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Hydrochemistry of Lakes in Opi Agu, Enugu State, Southeastern Nigeria

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ABSTRACT

A total of nine lakes and three rivers situated in Opi Agu of southeastern Nigeria was studied. The study area is underlain by (from the oldest), Nkporo Shales, Mamu and Ajali Formations. Two of the lakes were formed in the lower stretches of Ajali Formation while six of them were formed within the Mamu Formation. Only one lake was formed within the Nkporo Formation. The lakes originated as a result of fluvial processes and tectonism associated with the formation of the Nsukka – Okigwe Cuesta. The nine lakes were examined for their hydrogeologic settings,, limnology and hydrochemistry. Three types were identified on the basis of their groundwater – surface interaction and these were seepage, groundwater – drainage and drainage lakes. Limnological evaluation showed that two lakes and two rivers are trending towards eutrophication. Chemical analyses of the lake waters revealed that they have very low solute concentrations possibly due to small residence time of the precipitation in the lakes and their pH ranges from 5.6 to 6.8. Sodium (Na^+) and potassium (K^+) make up over 90% of the cations while chloride and bicarbonate dominate the anion levels. Hydrochemically the lake waters are of the Na^+ - Cl^- type. Some of the lakes have excess concentrations of total phosphorous and nitrate-nitrogen. Three trophic classes were identified on the basis of total phosphorous concentration. The excess nitrate – nitrogen levels are due to leaching from adjacent farmlands. The overall Na^+ - Cl^- composition of the lake waters are due to soil leaching, mixing and evaporation effects.

Key words: *Lakes; Total Phosphorous; Eutrophication; Groundwater-Surface Interactions; Leaching.*

1. INTRODUCTION

Lakes contain less than 2% of the entire planetary volume of water but they provide more than 50% of its freshwater. They are bodies of standing or very slowly moving water which develop in flood plains as part of a river system or as a result of isolated depressions in the earth's crust being filled with precipitation over long periods of time. Many lakes are associated with glaciation processes but this is not the case in tropical areas like Nigeria.

Interest in the study of lakes may vary from their physical to biological and from biochemical to chemical and environmental aspects. Hutchinson (1957) recognized 11 key genetic processes that produce 76 different lake types. These distinct processes produce basinal depressions in the earth's surface that make accumulation of lake water possible.

The biology of lakes have been studied extensively in order to establish their biodiversity and ecological relationships. Brónmark and Hansson (2005) outlined the biological processes common to lakes in Europe and other parts of the world. Shaw et al., (2004) produced guidelines that could help in making use of the data of lake water chemistry. The problem of eutrophication in lakes has also received a lot of attention in the works of Lillie and Mason (1983); Smith et al., (1999) and Shaw et al (2004).

Lakes are very important to the tourism and recreation industries of any nation because they provide a platform for nature viewing and relaxation for people.

Furthermore, because lakes are relevant to soil formation processes, biodiversity, groundwater replenishment and flood control it is necessary for them to be studied wherever they may be found.

The nine lakes which form the bulk of this study occur largely in the Opi Agu area which is located about 20km east of Nsukka. It is a rural community with a population of over 5,000 people. Their primary means of livelihood are farming and sand mining. Though the lakes in the area all contain fishes, the people do not fish in them because the lakes and fishes in them are considered sacred. A few of the lakes also have crocodiles. Opi Agu has been cut off developmentally before now due to lack of access roads and this may partly be responsible for the fact that no attempt has ever been made to study the lakes or develop them.

History was made recently when the state government built an access road leading from Nsukka – through Opi Uno and Opi Agu to Enugu. This access road has helped to bring Opi Agu to public attention, hence this study. It is hoped that with the opening up of the area, these beautiful lakes will now receive attention.

Some previous works on Nsukka include Ofomata (1978) who recognized four physiographic zones in Nsukka while Nwachukwu (1978) identified two hydrogeologic provinces in the area. Ezeigbo and Ozoko (1989) carried out an evaluation of the water resources of Nsukka. This however is the first attempt at assessing the occurrence of these lakes in Opi Agu and the primary objective here is its hydrochemistry.

