

Plankton-Based Assessment of the Trophic State of Three Tropical Lakes

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ABSTRACT

*In developing countries, lakes being important sources of water supply and fishing are vulnerable to anthropogenic impact, yet knowledge of their trophic state in relation to changes in species composition, and environmental variables, are limited. This study is aimed at assessing the trophic status of lakes by monthly sampling of three lakes located along the floodplain of Cross River, Nigeria between January 2008 and December 2009. Samples were analyzed for water quality parameters, zooplankton and phytoplankton composition and distribution. Results were subjected to community structure analysis using trophic state index, species richness and diversity indexes. Essential primary productivity nutrients, nitrates, sulphates and phosphates were highest in Ejagham Lake, and lowest in Ikot Okpora Lake. Dominant phytoplankton species *Oscillatoria lacustris* (Cyanophyceae), *Cyclotella operculata* (Bacilliarophyceae) and zooplankton *Keratella tropica*, *Keratella quadrata*, *Filinia longiseta*, *Branchionus anguillaris* and *Trichocerca pusilla* (rotifers) all typical of eutrophic communities were recorded in high densities in Ejagham Lake in both dry and wet seasons while *Cladocerans*, *Bosmina longirostris* and *Moina micrura* and copepods considered indicators of oligotrophy and mesotrophy were recorded in large numbers in Ikot Okpora and Obubra Lakes respectively. Higher values of species richness, Evenness and Shannon-Wiener diversity index for both phytoplankton and zooplankton, were recorded in Ejagham Lake during the dry season than wet. Also values of the Trophic state index were generally highest at the Ejagham Lake in the savanna region of the floodplain and lowest at Ikot Okpora in the forest region of the floodplain. Forest region is therefore a limiting factor in the productivity of lakes in the tropics.*

Keywords: Zooplankton, Phytoplankton, Trophic State Index, Diversity Indices, Species Richness

1. Introduction

Biological approaches to evaluating water quality involve assessing communities of organisms. "The basis for this approach is that different species have varying tolerances to environmental stressors" [1]. Fish productivity of water bodies is connected to primary production by many intermediate trophic links. The four groups of organisms that appear in The European Water Framework Directives WFD (Phytoplankton, Zooplankton, Fish and macrophytes), represent water ecological structure over a range of temporal and spatial scales and functional roles. It was recommended that the above biological indicators and, in addition to a range of supporting hydro-morphological and physico-chemical elements should form the core of any monitoring program on lakes [2]. Seasonal changes in mean temperature, radiations, hydrology and nutrient availability are the most impor-

tant variables which determine plankton abundance [3]. Also the qualitative and quantitative estimates of the plankton provide good indices of quality and productive capacity of water.

The estimation of phytoplankton density, productivity and trophic status of lakes is very important for fisheries management especially in Nigeria because of dominant tilapia fish culture. The trophic status of a water body is usually estimated by values of primary production measured for the growing season. Classification of lakes based on quantitative trophic indicators such as phosphorus (P) concentration, chlorophyll-a and transparency also allow the trophic status of lakes on a large gradient to be defined [4]. However, these parameters are not always relevant for short-term evolution within any given lake, especially when variations in phosphorus concentration are low. The values of chlorophyll-a ($\mu\text{g}\cdot\text{l}^{-1}$) are mostly used as the basic criteria, because it is relatively

easy and inexpensive to measure and it is a generally used biological measure of phytoplankton biomass and relatively few measurements are needed to get reliable mean value [5]. Carlson's Trophic State Index (TSI) classification [6] can be used to provide a single trophic criterion for the purpose of classifying and ranking water bodies in complex multi-wetland systems. Secchi depth is a much debated and used variable in lake management. Secchi disk transparency is a standard indicator of water clarity, which is strongly correlated with biomass and annual productivity of suspended algae. This is also closely related to the amount of sandy clay, detritus and organic and inorganic suspended and dissolved matter in water [7].

The use of zooplankton community structure as indicator of the wellbeing of water body dates back to 1879-1910 [8]. Zooplankton is an important component of the trophic food webs of lakes because of its particular position at the crossroads of carbon and energy flows from the lower levels of food chains to fish. Zooplankton biomass which is part of secondary production of lakes is bottom-up regulated by the availability of bacteria and phytoplankton as food and top-down controlled by predation from fish etc. [9]. The composition of zooplankton especially in relation to filter feeders depends on the quality of nutrient supply. So some zooplankton species (mainly rotifers, branchiopods and copepods) could be used as indicators of lakes trophic status [10] because their composition is affected by any of the several environmental parameters e.g. pH or alkalinity and salinity and other biological parameters [11-13]. Zooplankton abundance is usually closely related to phytoplankton concentration and species composition and increases with increasing nutrients concentrations [14].

Biodiversity is also one of the promising ecological criteria that could be added to lake monitoring programmes. Plankton richness within lakes appears to be largely controlled by factors related to productivity, water quality and fish predation levels. Diversity indices, such as Shannon-Weaver index appeared to detect significant differences in the structure of the communities.

Around the world several researches have been carried out using phytoplankton and zooplankton to investigate pollution [15-19] because they are relatively easy to identify, particularly when community sensitivity can be detected based on plankton body sizes or gross taxonomic classifications. Eastern Nigerian lakes in particular being important sources of water for drinking, fishing and domestic use are vulnerable to anthropogenic impact, yet there is limited water quality data [20,21]. This is the first-ever baseline study of the condition of the nation's lakes in eastern Nigeria using statistically valid approach.

It will help the government of the region implement lake monitoring and assessment programs, establish a baseline for lake condition that can be used for future trend assessment. It is focused on studying plankton diversity and evaluating trophic status of some wetlands of Eastern Nigeria for the first time.

