five stations (S_1 to S_5) located at equal distances of 2 km along the stretch of the lake (Fig. 1). Water samples were also obtained from the rivers associated with Oguta Lake.

The sampling points (of the associated rivers) were located 10 m from the contact point of each of the rivers with the lake. The sampling points were labeled Ra, Rn, Ro and Ru, representing samples from Rivers Awbana, Njaba, Orashi and Utu, respectively (Fig. 1). Sampling was carried out over a period of one year on a bi-monthly basis commencing from January, 2006 and ending in November, 2006.

A total of 30 surface water samples of the lake and 24 water samples of the associated rivers were obtained during the sampling period. Three 2.5-litre sample bottles were used to collect the water samples

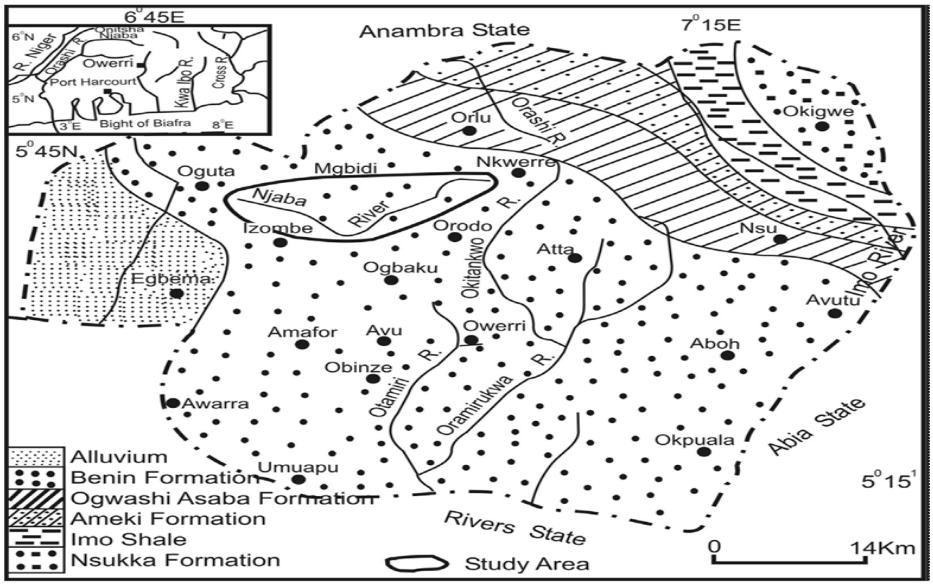

Fig. 2 Geologic map of Imo State showing the study area.

at each location using the grab method. The sample bottles were corked under water in order to prevent oxidation of the constituents. One of the three sample bottles was tested for pH, temperature, electrical conductivity and dissolved oxygen using digital meters. The second sample bottle was sent to the laboratory for analysis of heavy metals, major cations and anions using AAS (atomic absorption spectrophotometer) and microbial analysis using standard plate.

The third water sample obtained for the determination of DO (dissolved oxygen) and consequently, the BOD (biochemical oxygen demand) was treated in quick successions with 1 mL potassium fluoride and 2 mL manganese sulphate solutions, and thereafter, properly mixed and corked. The bottle was later sent to the laboratory within 24 hours of collection for analysis. The BOD was measured by diluting the sample and incubating it in the dark at 20 ^{o}C and the amount of oxygen that has been consumed by the sample was measured.

The concentrations of major cations and anions (of Oguta Lake and associated river waters) in milliequivalent/litre were used to construct Piper Trilinear and Stiff Diagrams. The concentrations of Na^{+}, Ca^{2+} and Mg^{2+} in milliequivalent/litre were used to determine the *SAR* (sodium adsorption ratio) value using Eq. (1) [8].

$$SAR = Na^{+}/(Ca^{2+} + Mg^{2+})^{0.5} \quad (1)$$

5. Results and Discussion

The results of field measurements (pH, temperature, electrical conductivity and dissolved oxygen) as well as laboratory analysis of both the lake and its associated rivers are shown in Tables 1 and 2, respectively. The conversion of values of the major cations and anions of the lake and associated rivers waters from milligram/litre (mg/L) to milliequivalent/litre (meq/L) is shown in Table 3.