This will be relevant to anyone planning the development of these water bodies in the future.

GEOLOGY AND GEOMORPHOLOGY

Opi-Agu is situated between latitudes 6^0 42^I and 6^0 47^I N and longitudes 7^0 28^I and 7^0 33^IE in Enugu State, Southeastern Nigeria. Ofomata (1978) divided Nsukka into four physiographic zones namely, the Anambra Plains, Nsukka Plateau, the Escarpment and the Cross River Plains. Opi-Agu belongs to the escarpment zone of the area (figure 1). Since these physiographic zones have different levels of groundwater/surface occurrences, they should also be considered as hydrogeologic zones.

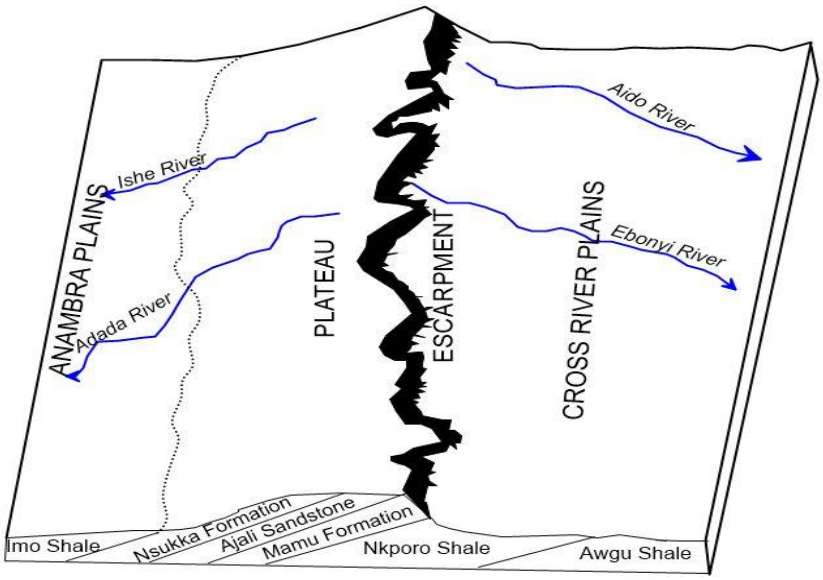


Figure 1: The four physiographic provinces of Nsukka (Anambra Plains, Nsukka Plateau, Escarpment and Cross River Plains). (after ofomata, 1978.)

The topography slopes towards the east and the west but the rock formations all dip west north-west at 3^0 – 5^0. All the surface waters at the foot of the escarpment flow eastwards but the underlying rocks dip west (figure 2).

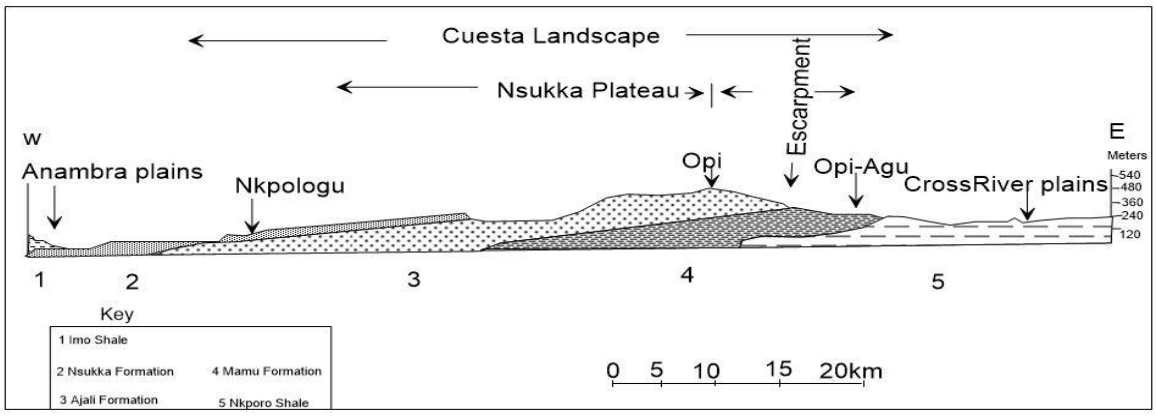


Figure 2: E-W Section through Nsukka (Note that eastwards though there rocks dip west, the topography slopes towards the east), (after Ofomata, 1978).