2. Materials and Methods

2.1. Study Site

The Cross River, a floodplain river in south-eastern Nigeria between latitude 4°25' - 7°00'N and longitude 7°15' - 9°30'E, is bounded in the south by the Atlantic Ocean, east by the Republic of Cameroun and the Nigerian states of Benue in the north, Ebonyi and Abia in the west and Akwa Ibom in the south-west (**Figure 1**). The climate of the study area comprises a wet season (April- October) characterized by high precipitation (3050 ± 230 mm) and a dry season (November - March) marked by low precipitation (300 ± 23 mm) [22]. Temperatures range from $15.5^\circ\text{C} \pm 7.6^\circ\text{C}$ in the wet season to $32.6^\circ\text{C} \pm 5.4^\circ\text{C}$ in the dry season [20]. Along the floodplain of Cross River are located series of wetlands consisting of lakes, ponds and swamps. The main source of water for these lakes is rainfall and flood water from the river. For the purpose of this study, three lakes were randomly selected along the floodplain of The Cross River, one each from upper section of the floodplain (Ejagham lake), middle portion (Obubra Lake) and down section (Ikot Okpora Lake). Ikot Okpora Lake covers an area of 4 hectares and has maximum depth of 8m with a muddy substratum. The lake is used mainly for fishing and has a shoreline thickly shaded by rainforest preventing the effect of direct sunlight rays on the lake water. The lake was almost covered by water hyacinth at the peak of wet season. Bamboo (*Bambusa bambusa*), Palm trees (*E. guinensis*) and some other trees characteristics of typical rainforest were present. There was palm oil processing mill near the station and common human activities included drinking, bathing, washing and fishing. Obubra Lake had a rocky, gravel and sandy substratum and covers 4 hectares with maximum depth of 6 m with shoreline sparsely shaded by forest and savanna grassland. Ejagham Lake, has a sandy and silt dominated substratum opened to direct effect of sunlight ray and shoreline dominated by dense macro-flora *Ipomoea pestigridis*, *Monechma ciliatum*, *Eragrostic pilosa* and *Setaria pallide-fusia*. The most visible human activities and excavation of sand.

2.2. Sampling Techniques

Monthly sampling of the three lakes was carried out from January 2008 to December 2009 at the middle of every

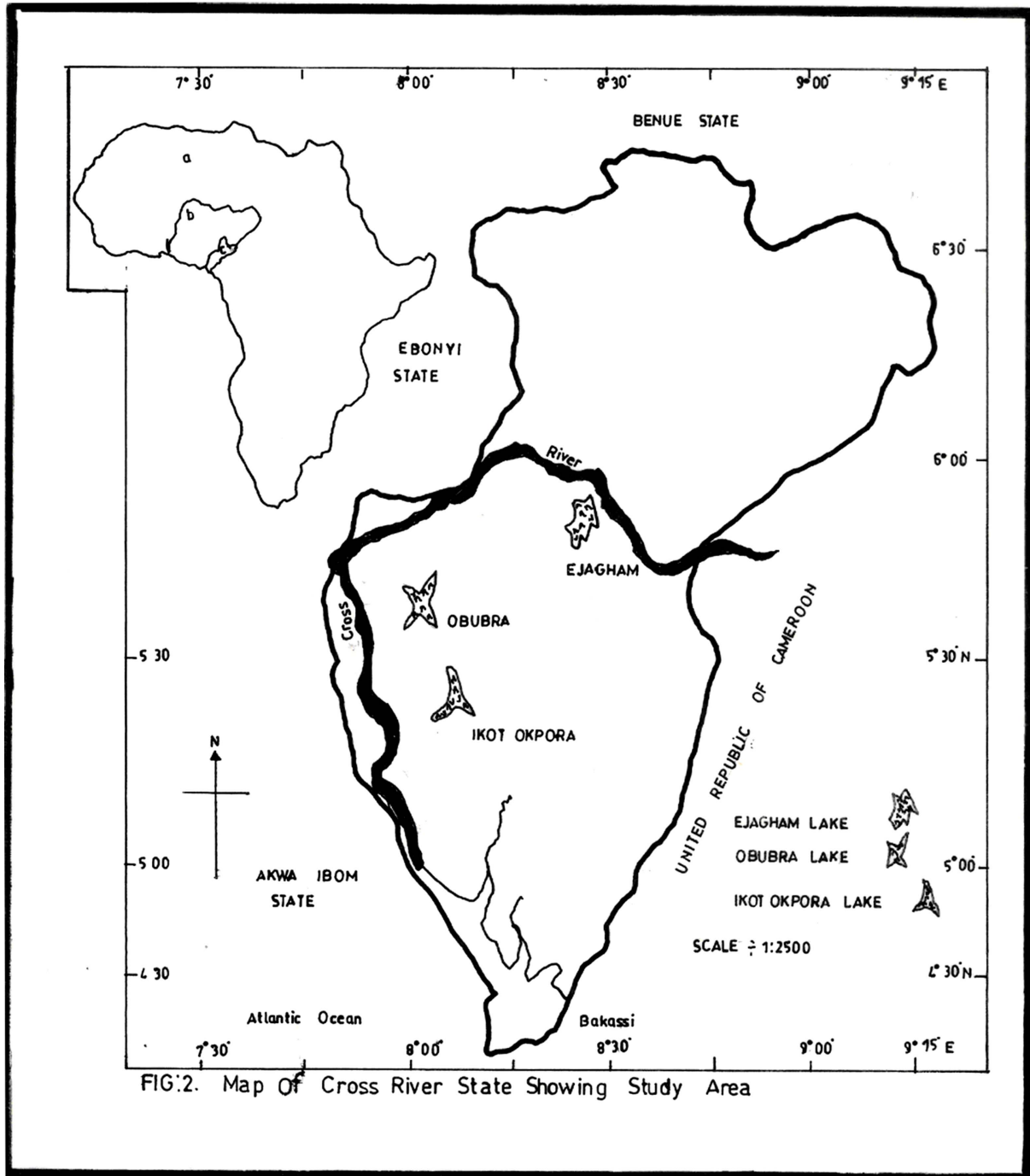


Figure 1. Map of Cross River State showing sampling sites (Source: Cross River State Ministry of lands and survey).

month, between 8 a.m. and 11 a.m. every sampling day.