Table 1 Result of geochemical and microbial analysis of Oguta Lake.

Parameters	Range	Mean	WHO (2006)
pH@ 25 ^{o}C	5.1-6.5	5.92	6.5-9.0
Temperature (^{o}C)	25.5-28.0	26.83	> 40
Electrical conductivity (μS/cm)	10.5-40	19.95	1,400
Turbidity (NTU)	10-40	21.77	
TDS (mg/L)	8.35-19.6	17.02	1,500
Total hardness (mg/L)	8.1-20	11.59	> 150
Total alkalinity (mg/L)	9-40	22.10	
BOD (mg/L)	1.5-3.0	2.95	
DO (mg/L)	5.6-8.0	7.01	
Total iron (mg/L)	0.06	0.02	0.03-1.0
Ca^{2+} (mg/L)	1.8-4.0	2.91	200
Mg^{2+} (mg/L)	0.60-2.0	1.12	150
Na^{+} (mg/L)	3.0-6.8	4.6	500
K^{+} (mg/L)	0.80-2.60	1.62	50
HCO_3^{-} (mg/L)	17.80-26.51	17.90	500
SO_4^{2-} (mg/L)	2.30-4.80	3.52	400
Cl^{-} (mg/L)	0.60-1.40	1.0	500
NO_3^{-}(mg/L)	0.9-2.2	1.40	40-70
PO_4^{3-} (mg/L)	0.01-0.35	0.12	10
Pb^{2+} (mg/L)	Nd	-	0.05
Zn^{2+} (mg/L)	Nd	-	5.0
Cu^{2+} (mg/L)	Nd	-	1.0
Cr^{3+} (mg/L)	Nd	-	0.05
Mn^{2+} (mg/L)	0.02	0.02	0.1-0.02
CO_3^{2-} (mg/L)	1.30-3.80	2.16	
T. coliform (cfu/100mL)	193-308.8	196.4	10 cfu/100 mL

Nd = not detected.

Table 2 Geochemical and microbial analysis of rivers associated with Oguta Lake.

Parameters	Utu	Awbana	Orashi	Njaba	WHO (2006)
pH@ 25 ^{o}C	6.35	6.30	6.20	6.40	6.50-9.0
Temperature (^{o}C)	27.10	26.30	26.00	26.70	> 40
Turbidity (NTU)	27.10	26.30	50.30	36.50	
Electrical conductivity (μS/cm)	27.10	20.50	30.20	22.40	1,400
TDS (mg/L)	16.30	14.30	16.80	15.70	1,500
Total hardness (mg/L)	8.40	8.20	12.70	11.30	< 150
Total alkalinity (mg/L)	8.60	6.60	8.30	7.90	
BOD (mg/L)	0.75	0.70	0.66	1.30	
DO (mg/L)	6.87	7.20	7.40	8.10	
Total iron (mg/L)	0.03	0.05	0.03	0.02	0.03-1.00
Ca^{2+} (mg/L)	3.02	2.70	4.20	4.20	200
Mg^{2+} (mg/L)	0.25	0.38	0.44	0.20	150
Na^{+} (mg/L)	5.18	5.30	5.00	4.90	500
K^{+} (mg/L)	1.50	1.27	1.50	1.20	50
HCO_3^{-} (mg/L)	17.90	17.30	19.80	17.70	500
SO_4^{2-} (mg/L)	3.40	3.18	4.60	3.90	400
Cl^{-} (mg/L)	1.00	1.08	1.20	1.10	500
NO_3^{-} (mg/L)	0.22	0.12	0.15	0.26	40-70
PO_4^{3-} (mg/L)	0.07	0.05	0.06	0.09	10
Pb^{2+} (mg/L)	Nd	Nd	Nd	Nd	0.05
Zn^{2+} (mg/L)	0.02	0.02	0.01	0.03	5.0
Cu^{2+} (mg/L)	Nd	Nd	Nd	Nd	1.00
Mn^{+} (mg/L)	Nd	Nd	Nd	Nd	0.20
Cr^{3+} (mg/L)	Nd	Nd	Nd	Nd	0.05
CO_3^{2-} (mg/L)	2.60	2.10	2.20	2.30	
Total coliform (cfu/10 mL)	120	100	80	132	10

Nd = not detected.