The geology of the study area is given in figure 3. Three formations underlie the area (from the oldest), Nkporo Shale Formation, Mamu Formation and Ajali Sandstone Formation. Together in the area, they form over1000m of dark grey shales, clay, siltstones, sandy shales, ironstones and friable sandstones. Nkporo Shales consist of black or grey, fissile and sometimes friable shales with occasional siltstones and sandy shales. Nkporo Shale Formation is Campanian to Lower Maastritchian in age and contains sulphur coatings in some places (Nwajide, 2013). Only one lake, Lake Ojii was formed within the Nkporo Shale Formation.

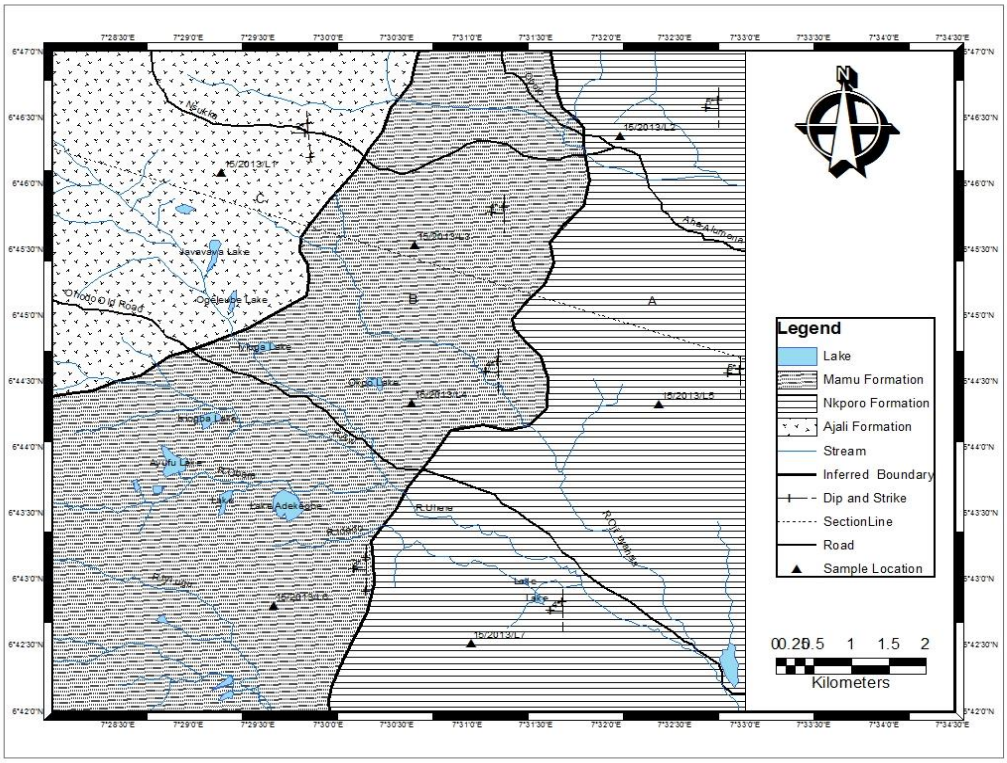


Figure 3: The geologic map of the study area.

The Nkporo Shales are overlain conformably by Mamu Formation. Nwachukwu (1978), Ofomata, (1978), and Umeji (1980) have shown that Mamu Formation is a narrow strip of rocks coinciding with the Nsukka-Okigwe cuesta. In other words, the escarpment is underlain by Mamu Formation. In the study area, it dips from $3^0 – 5^0$ to the west and consists of black shales, silty shales and fine grained sandstones. No coal seams were observed in the area though Mamu Formation in many places characteristically contains them. Most of the lakes in the study area were formed on the Mamu Formation. The lakes found within the Mamu Formation include: Orufu, Isiogba, Iyi-ikpa, Okpo, Iyi – Uga and Adekwegbe.