2.3. Water Quality Parameters

Temperature values were recorded from a mercury-in glass thermometer graduated in units of °C by immersing the thermometer slightly under the surface of water (2 cm) for 5 minutes until mercury stood at one place). Pye Unicam Model 7065 electronic metre at 25°C after stan-

dardization with buffer solution at pH 4, 7 and 9 was used for pH. Dissolved oxygen concentration of the water samples was determined with a Jen-way 9071 digital oxygen analyzer. Water transparency was measured by use of Secchi disc [23]. The disc was lowered into water and the depth at which it became invisible was recorded. It was then gradually withdrawn from the water and the depth at which it became visible was noted. The trans-

parency of the water at that station was the mean of the two readings. For the total dissolved solids (TDS), the Hach TDS meter was put on, the reading zeroed and then the electrode dipped into the water sample and the reading taken. Conductivity was assessed by putting on the Suntext conductivity meter, adjusting the reading portion and dipping the meter into the water sample and approximate reading taken. Total hardness, free Carbon dioxide, Acidity, Chemical Oxygen Demand, was obtained by titrimetric method [24]. Biological Oxygen Demand was determined by difference between initial and final dissolved oxygen after incubation for 5 days at room temperature of (20°C). Total alkalinity was measured by titrating water samples with sulphuric acid standard solution, using a drop of phenolphthalein solution and one sachet of bromcresol green-methyl red as indicator, until the sample changed from blue green to pink. Total alkalinity which is expressed in mg/L is the total number of drops of sulphuric acid solution used multiplied by 17.1 (Fish Farmers' Water Quality Testing Kit Manual, 1990). Nitrate and Phosphate were measured with brucine and Ascorbic acid methods respectively. Salinity was determined using hand held refractometer (S/mill-E 0-100%). Bicarbonate ion was measured with pH electrode dipped into the tip of the conical container. Sample water was passed through until a constant reading was obtained and a marble powder was added, to completely cover the electrode ball. After about 2 minutes, the pH was read again. The temperature of the marble was monitored with thermometer during measurement. Carbonate ions was determine by placing hydrochloric acid, between 2 and 10 ml of water sample in a gas generator and insert tube filled with 20 ml hydrochloric acid (10%). After connecting to the apparatus, the graduated tube was filled by raising the level container. The gas generator was then tilted so that the hydrochloric acid makes contact with the floor. A pressure compensation was attained by sinking the container so that, after about 10 minutes the gas volume can be read. Color was determine by assembling Filter apparatus (membrane filter, filter holder, aspirator and folter flask) and allowed about 50 ml of dematerialized water to pass through to rinse the unit. Discard rinse water. Approximately 50 ml of water sample was filtered and 25 ml poured into another clean cell. The dematerialized water was placed in a cell holder and sample compartment door was closed. The demineralization was used to set the zero concentration point.

2.4. Phytoplankton

Planktons were collected in sterilized, one-litre wide

mouth dark colour plastic bottles at each sampling station, reduced to 10 ml by decanting the supernatant aliquot and preserved with Lugol's solution. Samples were shifted to laboratory where they were identified after Prescott [25], Edmondson [26] and John *et al.* [27]. For Chlorophyll-a analysis 100 ml water sample were filtered through Millipore micro filters (47 mm; 45 µm pores). Concentration of Chlorophyll-a in supernatant was determined by spectrophotometer, with absorbance at 665 nm and 750 nm [28].

2.5. Zooplankton

Zooplankton was collected by towing a-55µ mesh-sized plankton net against the current flow at the subsurface level for two minutes [29]. The filtered samples were washed into the sterilized collecting bottles and immediately fixed in 4% formalin. The percentage relative abundance of the specimen was estimated by direct count. Each quantitative sample was concentrated to 10 ml and from this; 1 ml of sample was taken and all individual taxa present were counted. Relative abundance was calculated as the number of individuals per liter of water filtered through the net. They were identified with an Olympus Vanox Research Microscope (mag X60) Model 230485 using keys given by Kadiri [30] and Kemdirim [31].

2.6. Community Structure Analysis

Trophic state index based on Secchi Depth TSI (SD) and Trophic state index based on Chlorophyll-a, TSI (Chl-a) and that based on phosphorus, TSI(TP) were calculated after Carlson [32] using the following equations:

$TSI(\text{Secchi Disk}) = 60 - 14.1 \ln(\text{SD})$ where SD is Secchi Disk in meters(m)

$TSI(\text{Chlorophyll a}) = 9.81(\ln \text{Chl-a}) + 30.6$ where Chl a is mean chlorophyll a in $\mu\text{g}\cdot\text{l}^{-1}$

$TSI(\text{Total Phosphorus}) = 14.41 \ln(\text{TP}) + 4.15$ where TP is mean total phosphorus in $\mu\text{g}\cdot\text{l}^{-1}$.

Diversity indices used were species diversity (H'), species richness (d) and species evenness. Shannon-Weaner diversity function was used to calculate heterogeneity for each site. This index takes into account the total number of species present as well as their respective abundance thus providing a more convenient means of comparing differences between ecological communities. These changes in the environment are reflected in the types and number of organisms.

Richness index was expressed using Margalef's richness index. This measure relies only on the number of taxa. Richness increases when abundance is spread over a greater number of categories but does not take into account the evenness of the distribution. Also between two samples with the same S, richness will be higher in

the one with lower abundance. Evenness Index, which expresses the degree of uniformity in the distribution of individual among the taxa in the collection [33] was also calculated.

$$d = (S - 1) / \log N \text{ (Equation 1)}$$

$$H = - \sum p_i (\log p_i) \text{ (Equation)}$$

$$E = H/SE = \text{Equitability}$$

d = Margalef's richness index and H' = Shannon-Wiener Diversity Function

S = total species number

p_i = proportion of each species in each sample,

besides the application of diversity indices, inter-stations comparison were carried out to test for significant differences in faunal abundance using one-way analysis of variance (ANOVA) [34].