Table 3 Mean concentrations of major cations and anions of Oguta Lake and associated rivers in milliequivalent/litre (meq/L).

Parameters	Concentration (meq/L)					Percentage of concentration				
	Oguta	Utu	Awbana	Orashi	Njaba	Oguta	Utu	Awbana	Orashi	Njaba
Ca^{2+}	0.146	0.151	0.133	0.210	0.208	30.50	34.4	31.5	39.1	44.6
Mg^{2+}	0.029	0.020	0.031	0.036	0.013	19.2	4.5	7.2	6.7	2.8
Na^{+}	0.200	0.225	0.232	0.253	0.214	41.8	51.3	54.1	47.1	45.9
K^{+}	0.041	0.038	0.033	0.038	0.031	8.5	8.7	7.7	7.1	6.7
Total	0.396	0.439	0.429	0.537	0.466	100	100	100	100	100
HCO_3^{-}	0.293	0.293	0.284	0.316	0.273	59.7	60.2	63.3	60.7	58.5
CO_3^{2-}	0.072	0.089	0.069	0.074	0.076	4.7	18.3	15.4	14.2	16.3
SO_4^{2-}	0.071	0.070	0.066	0.095	0.082	14.5	14.6	14.7	18.2	17.6
NO_3^{-}	0.024	0.004	0.002	0.002	0.003	4.9	0.8	0.4	0.4	1.1
Cl^{-}	0.031	0.028	0.030	0.034	0.030	6.5	15.7	6.7	6.5	6.4
Total	0.421	0.487	0.449	0.521	0.467	100	100	100	100	100

5.1 Physical Parameters

The pH of Oguta Lake water varies from 5.1 to 6.5 with a mean of 5.92, while the mean pH of Rivers Utu, Awbana, Orashi and Njaba are 6.35, 6.30, 6.20 and 6.40, respectively. The pH values of the lake and associated rivers are not in conformity with the standard for safe drinking water [9], and thus constitute a threat to both human beings and animals. However, the pH of the lake and associated rivers can be raised using sodium bicarbonate. The low pH is a direct function of incessant acid rains prevalent in the area that arise from gas flaring activities in the area.

The mean temperature, electrical conductivity, TDS (total dissolved solids) and turbidity values of the lake and associated rivers fall within the standard for safe drinking water [9]. Water with TDS value between 0 and 1,500 mg/L (as is the case with the Oguta Lake and the associated rivers) is classified as fresh [10]. Maximum temperatures have been recommended for various fish species and biota [11]. Based on this classification, water with maximum temperature of 26.7 ^{o}C (as is the case with the Oguta Lake and its associated rivers) is favourable for spawning.

The mean total hardness value of the lake and associated rivers also conformed to the standard for safe drinking water [9]. The values for the lake and associated rivers are below 150 mg/L (Tables 1 and 2). Water with total hardness of less than 150 mg/L has also been classified as soft [12].

5.2 DO and BOD

The DO in the Oguta Lake water varies from 5.6 to 8.0 mg/L with a mean value of 7.01 mg/L. It has been shown that surface waters with DO of 6.2 and 7.8 mg/L fall within acceptable and excellent levels respectively, [13]. The values of DO therefore imply that the Oguta Lake water is well oxygenated throughout the year. The mean DO values of the Utu, Awbana, Orashi and Njaba Rivers are 6.7, 7.20, 7.40 and 8.10 mg/L, respectively. These values are similar to that recorded for the lake. The oxygen level of Oguta Lake water and associated is quite favourable for survival of aquatic life.

BOD (bio-chemical oxygen demand) of Oguta Lake water varies from 1.6 to 3.0 mg/L with a mean value of 2.95 mg/L. The mean BOD values of Utu, Awbana, Orashi and Njaba Rivers are 0.75, 0.70, 0.66 and 1.30 mg/L, respectively. The quality of surface water with BOD values of 1.5 and 3.0 mg/L are classified as excellent and acceptable waters respectively. And, the quality of surface water with BOD values of 6.0 and 3.0 mg/L are classified as slightly polluted and polluted respectively [13]. Although the BOD values of both the lake and associated rivers indicate organic input into them, they are not yet polluted with respect to the established standard [13]. It is also important to note that the mean BOD value of the lake indicates higher organic contents compared to the organic input in the associated rivers. Continuous loading of organic constituents into the lake in an uncontrolled manner can result in its pollution. There is therefore need to ensure effective pollution preventive and mitigation strategy for the lake ecosystem.