The Mamu Formation is conformably overlain by Ajali Sandstone Formation. Ajali Formation covers the northwestern portion of the map. It consists of friable, medium to coarse grained sandstone with subordinate sandy clays. The lakes found within the Ajali Formation are: Varavara and Ogeleube.

According to Umeji (1980), the origin of the Nsukka part of the Nsukka – Okigwe is due to tectonism. The inference here is that these lakes were probably formed as a result of tectonism and fluvial processes.

Physical characteristics of the lakes are given in table 1. The largest lake, Lake Ojii has an areal extent of 11.2 sq.km. The smallest is Lake Varavara which has 1 sq.km. The deepest lake is Lake Adekwegbe (12m) while the shallowest is 3m (Lake Isiogba). All the depths are within the zone of light penetration hence there should be plenty of photosynthetic activity going on but several of the lakes are full of decaying organic matter which reduces penetration levels. Lake Iyi-Ikpa occurs at 263m above sea level (the highest point) while the lowest point is Lake Ojii (191m above sea level).

Table 1:Physical Characteristics of the Lakes at Opi-Agu

S/n	Lake	Meters above sea level	Length (m)	Width (m)	Depth (m)	Areal Extent (m^2)	GPS location
1	Ojii	191	160	70.0	7.5	11,200	6^0 42' 10.7''N 7^0 32' 52.9''E
2	Orufu	249	120	70.8	7.0	8496	6^0 44' 5.6''N 7^0 28' 54.3''E
3	Adekwegbe	249	90	60.0	12.0	5400	6^0 43' 45.4''N 7^0 29' 20.1''E
4	Isiogba	248	101.5	30.0	3.0	3045	6^0 44' 13.3''N 7^0 29'25.2'' E
5	Okpo	221	45	30.0	6.0	1350	6^0 44' 35.5''N 7^0 29' 49.9''E
6	Iyi-Uga	237	60	45.0	6.0	2700	6^0 44' 54.4''N 7^0 29'36.1'' E
7	Iyi-Ikpa	263	40	30.7	5.4	1228	6^0 45' 44.5''N 7^0 29' 08.8''E
8	Ogeleube	246	60	25.0	4.0	1500	6^0 45' 16.2''N 7^0 29' 26.9''E
9	Varavara	263	40	25.0	3.0	1000	6^0 45' 33.4''N 7^0 29' 05.4''E

GROUNDWATER – SURFACE WATER INTERACTIONS AND LAKE TYPES

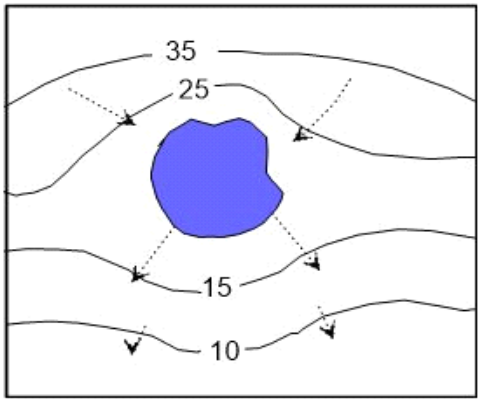
Fetter (2001) attempted to classify lakes on the basis of groundwater – surface interactions. On the basis of this criterion, he identified two basic types of lakes – seepage lakes and surface – water controlled lakes but there could be variations of the two types. Seepage lakes are those controlled mainly by groundwater movements while surface – water lakes are controlled by surface – water inflows into or outflows from the lake. Shaw et al., (2004) using the same criteria of groundwater – surface water interaction, identified four types of lakes, namely: Seepage, Drainage, Groundwater – Drainage and Impoundment types. Table 2 shows, the types of lakes in the area based on the field examination of the groundwater – surface water interactions in the area and Shaw's work.