3. Result

3.1. Environmental Conditions

As shown in **Table 1**, significant spatial variation with higher values ($p < 0.05$) was observed for air temperature, surface temperature, turbidity, alkalinity, conductivity, BOD, phosphates, sulphates, chlorides, calcium, magnesium, silicon, total hardness, total solids and total dissolved solids in the Ejagham Lake than Obubra and Ikot Okpora Lakes while Dissolved Oxygen and alkalinity

were least in Ejagham Lake. Other variables showed no significant spatial differences ($p > 0.05$).

3.2. Phytoplankton

A total of 46 planktonic algae from 5 taxa were recorded: 17 Bacillariophyceae, 19 Chlorophyceae, 8 Cyanophyceae, 1 Chrysophyceae and 1 Euglanophyceae (**Table 2**). There was significant seasonal and spatial variation in the phytoplankton abundance and distribution. Apart from *Rhizosolenia longiseta*, *Melosera varians*, *Cyclotella operculata*, *Chlorococcum humicolum*, *Closteridium lanceolatum* *Golonotozygon aculeatum*, *Sphaerocystis species*, *Raphidiopsis species*, *Epithermal zebra*, *Chlamydomonas atactogam*, *Closteriopsis longissinna*, *Golonotozygon aculeatum* *Schizoponium praisiola*, *Tetrahedron species*, *Spirulina substilissinna*, *Colectum cyclopicola*, *Closterium junoidum* and *Golonotozygon aculeatum* that had higher wet season counts, all other species in the three lakes had higher dry season counts. The highest number of algal counts was recorded in the Ejagham Lake while the least occurred in Ikot Okporo. *Cocconeis diminuta*, *Oscillatoria Lacustria* and *Dinobryon species* were however completely absent from the Ejagham Lake. The observed dominant species in the Ejagham Lake, during both wet and dry seasons was *Oscillatoria lacustria* (Cyanophyceae) closely followed by *Cyclotella operculata* (Bacillariophyceae) while

Table 1. Mean (\pm SD) values of some physical and chemical characteristics of the three lakes (Ikot Okpora, Obubra and Ejagham).

Parameters	Ikot Okpora	Obubra	Ejagham
Total Storage (m ³)	638 ^a	1099 ^b	1236 ^b
Lake Area (ha)	45.4 \pm 8.76 ^a	51.3 \pm 5.66 ^a	76.4 \pm 12.34 ^b
Mean Depth (m)	8.2 \pm 2.81 ^a	7.6 \pm 3.23 ^a	8.9 \pm 2.45 ^a
Air Temperature ($^{\circ}$ C)	30.9 \pm 2.23 ^a	32.5 \pm 1.84 ^a	34.4 \pm 3.42 ^b
Surface Temperature ($^{\circ}$ C)	27.7 \pm 1.71 ^a	29.4 \pm 2.11 ^a	33.8 \pm 2.89 ^b
Turbidity (NTU)	12.5 \pm 2.23 ^a	66.9 \pm 6.33 ^b	132.4 \pm 23.34 ^c
Ph	6.5 \pm 0.66 ^a	7.2 \pm 1.12 ^a	6.8.5 \pm 1.81 ^a
Dissolved Oxygen (mg \cdot l ⁻¹)	3.2 \pm 1.21 ^a	2.7 \pm 0.89 ^b	2.3 \pm 0.76 ^c
Alkalinity (mg \cdot l ⁻¹)	53.2 \pm 4.42 ^a	40.8 \pm 5.43 ^b	67.4 \pm 12.98 ^c
Conductivity (μ S \cdot cm ⁻¹)	22.4 \pm 14.78 ^a	87.6 \pm 10.32 ^b	102.8 \pm 16.78 ^c
BOD (mg \cdot l ⁻¹)	1.4 \pm 1.66 ^a	2.6 \pm 0.87 ^b	4.5 \pm 1.64 ^c
Phosphates (mg/l)	0.5 \pm 0.01 ^a	1.5 \pm 0.04 ^b	2.5 \pm 0.23 ^c
Calcium (Ca ²⁺)	10.4 \pm 3.4 ^a	9.3 \pm 2.87 ^a	19.4 \pm 4.83 ^b
Magnesium (Mg ²⁺)	1.8 \pm 0.22 ^a	2.1 \pm 0.54 ^a	3.2 \pm 0.99 ^b
Total iron	1.4 \pm 0.56 ^a	0.7 \pm 0.43 ^a	1.9 \pm 0.36 ^a
Silicon (SiO ₂)	38.9 \pm 2.89 ^a	28.4 \pm 5.34 ^b	56.8 \pm 9.65 ^c
Sulphates (SO ₄)	11.4 \pm 1.23 ^a	14.8 \pm 2.88 ^a	19.8 \pm 7.81 ^b
Nitrates (NO ₃)	0.2 \pm 0.78 ^a	0.4 \pm 0.34 ^b	0.8 \pm 0.56 ^a
Chlorides (Cl)	13.6 \pm 5.99 ^a	11.6 \pm 3.21 ^a	18.8 \pm 6.77 ^b
Total hardness	57.5 \pm 8.88 ^a	94.3 \pm 6.54 ^b	143.5 \pm 23.56 ^c
Total solids (mg/l)	68.9 \pm 12.34 ^a	187.6 \pm 8.76 ^b	208.3 \pm 54.50 ^c
Total Dissolved solids (mg/l)	59.8 \pm 6.54 ^a	178.5 \pm 6.66 ^b	222.8 \pm 65.44 ^c

Values in the same rows with the same superscript are not significantly different ($p > 0.05$).

Table 2. Phytoplankton of Ikot Okpora, Obubra and Ejagham Lakes during wet (W) and dry (D) seasons.