5.3 Major Cations and Anions

The concentration of the major cations and anions of Oguta Lake and associated rivers (Tables 1 and 2) conform to the standard for safe drinking water [9]. The mean values of Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} (of the 30 water samples obtained from Oguta lake) are 2.91, 1.12, 4.60 and 1.62 mg/L respectively, while the mean HCO_3^{-}, SO_4^{2-}, Cl^{-}, NO_3^{-} and PO_4^{3-} values (of the 24 water samples obtained from the associated Rivers) are 17.90, 3.52, 1.50, 1.40 and 0.12 mg/L, respectively.

The concentrations of major cations and anions of Oguta Lake and associated Rivers are generally low (Tables 1 and 2), which is typical of most tropical lakes [14]. This resulted to low nutrient levels of the lake and associated rivers implying very low

eutrophication. The condition is a reflection of the low concentration of dissolved silica, nitrates and phosphates. The relative abundance of major cations of the lake and rivers followed the trend $Na^+ > Ca^{2+} > K^+ > Mg^{2+}$ while the major anions followed the trend $HCO_3^- > SO_4^{2-} > Cl^- > NO_3^-$. This trend is characteristic and typical of most surface water resources of southeastern Nigeria [6].

5.4 Heavy Metals

The rivers and the lake waters are similar in terms of heavy metal concentrations (Tables 1 and 2). The average concentration of heavy metals in the surface water bodies conformed to the standard for safe drinking water [9]. The concentrations of heavy metals in water in excess of that recommended can cause various health problems. For instance, high concentrations of Pb^{2+} in water cause cancer and also interfere with vitamin D development in infants; it is also toxic to the central peripheral nervous system. High levels of Cd^{2+} cause kidney failure while high concentrations of Cr^{3+} and Cu^{2+} cause cancer and gastrointestinal disorder respectively. There is therefore need to monitor the concentrations of heavy metals in water on regular basis.

5.5 Microbial Constituents

The total coli form counts of the Oguta Lake water varies from 193 to 308.8 cfu/100 mL with a mean of 196.40 cfu/100mL, while that for the associated rivers varies from 80 to 132 cfu/100mL. These values do not conform to the standard for safe drinking [9]. The high levels of microbial constituents of both the lake and associated rivers are typical of most surface water resources in the area as the resources also serve as outlets for sewage.

The microbial constituents of the lake and associated rivers can be improved by relevant treatments. It is imperative to note that high levels of microbial constituents of water cause diseases of bacterial origin such as dysentery, gastroenteritis, typhoid and cholera.

5.6 SAR (Sodium Adsorption Ratio)

The computed *SAR* values using Eq. (1) indicate that Oguta Lake has a mean *SAR* value of 0.58 while those of Utu, Awbana, Orashi and Njaba Rivers are 0.77, 0.81, 0.72 and 0.64, respectively. Water with *SAR* values that range between 0 and 10 is excellent for irrigation purposes, while those with values more than 26 are considered poor [8]. Hence, the Oguta Lake and associated river waters are excellent for irrigation purposes.

5.7 Water Characterization

Piper Trilinear diagram (Fig. 3) of both the lake and associated rivers shows very close relationships in chemical characteristics. The sources plotted within the potable zone of the diamond portion of the Piper diagram. A further confirmation of the close relationship in the chemical characteristics of the lake and associated rivers is shown in the Stiff Diagram (Fig. 4). The shapes of the Stiff Diagrams of the lake and associated rivers are similar though with slight variations in their sizes showing slight variations in concentration levels (Fig. 4).

The relative abundance of the major cations and anions (of the lake and rivers) indicated that water type is sodium bicarbonate water ($NaHCO_3$-Water).

