Assessment of Physicochemical Attributes and Zooplankton Composition of Agulu Lake in Anambra State, Nigeria

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Abstract
An assessment of physicochemical conditions and zooplankton diversity in Agulu Lake was conducted for a period of eight months from February 2023-September 2023. Water samples were collected every month in sterilized containers from three of the six arms of the lake which constituted the three sampling stations of the study. The study stations were designated as S1, S2, S3 (Dry Season) and S4, S5, and S6 (Rainy Season). The samples were analysed for both physicochemical attributes and zooplankton diversity. Zooplankton species were determined following standard procedures. The physicochemical properties of the lake were investigated by measuring the degree of correlation with the plankton diversity. The zooplankton diversity of the Lake correlated significantly ($p<0.05$) with physicochemical parameters. A total of 112 species of zooplankton were encountered during the Dry season, consisting of 47 species of Rotifera, 32 species of Cladocera and 33 species of Copepoda. While during the Rainy season, a total of 74 species of zooplankton were encountered, consisting of 29 species of Rotifera, 22 species of Cladocera and 23 species of Copepoda. The result revealed that Rotifera was the most dominant group in both the Dry and Rainy seasons, while Cladocera was the least encountered in both seasons. There were more zooplankton species encountered during the dry season than during the rainy season. This was attributed to the high photosynthetic activity during the dry season that provides the food for zooplankton. Rotifera was the most dominant group in both the Dry and Rainy seasons, while Cladocera was the least encountered in both seasons. Human activities around the catchment of the Lake should be monitored since they have significant effect on the water quality as revealed by the variations in physicochemical characteristics and zooplankton diversity.

Keywords: *Assessment, Diversity, Dominant, Physicochemical, Zooplankton*

INTRODUCTION

Water-bodies such as lakes and rivers are important systems of biodiversity and are among the most productive ecosystems on the earth because of the favourable conditions that supports a number of flora and fauna. They play a vital role in productivity as they are beset with varieties of flora and fauna including planktons. Urbanization, expansion of irrigation and increasing trend of

industrialization has contributed towards the demand for water. Most of the fresh water bodies all over the world are getting polluted, thus decreasing the portability of the water (Gupta, S.K., Dixit, S. and Tiwari, S. 2005). The pivotal role of plankton in aquatic food web cannot be overemphasized. Their importance as food to juvenile and adult fish is well known (Ogbeigbu, 2001). Plankton serves as bioindicator and is also an important tool for understanding water pollution status. Clausen and Biggs (1998) stated that the growing problem of degradation of our river ecosystem has necessitated the monitoring of water quality of various water-bodies to evaluate their production capacity, utility potential and to plan restorative measures. The efforts of hydrologists to preserve a healthy aquatic environment are strengthened through monitoring of the physicochemical condition of the water. Plankton diversity and physicochemical parameters are an important criterion for evaluating the suitability of water for drinking and other purposes (Fouzia and Amir, 2013). Plankton consists of phytoplankton and zooplankton. Phytoplanktons are the autotrophic components of the plankton community while zooplanktons are microscopic animals. They are found in oceans, seas, river, lakes, and ponds. Zooplankton feed mainly on phytoplankton. Zooplankton consume large quantities of phytoplankton, thereby limiting their abundance and preventing excessive algal blooms (Jiang *et al.*, 2019) while on the other hand acting as food source for a wide range of organisms of higher trophic levels, including larger invertebrates, fish and birds, thereby supporting the entire food web of aquatic ecosystems (Michaelidis *et al.*, 2020).

Changes in the phytoplankton community are rapidly affected by the zooplankton because of their short life cycles; this makes the zooplankton community a key element for the understanding of the changes occurring in aquatic ecosystems. The aim of this study is to carry out an analysis of the physicochemical conditions of Agulu Lake in Anambra State, and to assess the composition and abundance of zooplankton assemblage of the lake.