Season	Okpora W	D	Obubra W	D	Ejagham W	D
Phytoplankton Species	No/ml	No/ml	No/ml	No/ml	No/ml	No/ml
Bacillariophyceae						
<i>Tabellaria Flocculosa</i>	34	49	87	192	134	234
<i>Synedra Cyclopus</i>	00	65	09	87	26	198
<i>Suriellia Spiralis</i>	00	50	00	76	00	86
<i>Rhizosolenia Longiseta</i>	122	36	156	48	222	433
<i>Melosera Varians</i>	134	88	223	176	320	482
<i>Navicula Rostellata</i>	00	98	102	267	243	543
<i>Nitzschia Closterium</i>	89	101	112	344	176	410
<i>Cytosigma Attenuatum</i>	67	45	136	233	267	309
<i>Flagilaria Intermedia</i>	94	222	87	342	120	654
<i>Epithermal Zebra</i>	34	98	243	132	298	499
<i>Cocconeis Dimunuta</i>	00	76	00	67	00	00
<i>Cymatopleura Solea</i>	65	98	98	200	110	222
<i>Cyclotella Glomerata</i>	76	118	99	199	230	349
<i>Cyclotella Comta</i>	00	223	87	322	167	276
<i>Cyclotella Operculata</i>	816	1464	511	1389	624	1195
<i>Amphora Ovalis</i>	222	553	87	627	187	299
<i>Amphilpleura Pellicuda</i>	98	112	202	322	324	562
Chlorophyceae						
<i>Spirogyra sp</i>	223	655	127	498	242	576
<i>Chlorococcum Humicolum</i>	232	98	299	456	342	399
<i>Chlamydomonas Atactogam</i>	67	633	276	202	433	00
<i>Closteriopsis Longissinna</i>	87	87	123	00	234	488
<i>Codiolum Gregarii</i>	99	211	97	110	178	876
<i>Closterium Jennen</i>	77	199	88	290	134	489
<i>Drapamidia Species</i>	00	120	155	388	209	119
<i>Neomens Dumetosa</i>	72	432	87	282	198	198
<i>Charales Fragilis</i>	00	87	54	389	123	467
<i>Shroederia Setigera</i>	39	108	98	98	176	198
<i>Closterium Junoidum</i>	00	56	63	187	233	67
<i>Closteridium Lanceolatum</i>	95	73	59	78	00	78
<i>Golonotozygon Aculeatum</i>	66	18	167	56	234	378
<i>Schizoponium Praisiola</i>	101	193	91	21	145	576
<i>Serastrium Spinolosum</i>	56	198	66	134	133	366
<i>Spirotaenna Condensate</i>	78	97	102	167	187	266
<i>Volvox Aurus</i>	39	67	23	101	43	102
<i>Sphaerocystis Species</i>	100	44	00	122	00	736
<i>Tetrahedron Species</i>	00	194	233	65	129	234
Cyanophyceae						
<i>Oscillatoria Lacustria</i>	12	23	54	32	1878	2842
<i>Pharmidium Species</i>	101	134	55	71	134	1120
<i>Spirulina Substilissinna</i>	00	134	129	76	489	1564
<i>Rivularia Plankton</i>	81	234	31	92	87	342
<i>Anabaena Species</i>	0	67	78	102	110	1290
<i>Microcystis Species</i>	230	1222	188	981	1558	2733
<i>Anabaenopsis Species</i>	0	26	83	233	134	556
<i>Raphidiopsis Species</i>	33	0	45	00	987	1234
Chrysophyceae						
<i>Dinobryon Species</i>	1	2	0	12	0	0
Euglenaphyceae						
<i>Colactum Cyclopicola</i>	00	32	34	0	78	324

Table 3. Seasonal variation of phytoplankton diversity indices in Ikot Okpora, Obubra and Ejagham Lakes.

Lakes	Phytoplankton	Seasons	Dorminance	Evenness	Margalef	Shan non	
Ikot Okpora	Bacillariophyceae	Wet	0.17 ± 0.03 ^a	0.76 ± 0.13 ^a	3.24 ± 0.12 ^a	0.45 ± 0.17 ^a	
		Dry	0.43 ± 0.02 ^b	0.56 ± 0.34 ^b	3.97 ± 0.23 ^a	0.95 ± 0.22 ^b	
	Chlorophyceae	Wet	0.22 ± 0.01 ^a	0.66 ± 0.04 ^a	3.45 ± 0.21 ^a	0.59 ± 0.14 ^a	
		Dry	0.48 ± 0.02 ^b	0.58 ± 0.11 ^b	3.89 ± 0.33 ^a	0.89 ± 0.28 ^b	
	Cyanophyceae	Wet	0.13 ± 0.15 ^a	0.81 ± 0.13 ^a	2.31 ± 0.19 ^a	0.36 ± 0.19 ^a	
		Dry	0.35 ± 0.11 ^b	0.61 ± 0.23 ^b	2.81 ± 0.26 ^a	0.66 ± 0.28 ^a	
	Chrysophyceae	Wet	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	
		Dry	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	
	Euglenaphyceae	Wet	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	
		Dry	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	
	Obubra	Bacillariophyceae	Wet	0.12 ± 0.01 ^a	0.91 ± 0.10 ^a	3.76 ± 0.17 ^a	1.03 ± 0.15 ^a
			Dry	0.18 ± 0.03 ^b	0.89 ± 0.19 ^b	3.97 ± 0.29 ^a	1.76 ± 0.21 ^b
Chlorophyceae		Wet	0.29 ± 0.05 ^a	0.66 ± 0.21 ^a	3.91 ± 0.19 ^a	1.05 ± 0.33 ^a	
		Dry	0.17 ± 0.11 ^b	0.79 ± 0.11 ^b	4.11 ± 0.26 ^a	1.88 ± 0.29 ^b	
Cyanophyceae		Wet	0.23 ± 0.06 ^a	0.82 ± 0.17 ^a	3.11 ± 0.22 ^a	0.68 ± 0.16 ^a	
		Dry	0.44 ± 0.13 ^b	0.54 ± 0.29 ^b	3.88 ± 0.16 ^a	1.22 ± 0.19 ^b	
Chrysophyceae		Wet	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	
		Dry	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	
Euglenaphyceae		Wet	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	
		Dry	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	
Ejagham		Bacillariophyceae	Wet	0.23 ± 0.16 ^a	0.84 ± 0.18 ^a	3.85 ± 0.25 ^a	1.69 ± 0.33 ^a
			Dry	0.36 ± 0.21 ^b	0.54 ± 0.32 ^b	4.32 ± 0.28 ^a	2.88 ± 0.21 ^b
	Chlorophyceae	Wet	0.18 ± 0.05 ^a	0.95 ± 0.22 ^a	4.21 ± 0.14 ^a	1.55 ± 0.14 ^a	
		Dry	0.64 ± 0.29 ^b	0.42 ± 0.17 ^b	4.87 ± 0.21 ^a	2.97 ± 0.43 ^b	
	Cyanophyceae	Wet	0.540 ± 0.07 ^a	0.44 ± 0.14 ^a	2.88 ± 0.24 ^a	1.69 ± 0.22 ^a	
		Dry	0.86 ± 0.16 ^b	0.29 ± 0.23 ^b	3.07 ± 0.18 ^a	1.92 ± 0.19 ^a	
	Chrysophyceae	Wet	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	
		Dry	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	
	Euglenaphyceae	Wet	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	
		Dry	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	