Broadly speaking, there are three types of lakes in the area. Type 1 lakes are seepage lakes. They have no visible input or output from surface water. Type 2 lakes are groundwater drainage lakes. They receive input from both groundwater and springs. They also discharge into surface water. Type 3 lakes are those that receive water mainly from surface water and also discharge into surface water.

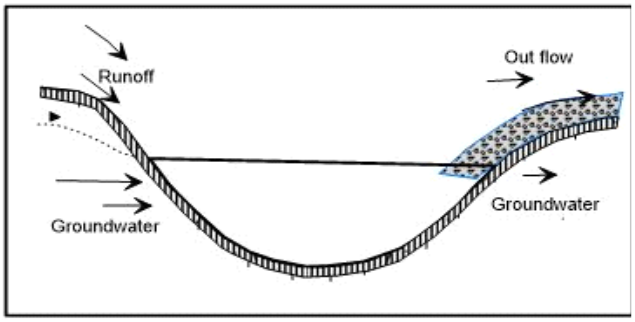
Table 2: A Classification of Opi-Agu Lakes on the Basis of Groundwater/Surface water Interactions.

s/n	Lake	Underlying Geologic Formations	How it receives recharge	How it is discharged	Type of Lake
1	Ojii	Nporo Shale Formation	Seepage by groundwater	Seepage by groundwater	Type 1
2	Orufu	Mamu Formation	Seepage by groundwater	Seepage by groundwater	Type 1
3	Adekwegbe	Mamu Formation	Seepage by groundwater	Seepage by groundwater	Type 1
4	Isiogba	Mamu Formation	Seepage by groundwater	Surface water (River Api)	Type 2
5	Okpo	Mamu Formation	Seepage by groundwater	surface water (River Uhere)	Type 2
6	Iyi – Uga	Mamu Formation	Seepage by groundwater	Surface water (river Uhere)	Type 2
7	Iyi – Ikpa	Mamu Formation	Seepage by groundwater	Surface water (River Uhere)	Type 2
8	Ogleube	Ajali Formation	Seepage by groundwater	Surface water (River Uhere)	Type 2
9	Varavara	Ajali Formation	Surface water (Springs)	Surface water (River Uhere)	Type 3

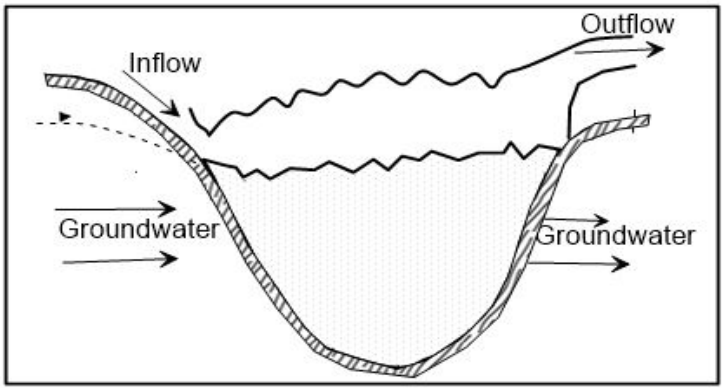
Figure 4 depicts schematically, the groundwater - lake or surface water – lake interactions in the area. They show how the groundwater/surface waters interact with the various lakes.



Type 1: seepage lakes (ojii, Orufu and Adekwegbe) they have no stream outlet.



Type 2: Groundwater Drainage Lake (lakes Isiogba, Okpo Iyi-Uga, Iyi-Ikpa and Ogeleube) they have stream outlet



Type 3: Drainage Lakes (e.g. Lake Varavara)

Figure 4: Different lake types and how they interact with groundwater/surface water

2. MATERIALS AND METHODS OF HYDROCHEMISTRY

Samples were collected from the 9 (nine) lakes and three rivers. They were collected using 1 liter plastic bottles. The bottles were gently lowered into the lakes in such a way to avoid accidentally collecting sediments along with the water. In all the sites, electrical conductivity (EC), pH and temperature were measured at mid – depth with a multi-parameter water quality meter (Hanna instruments). Each bottle was flushed with the water to be sampled several times and tightly closed leaving a small air bubble.