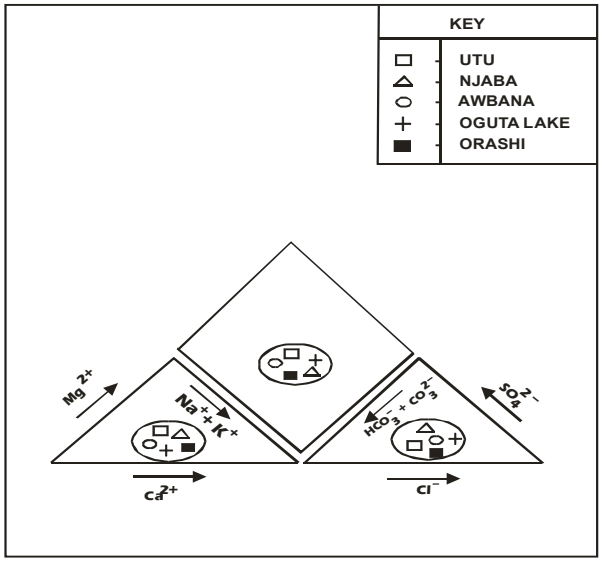

Fig. 3 Piper trilinear of Oguta Lake and associated rivers.

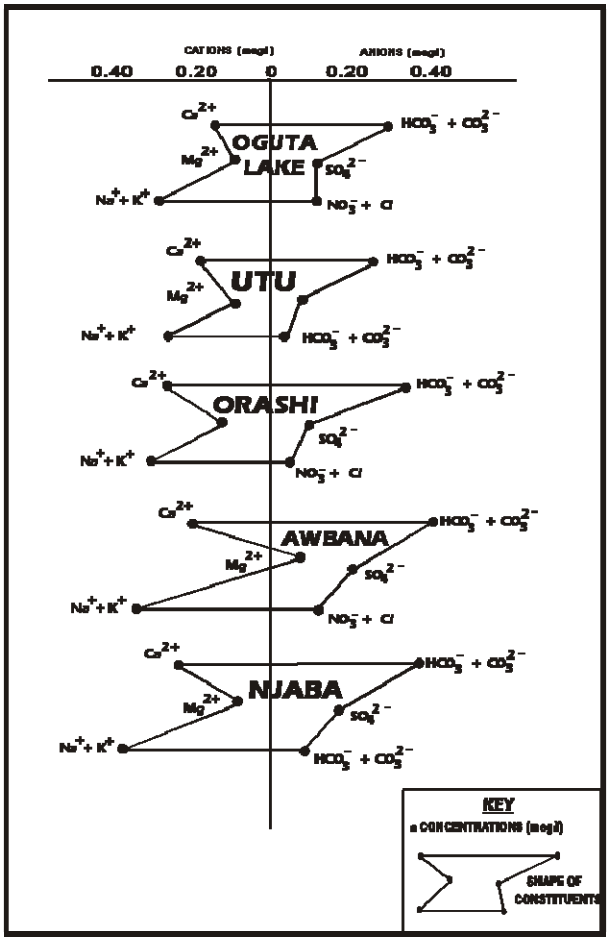

Fig. 4 Stiff diagram showing Oguta Lake and associated rivers.

The geochemical regime is therefore characterized by Type I waters, which are slightly acidic and very fresh waters (total dissolved solids content less than 100 Mg/L), in which HCO_3^- is the dominant anion while Na and Ca are the predominating cation [15].

Even though the lake and associated river waters plotted in the potable water zone of the Piper Diagram, low pH and high microbial constituents imply that the waters must be treated in order to make the water potable for human consumption.

The overall water quality of the surface water bodies, however, is suitable for irrigation purposes. On the basis of heavy metal contents, the surface water sources have excellent quality.

6. Conclusions

The geochemical characteristics of Oguta Lake and associated rivers (Utu, Awbana, Orashi and Njaba) conformed to the standard for safe drinking water [9].

The hydrogen index (pH) of the lake and associated rivers is slightly low (acidic) attributed to gas flaring activities in the region, while high microbial constituents in the waters have been linked to poor waste disposal practices.

The lake and associated river waters are however excellent for irrigation purposes. Water characterization showed that the Oguta Lake and associated waters are Type I waters, which are slightly acidic, very fresh waters (total dissolved solids content less than 100 mg/L), in which HCO_3^- is the dominant anion and Na and Ca are the predominating cations.

The Oguta Lake and associated rivers can be described as soft, fresh and without laxative effects.

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