Means with the same superscript are not significantly different ($p > 0.05$).

the least species recorded was *Dinobryon species* (Chrysophyceae). There were significant seasonal variations of species diversity indices for all phytoplankton taxa ($p < 0.05$) except Margalef index none for all the species from the three lakes (Table 3).

3.3. Zooplankton

A total of 26 zooplankton species consisting of 4 taxa were recorded (Table 4). Rotifers (9) and Cladocerans (8) had the highest representation by species followed by Copepoda (5) while Decapods were least represented (4). Among the rotifers, *Keratella tropica*, *Keratella quad-rata*, *Filinia longiseta*, *Branchionus anguillaris* and *Trichocerca pusilla* and cladocerans, *Ceriodaphnia cornuta*, *Chydorus sphaericus* and *Diaphanosoma excisum* were common in Ejagham Lake. Rotifers like *Synchaeta longipes* and *Conochilus dossuarius* and Cladocera, *Bosmina longirostris* and *Moina micrura* were recorded in high densities in Ikot Okpora Lake. Cyclopoid copepodids and nauphlii increased the population of Copepoda particularly in Ikot Okpora Lake during dry season while the numerical abundance reduced drastically in Ejagham Lake.

Seasonal variation of species diversity indices for zoo-

plankton were significant ($p < 0.05$) for all 3 lakes (Table 5). However, seasonal variation of Margalef index was not significant for all species in the 3 lakes. Higher values of species richness, Evenness and Shannon-Wiener diversity index were recorded during the dry season than the wet.

3.4. Trophic State Index

In the three lakes studied chlorophyll-a concentration increased in dry season and decrease in the wet. Trophic State Index dry season values based on Chlorophyll-a, Secchi Disk and Phosphorus were generally highest at the Ejagham (57.02, 77.22 and 74.40) Lake and lowest at Ikot Okpora (41.21, 49.52 and 60.9) respectively (Table 6). In all the lakes Trophic Index value based on total phosphorus; TSI (TP) is higher (60.9, 63.12, 74.4) than the values by Chlorophyll-a; TSI (Chl-a) (41.21, 52.43, 56.01) and Secchi disk; TSI (SD) (49.52, 51.11 77.22) respectively.

4. Discussion

4.1. Physico-Chemistry

Essential primary productivity nutrients, nitrates, sulphates and phosphates were highest in Ejagham Lake,

Table 4. Zooplankton of Ikot Okpora, Obubra and Ejagham Lakes during wet (W) and dry (D) seasons.

Species	W	D	W	D	W	D
Cladocera						
<i>Alona rectangula</i>	59	185	23	40	7	23
<i>Ceriodaphnia cornuta</i>	34	149	87	83	12	13
<i>Chydorus sphaericus</i>	29	254	74	88	3	28
<i>Diaphanosoma excisum</i>	40	176	2	94	23	13
<i>Simocephalus</i>	0	113	15	56	24	89
<i>Moina micrura</i>	65	198	24	33	12	44
<i>Bosmina longirostris</i>	69	123	30	11	0	0
<i>Macrothrix spinosa</i>	65	12	56	0	122	67
Copepoda						
<i>Ectocyclops phaleratus</i>	92	178	34	56		41
<i>Mesocyclop notius</i>	85	177	33	57	0	48
<i>Merocyclop</i>	118	184	19	56	0	10
<i>Metacyclops minutus</i>	11	0	8	12	23	45
<i>Microcyclops</i>	85	13	23	34	57	78
Decapoda						
<i>Lucifer hansenii</i>	45	87	76	124		176
<i>Bipinnaria larva</i>	18	34	34	76	32	45
<i>Mysid larvae</i>	23	45	34	56	45	121
<i>Diphanosoma excisum</i>	43	87	12	111	98	101
Rotifera						
<i>Keratella tropica</i>	22	44	12	84	23	176
<i>Keratella quadrata</i>	0	0	7	56	23	66
<i>Epiphanes macromma</i>	59	123	43	58	13	83
<i>Trycoerca similis</i>	62	165	28	42	22	18
<i>Synchaeta longipes</i>	112	98	29	66	2	6
<i>Conochilus dossuarius</i>	122	101	34	55	3	8
<i>Trichocerca pusilla</i>	10	12	8	34	23	98
<i>Branchionus anguillaris</i>	23	34	23	56	98	178
<i>Filinia longiseta</i>	9	45	39	65	67	234

surrounded by the savanna vegetation and lowest in Ikot Okpora Lake; the forest portion of the floodplain. Forest ecosystem readily immobilise these nutrients [35], which explains its limiting inputs into the water body in the forest area. The levels of nutrients are fundamental to the eutrophic nature of the lakes. Evidence for high production is also seen in the lakes oxygen profile which went down low (2.3 mg/L) at the Ejagham Lake, a condition which contributes to the increase of lake phosphorus through the release of phosphorus by deoxidized iron in the sediments. The concentrations of calcium and magnesium salts combined with various anions (usually carbonates) that constitute the total hardness of water were high in Ejagham Lake indicating hard water lake. The lower values of these parameters in Ikot Okpora lake and Obubra showed the soft water nature of these lakes. Lake water was clearer at Ikot Okpora than other lakes due to lower values of turbidity at this forest lake.