The cations were then analyzed in the laboratory with Atomic Absorption Spectrophotometer while the anions were analyzed using the methods prescribed by American Public Health Association (Clesceri et al., 1996).

3. RESULTS AND DISCUSSION

Results from the chemical analysis of major ions are presented in table 3. Generally, all the lakes have very low solute concentrations as indicated by their TDS values. The highest value for total dissolved solids is 26.4mg/l (Lake Orufu) which is very low indeed. The lowest value is 9.6mg/l at Iyi- Uga and Ogeleube.

The pH range for the lakes and rivers is 5.6 to 6.9 which indicates mildly acidic to almost neutral. The pH of the waters influences the kind of fish that could live in them. Olyswic (1980) have demonstrated that certain fish species cannot survive in low pH levels but the pH range of the lakes and rivers permit good number of fish species to thrive.

Alkalinity values from 12.5mg/l at lakes Ojii, Orufu Adekwegbe, Iyi-Uga, Ogeleube to 75mg/l at Lake Isiogba. These alkalinity values influence the pH of the lake waters. Since the alkalinity values are low, the waters are mildly acidic. Most of the alkalinity is in the HCO_3^- (bicarbonate form). This means that the waters are not well buffered.

The CO_2 levels in the lakes range from 4.34mg/l at Adekwegbe to 177.60mg/l at Lake Isiogba. These levels are influenced by such activities as photosynthesis, respiration, contact with air and reactions involving carbonate minerals. Studies have shown that CO_2 fluctuations are highest in night times and lowest in the mornings (Shaw et al., 1980). These fluctuations affect pH and alkalinity levels and invariably the productivity of the lake.

Table 3: Physico-Chemistry and Hydrochemistry of Opi-Agu Lakes

S/n	Lakes & River	pH	Temp ^0C	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	K+ mg/l	Na+ mg/l	Fe^{Total} mg/l	PO_4^- mg/l	Total Phosphorous. µg/l	Cl^- mg/l	HCO_3^- mg/l	SO_4^{2-} mg/l	NO_3^- mg/l	NO_3-N mg/l	CO_2^- mg/l	Alkal-inity mg/l
1	Ojii	5.6	26^0c	019	15.2	0.11	0.11	0.80	4.12	1.42	0.020	6.524	90.00	15.25	24.14	25.43	5.745	46.02	12.50
2	Orufu	6.4	29^0c	033	26.4	0.10	0.11	0.70	4.03	0.00	0.282	91.988	108.00	15.25	49.55	36.64	8.277	6.89	12.50
3	Adekwegbe	6.6	29^0c	029	23.2	1.32	0.22	1.40	30.62	0.21	0.107	34.903	90.00	15.25	41.41	12.07	2.727	4.34	12.50
4	Isiogba	5.8	25^0c	029	23.2	0.09	0.04	0.30	3.07	0.00	0.015	4.893	126.00	91.50	11.41	23.71	5.356	177.60	75.00
5	Okpo	6.0	29^0c	030	24.0	0.21	0.13	0.72	5.07	0.23	0.042	13.700	90.00	30.50	12.05	4.74	1.071	34.65	25.00
6	Iyiuga	6.0	29^0c	012	9.6	0.33	0.15	0.80	8.03	0.00	0.020	6.524	108.00	15.25	0.83	23.47	5.302	17.32	12.50
7	Iyi-ikpa	6.2	28^0c	012	9.6	0.20	0.07	0.23	3.42	0.22	0.028	9.134	126.00	30.50	46.81	80.17	18.111	22.25	25.00
8	Ogeleube	6.5	31^0c	013	10.4	0.10	0.17	0.52	2.12	0.83	0.037	12.069	108.00	15.25	7.20	3.88	0.877	5.28	12.50
9	Varavara	5.9	30^0c	016	12.8	0.10	0.11	0.43	1.00	0.16	0.026	8.481	90.00	30.50	23.39	23.71	5.356	42.85	25.00
10	R. Uhere	6.9	25^0c	009	26.4	0.08	0.13	0.62	2.21	1.93	1.93	629.566	90.00	45.75	30.62	78.02	17.625	7.06	37.50
11	Api	6.6	29^0c	012	11.2	0.11	0.08	0.36	3.04	0.22	0.143	46.647	108.00	30.50	33.52	34.05	7.692	8.69	25.00
12	R.Ojiiuyahala	6.3	25^0c	010	6.60	0.30	0.10	0.70	8.03	1.40	0.023	7.503	90.00	30.50	52.30	8.62	1.947	18.71	25.00