2.0. METHODOLOGY

2.1. Study Area

Agulu Lake is a natural lake that lies in a valley, with the surrounding slopes used for farming activities by the local population. The lake is located in Anambra State of Nigeria. Anambra State lies between Longitudes $6^{0}35^{1}$E and $7^{0}21^{1}$E, and Latitudes $5^{0}40^{1}$N and $6^{0}45^{1}$N. The climate is tropical with an average yearly rainfall of 2000mm and mean temperature of 27.6^{0}C. Heavy rainfall occurs within the months of April to October while the months of November to February have scanty rainfall, higher temperature and low humidity. The lake lies in a valley and the surrounding slopes are used for subsistence farming of various crops. The local population uses the lake for washing, fishing, ritual sacrifices and domestic water supply.

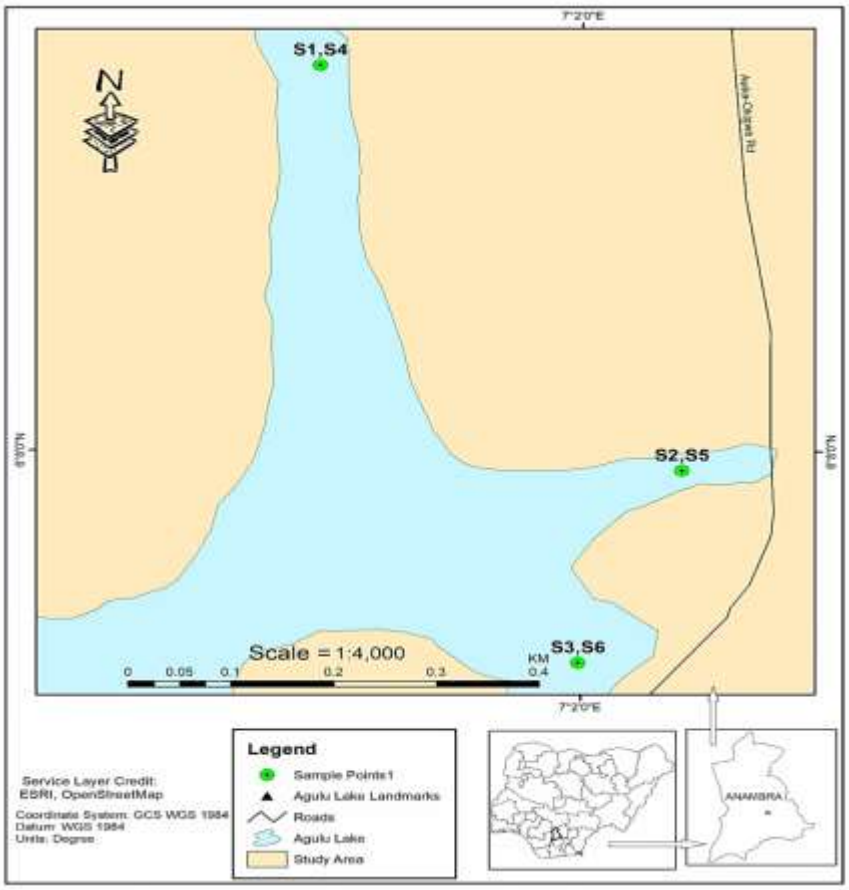

Figure 2.1: Map of Study Area showing Sampling Stations

2.2. COLLECTION OF SAMPLES

Samples were collected every month in sterilized containers from three of the six arms of the lake which constituted the three sampling stations of the study. The sampling stations were designated as SP1, SP2 and SP3 (dry season), and SP4, SP5 and SP6 (rainy season) with distance of at least 500 meters apart. The zooplanktons were collected with the use of plankton nets of size 50 µm which was used to drag through horizontally and vertically on the lake. The sampling was done in the morning before 8:00 am between the months of February 2023 - September 2023. Pour-through method was used to collect the samples. A 10-liter graduated bucked was used to collect water at a depth of about 30cm below the water surface and then poured into a plankton net of mesh size 50µm, this was done 10 times to make a total of 100litres of filtered water. The collected zooplankton were then carefully transferred into properly labeled storage containers, 4% of formalin was then added to serve as a preservative for the zooplankton. The samples were taken to the laboratory for further analysis.

The water samples were collected with sterile containers, properly labeled, stored in a refrigerator and taken to the laboratory within 72 hours of collection for analysis of physicochemical parameters of the lake.