4.2. Phytoplankton

Although Bacillariophyta and Chlorophyta were dominant in respect to species number, Cyanophyta type phytoplankton were more in terms of population density in Ejagham Lake. *Oscillatoria lacustris* *Microcystis spe-*

cies, *Spirulina substilissinna*, *Raphidiopsis species* were dominant and sub-dominant organisms in certain seasons. Cyanophyta dominance, and sometimes bloom formation are among the most visible symptoms of accelerated eutrophication of lakes and reservoirs [36-38]. Also the permanent dominance of *Oscillatoria* species during dry and wet seasons has often been reported for eutrophic lakes in Central Europe [39]. The observed dominant species, *Cyclotella operculata* (Bacillariophyta) by Nwankwo [40] and *Microcystis* by Silva [18] in both wet and dry season was reported to be as a result of physiological and behavioural flexibility of these species which can accommodate environmental stresses better than most fast growing species.

4.3. Zooplankton

Numerous species of rotifers and crustaceans considered good indicators of the trophic state of lakes were found in the zooplankton community. Rotifers recorded frequently in the Ikot Okpora Lake, *Synchaeta longipes* and *Conochilus dossuarius* are typical of oligotrophic to mesotrophic systems [41]. However, the regularly most dominant species in the Ejagham Lake like *Keratella tropica*, *Keratella quadrata*, *Filinia longiseta*, *Bran-*

chionus anguillaris and *Trichocerca pusilla* are considered indicators of advanced lake trophy [10]. The crustacean zooplankton community was made up of cladocerans and copepods. Copepod abundance in Ikot Okpora and Obubra lakes was driven by the increase of Ectocyclops, Mesocyclops, merocyclops, Microcyclops which are indicative of higher water quality signifying oligotrophic status. Crustacean abundance increases only between mesotrophic and meso-eutrophic [42]. Also dominant cladocerans, *Alona rectangular*, *Ceriodaphnia*

cornuta, *Chydorus sphaericus*, *Diaphanosoma excisum*, *Simocephalus sp.*, *Moina micrura* and *Bosmina longirostris* represented in most samples in the Ikot Okpora Lake are well recorded by Sendacz *et al.* [43] and Swierzowski *et al.* [44] in oligotrophic and mesooligotrophic systems. Generally increase in the abundance of zooplankton in the Ejagham Lake further confirms the eutrophic status of the lake since zooplankton abundance increases with increasing nutrient concentration [14] and decreases with decreasing nutrient concentration.

Table 5. Seasonal variation of zooplankton diversity indices in Ikot Okpora, Obubra and Ejagham Lakes.

Lakes	Zooplankton	Seasons	Dominance	Evenness	Margelf	Shannon	
Ikot Okpora	Cladocera	Wet Season	0.44 ± 0.07 ^a	0.56 ± 0.12 ^a	3.56 ± 0.17 ^a	0.55 ± 0.05 ^a	
		Dry Season	0.29 ± 0.11 ^b	0.96 ± 0.16 ^b	4.87 ± 0.21 ^a	0.73 ± 0.19 ^b	
	Copepoda	Wet Season	0.63 ± 0.09 ^a	0.51 ± 0.07 ^a	2.11 ± 0.15 ^a	0.47 ± 0.18 ^a	
		Dry Season	0.32 ± 0.22 ^b	0.87 ± 0.10 ^b	2.99 ± 0.03 ^a	0.88 ± 0.14 ^b	
	Decapoda	Wet Season	0.58 ± 0.06 ^a	0.44 ± 0.26 ^a	1.68 ± 0.22 ^a	0.23 ± 0.18 ^a	
		Dry Season	0.20 ± 0.15 ^b	0.79 ± 0.15 ^b	1.94 ± 0.18 ^a	0.44 ± 0.11 ^b	
	Rotifera	Wet Season	0.76 ± 0.23 ^a	0.25 ± 0.08 ^a	1.66 ± 0.11 ^a	0.36 ± 0.26 ^a	
		Dry Season	0.51 ± 0.22 ^b	0.55 ± 0.01 ^b	1.23 ± 0.20 ^a	0.69 ± 0.18 ^b	
	Obubra	Cladocera	Wet Season	0.75 ± 0.19 ^a	0.25 ± 0.11 ^a	4.81 ± 0.34 ^a	0.45 ± 0.08 ^a
			Dry Season	0.46 ± 0.12 ^b	0.50 ± 0.02 ^b	4.33 ± 0.16 ^a	0.86 ± 0.43 ^b
		Copepoda	Wet Season	0.955 ± 0.18 ^a	0.11 ± 0.11 ^a	3.22 ± 0.16 ^a	0.42 ± 0.22 ^a
			Dry Season	0.57 ± 0.19 ^b	0.43 ± 0.05 ^b	3.89 ± 0.20 ^a	0.87 ± 0.43 ^b
Decapoda		Wet Season	0.64 ± 0.10 ^a	0.41 ± 0.19 ^a	2.20 ± 0.14 ^a	0.46 ± 0.17 ^a	
		Dry Season	0.35 ± 0.08 ^b	0.88 ± 0.16 ^b	2.88 ± 0.10 ^a	0.75 ± 0.21 ^b	
Rotifera		Wet Season	0.75 ± 0.12 ^a	0.64 ± 0.13 ^a	1.58 ± 0.28 ^a	0.48 ± 0.11 ^a	
		Dry Season	0.39 ± 0.11 ^b	0.30 ± 0.22 ^b	1.68 ± 0.18 ^a	0.88 ± 0.27 ^b	
Ejagham		Cladocera	Wet Season	0.86 ± 0.22 ^a	0.24 ± 0.12 ^a	5.34 ± 0.21 ^a	0.87 ± 0.13 ^a
			Dry Season	0.47 ± 0.13 ^b	0.55 ± 0.11 ^b	4.99 ± 0.31 ^a	0.48 ± 0.11 ^b
	Copepoda	Wet Season	0.86 ± 0.10 ^a	0.242 ± 0.15 ^a	4.34 ± 0.24 ^a	0.59 ± 0.22 ^a	
		Dry Season	0.45 ± 0.25 ^b	0.64 ± 0.14 ^b	4.33 ± 0.3 ^a	0.97 ± 0.33 ^b	
	Decapoda	Wet Season	0.75 ± 0.15 ^a	0.22 ± 0.19 ^a	3.12 ± 0.22 ^a	0.46 ± 0.13 ^a	
		Dry Season	0.32 ± 0.12 ^b	0.52 ± 0.08 ^b	3.55 ± 0.12 ^a	0.86 ± 0.32 ^b	
	Rotifera	Wet Season	0.82 ± 0.18 ^a	0.20 ± 0.18 ^a	1.88 ± 0.32 ^a	0.52 ± 0.21 ^a	
		Dry Season	0.54 ± 0.21 ^b	0.50 ± 0.16 ^b	2.44 ± 0.21 ^a	0.97 ± 0.17 ^b	