Calcium, (Ca^{2+}) varies from 0.10 mg/l at lakes Orufu, Ogeleube and Varavara to 1.32mg/l at Adekwegbe while magnesium (Mg^{2+}) ranges from 0.07mg/l at Iyi-Ikpa to 0.22mg/l at Adekwegbe. Potassium (K^+) ranges from 0.23mg/l at Iyi-Akpo to 1.40mg/l at Adekwegbe.

The dominant cation is sodium (Na^+) which ranges from 1.00mg/l at Varavara to 30.62mg/l at Adekwegbe. Total iron (Fe^{total}) ranges 0.00mg/l at Lake Orufu to 1.42mg/l at Lake Ojii. River Uhere has 1.93mg/l. the dissolved iron species is Fe^{2+}.

Bicarbonate (HCO_3^-) values range from 15.25mg/l at lakes Orufu, Adekwegbe, Iyi-Uga and Ogeleube to 91.50mg/l at Lake Isiogba while sulphates (SO_4^{2-}) values vary from 0.83mg/l at Iyi-Uga to 49.55mg/ll at Lake Orufu. Chloride (Cl^-) which is the dominant anion ranges from 90.00mg/l at lakes Ojii, Adekwegbe, Okpo and Varavara to 126.00mg/l at Lake Isiogba. The river samples for chloride vary from 90.00mg/l to 108.00mg/l.

Nitrates (NO_3^-) and nitrate-nitrogen (NO_3-N) levels were determined. Both of them indicate the presence of nitrogen concentration in the lake waters. NO_3^- values range from 3.88mg/l at Ogeleube to 80.17mg/l at Iyi – Ikpa while NO_3^--N values range from 0.87mg/l at Ogeleube to 18.11 mg/l at Iyi-Ikpa. For unpolluted water, the NO_3-N levels is expected to be less than unity (< 1) while the maximum contaminant levels (MCL) is 10mg/l for public water supplies (U. S. E. P. A). The implication therefore is that the water at Ogeleube lake is unpolluted with respect to nitrates while Iyi – Ikpa and River Uhere waters are polluted since they have excess nitrates (in the form of NO_3-N).

Excess nitrates in water usually lead to rapid growth of algae and vascular plants particularly where phosphorous are present. Eventually this could lead to eutrophication. Furthermore, when nitrate is more than 10mg/l of NO_3-N, it becomes dangerous to human health, particularly those of infants.

Phosphates in the lakes range from 0.015mg/l at Lake Isiogba to 0.282mg/l at Lake Orufu. The picture is made clearer by

looking at the levels of phosphorous in the waters. When converted to Total Phosphorous in µg/l, the range goes from 4.89 µg/l at Lake Isiogba to 629.56 µg/l at River Uhere. Phosphorous and Nitrogen are the most important nutrients in lake water. They determine plant growth. Phosphorous in water may be sourced from human/animal waters, run off from farm lands and soil erosion. Lillie and Mason (1983) used the concentration of Total Phosphorous (TP) to classify lake waters and as an indicator of lake water quality (See Table 4 and 5).

Table 4:Trophic Classification of Lake Waters Based on Concentration of Total Phosphorous (after Lillie and Mason, 1983).