Table 6. Trophic state index due to chlorophyll-a, secchi disk and total phosphorus.

Lakes	Parameter	Mean Values		Trophic Points		Classification	
		W	D	W	D	W	D
Ikot Okpora	Chlorophyll-a (µg/L)	1.77	2.54	31.11	41.21	Oligotrophy	Mesotrophy
	Secchi Disk (m)	2.16	1.17	34.23	45.52	Mesotrophy	Mesotrophy
	Total Phosphorus (µg/L)	0.05	0.18	51.25	60.9	Eutrophy	Eutrophy
Obubra	Chlorophyll-a (µg/L)	2.24	2.89	42.31	52.43	Mesotrophy	Eutrophy
	Secchi Disk (m)	2.85	1.78	42.27	51.11	Mesotrophy	Eutrophy
	Total Phosphorus (µg/L)	0.05	0.06	57.34	63.12	Eutrophy	Eutrophy
Ejagham	Chlorophyll-a (µg/L)	3.42	4.08	50.78	57.02	Eutrophy	Eutrophy
	Secchi Disk (m)	1.34	0.95	54.3	77.22	Hypereutrophy	Eutrophy
	Total Phosphorus (µg/L)	0.09	0.11	70.21	74.4	Hypereutrophy	Hypereutrophy

4.4. Diversity

Species diversity measured by Shannon Weaner index is directly proportional to the number of species in the sample and the uniformity of the species distribution in the total abundance [45]. In the three lakes species diversity was relatively high, which indicates good environmental conditions conducive to the development of many species, and according to Kajak [46] - moderate trophy of waters. It was only in wet season samples that values were much lower which was reflected by the lowest recorded number of species in the zooplankton community [47] as well as by the domination of single species, accompanied by low proportions of other taxa. This indicated poor lake conditions. This hypothesis that decrease in lake condition followed by community structure simplification was also confirmed by Rogozin [48].

4.5. Trophic State Index (Tsi)

Chlorophyll-a is used by all phytoplankton to capture sunlight for photosynthesis. Chlorophyll (Chl-a) concentration is a uniquely algal trait of the water column and function as a reliable measure of phytoplankton biomass [49]. Secchi depth is generally a good indicator of chlorophyll-a concentration and reported to be negatively related to chlorophyll-a concentration [50]. In Ejagham Lake, when minimum Secchi depth was observed, the highest chlorophyll-a value was recorded. However secchi disk visibility may not always be acceptable as an index of high productivity as some regions are affected by non-algal turbidity. In Ejagham and Obubra lakes, TSI (Chl-a) was found to be 70.02 and 52.43 respectively while TSI (SD) was 57.22 and 51.11 respectively and TSI value greater than 50 is usually associated with eutrophy or high productivity [5]. For lakes that have a few rooted aquatic plants and little non-algal turbidity, the TSI (SD) and TSI (Chl-a) are approximately the same [6] as was observed in the Ikot Okpora and Obubra Lakes. Therefore, TSI (SD) is only useful to those lakes where turbidity is as a result of algal biomass [51]. In this study non algal turbidity was observed in Ejagham lake where the TSI (SD) was highest. Many factors are known to influence Secchi depth. The most important factors include primary production, the amount of resuspended material and the amount of coloured matter in the lake. Secchi depth do not depend solely on autochthonous lake production but also very much on allochthonous influences and resuspension [5]. So it is not correct to classify Ejagham lake as hypereutrophic on basis of secchi depth measurements. Same difference between TSI (SD) and TSI (Chl) values has been found for Sri Lankan reservoirs [52] and TSI (Chl) has been found to be a reliable means for quantifying trophic state at least for fisheries

management purposes. Lake Ejagham can be characterized as eutrophic during both seasons on the basis of Chlorophyll-a concentration while Obubra Lake is eutrophic and mesotrophic during dry and wet seasons respectively. The Ikot Okpora Lake, however, show mesotrophic and oligotrophic characteristics in dry and wet seasons respectively. Oligotrophic lake generally host very little or no vegetation and is relatively clear while eutrophic lakes tend to host large quantities of organisms, including algal bloom. Each trophic class supports different types of fish and other organisms. If the algal biomass in a lake reaches very high level (> 80) fish kills occur as decomposing biomass deoxygenate the water. A lake situated in nutrient rich area may be naturally eutrophic. Nutrients carried into water bodies from non-point sources such as agricultural run-offs, residential fertilizers and sewage, will all increase biomass and can cause oligotrophic lake to become hypereutrophic.

The three lakes are at different stages of development and are influenced by season and location. Lake located at the savannah area of the floodplain eutrophies faster than lake at the forest section due to higher intensity of direct sunlight penetration and temperatures which increases photosynthesis and biodegradation respectively, in the former. The forest helps limit eutrophication due to the absence of anthropogenic inputs. The dry season trophic state of the tropical lakes seems to be more advanced because of the dilution factor by rain water. Lake Ikot Okpora may be recommended for an unfiltered water supply particularly during the wet season and is suitable for fisheries and recreation in all seasons. Obubra Lake may be suitable for fisheries but dominated mostly by tolerant species, Clariidae and Cichlidae families during the wet season while Ejagham Lake maybe have very few tolerant fish species and not suitable for recreation.

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