Total Phosphorous (µg/l)	Trophic Class
28-50	Eutrophic
13-27	Mesotrophic
12	Oligotrophic

Table 5:Classification of Lake Water Quality on Total Phosphorous (after Lillie and Mason, 1983)

Total Phosphorous (µg/l)	Water Quality Indices
0-1	Excellent
1-15	Very Good
15-32	Good
32-50	Fair
50-150	Poor
>150	Very Poor

Table 6 shows the trophic class and water quality indices of the waters on the basis of total Phosphorous content. Only 4 of the lakes and rivers show tendencies towards eutrophication. These include lakes Orufu and Adekwegbe and rivers Uhere and Api.

Lake Okpo appears to be undergoing eutrophication but the total phosphorous levels puts it into the Mesotrophic category. There will certainly be a need to investigate the nutrient characteristics of this lake on a more detailed level. The water quality indices for the lake range from good to excellent but again all the eutrophic lakes rivers had poor water quality indices.

Smith et al., (1999) discussed some of the effects of excess nutrients loading on lakes. They found out that very eutrophic lakes often experience high levels of poisonous cyano – bacteria. Other effects may include reduced water clarity, increased fish production, decreased aesthetic value of the lake water system, vascular plant production and increased biomass of freshwater phytoplanktons.

Table 6: The Trophic Classes and Water Quality Indices of lakes in Opi Agu.

S/n	Name	TP (µg/l)	Trophic Class	Water Quality Index
1	Ojii	6.52	Oligotrophic	Very Good
2	Orufu	91.99	Eutrophic	Poor
3	Adekwegbe	34.90	Eutrophic	Fair
4	Isiogba	4.89	Oligotrophic	Very Good
5	Okpo	13.70	Mesotrophic	Very Good
6	Iyi-Uga	6.52	Oligotrophic	Very Good
7	Iyi-Ikpa	9.13	Oligotrophic	Very Good
8	Ogeleube	12.07	Mesotrophic	Very Good
9	Varavara	8.48	Oligotrophic	Very Good
10	R. Uhere	629.57	Eutrophic	Very Poor
11	R. Api	46.65	Eutrophic	Fair
12	R. Ojii-Uyahala	7.50	Oligotrophic	Very Good

The low solute concentrations in these lakes could be due to a number of factors. Sources of recharge and solute concentrations are due to rainfall, groundwater recharge, stream discharge into the lakes, organic matter, flood or runoff from the surroundings and agricultural activities. The low TDS values may be an indication that rainfall and soil erosion are the main sources of the solute concentrations. Other sources may not be significant.

The dominance of sodium (Na^+) and Chloride (Cl^-) shows that the lakes can be characterized as Na^+ - Cl^- type water, but this is likely due to evaporation effects and soil erosion rather than to any contribution from sea water. The significant levels of nitrate (NO_3^-) shows that the use of fertilizers in the soils around these lakes may be the main sources of nitrate, to the lakes.

Groundwater/surfacewater – lake interactions may be influencing the chemistry of the lakes. Lake Varavara receives significant inflows from springs and provides outflows to river Uhere in the area. Expectedly, the Na^+ and Cl^- levels are quite low. Its chemistry is a product of mixing processes.

Lake Adekwegbe which has the highest value of 30.62mg/l receives water through seepage from shallow aquifers and water is taken out of it via seepage. Here the chemistry of the lake water is established by flushing of shallow aquifer minerals and cation exchange processes.

Lake Isiogba receives water through seepage from shallow aquifers but the outflow is by a stream called River Api. It

has the highest value of chloride Cl^- and zero value for iron (Fe^{total}). The mechanism for this Cl^- enrichment is not clear.

4. CONCLUSION

Out of the 9 (nine) lakes studied at Opi – Agu, 3 (three) are seepage lakes and 5 (five) are groundwater – drainage lakes. Only 1 (one) is a drainage lake. Three of the lakes have serious tendencies towards eutrophication while the rest are eutrophic. The chemical composition of the lake waters is Na^+ - Cl^- type and is due to soil erosion and evaporation effects.

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