2.3. Sample identification

Identification of the plankton was done with the use of a compound microscope. A dissecting microscope was used for sorting and counting the number of species. After they were taken to the laboratory, each preserved plankton sample was poured into a graduated centrifuge tube and centrifuged using a 'Gallen Kamp- Medico' model (90) centrifuge. This was allowed to settle and the supernatant decanted. After decanting the concentrated plankton was analyzed. The Specimens were mounted on glass slides and examined at 25-100X magnification. A pipette was used to place the concentrated plankton on a glass slide with a cover slip and then viewed under a compound. The planktons were then identified (qualitative analysis) and counted (quantitative analysis) using standard identification keys and taxonomic guide (Pennak, 1979; Jeje & Fernando, 1986). The general body shape, the color (Opaque or translucent), the relative length of appendages (e.g. antennae, legs) and setae (hair-like processes) were features used in identification of the zooplankton species. The above processes were repeated five times, in order to determine the abundance and diversity of zooplankton at the sampling locations during the Dry season (S1, S2 and S3) and during the Rainy season (S4, S5 and S6).

2.4. Determination of parameters

The Physicochemical parameters measured were temperature, pH, turbidity, conductivity, nitrate, phosphate, BOD, COD, dissolved oxygen, total suspended solids, total dissolved solids, total solids, total alkalinity, total hardness, potassium, sodium, chloride and calcium. The methods of determination of the parameters are as follows:

The temperature was determined *in situ* by using the mercury in glass thermometer in centigrade scale. A multi-purpose pH meter model D46 (pH/MV/^{O}C meter) was used to determine the pH of the water samples. The turbidity of the samples was measured in the laboratory using the LABTECH DIGITAL turbidity meters. The values were read out directly in nephelometric units (NTU) after the instrument had been standardized using already-prepared standard. The specific conductance of the samples was measured using the battery operated conductivity bridge model MC-1 mark V Electronic switchgear at room temperature. Total Dissolved Solids, Total Suspended Solids and Total solids were measured by gravimetric analysis. Alkalinity values were determined using the titration method. The total hardness was determined by Titrimetric method. Total Alkalinity, Total Hardness, Calcium, Chloride, Dissolved Oxygen, Chemical Oxygen Demand, and Biological Oxygen Demand were analyzed by the titration method. Potassium and Sodium were determined by Flame photometer; while Phosphate and Nitrate were analyzed by UV-visible spectrophotometer.

2.5. Statistical Technique

Species diversity index was determined using Shannon Wiener index found in the PAST Software Package. Correlation analysis was used to determine the relationship between physicochemical properties and the zooplankton diversity and abundance.

3.0. Result

The mean result of physicochemical parameters at different sampling points in Agulu Lake is shown in Table 3.1. The mean values of temperature in the lake, during the Dry season, varied from 28.3^{0}C at S3 to 28.8^{0}C at S1, and from 29.4 at S5 to 29.9 at S4 during the Rainy season. The mean values of pH in Agulu Lake during the Dry season ranged from 7.24 at S1 to 7.80 at S2 whereas during the Rainy season, the pH values ranged from 7.14 at S5 to 7.38 at S4. The turbidity values ranged from 10.42FTU (S3) to 20.06 FTU (S1) during the Dry season and from 9.42FTU (S6) to 10.66 FTU (S5) during the Rainy season. Conductivity values ranged from 26.6at S1 to 32.3 µohmCm^{-1} at S3 during the Dry season, while the values for the Rainy season ranged from 36.2 at S4 to 48.0 µohmCm^{-1} at S5. The mean TDS values during the Dry season varied from 47.56mg/L at S3 to 88.03 mg/L at S3 while the values during the Rainy season varied from 23.08 mg/L at S6 to 40.14 mg/L at S4. The mean TSS values for the Dry season ranged from 16.86 mg/L at S3 to 41.60 mg/L at S1 whereas for the Rainy season, the mean TSS values varied from 10.42 mg/L at S6 to 22.17 mg/L at S5. The mean values of TS for the Dry season ranged from 64.42 mg/L at S3 to 129.63 mg/L at S1 while the mean values during the Rainy season varied from 33.5 mg/L at S6 to 60.34 mg/L at S1.

The mean total alkalinity values during the Dry season ranged from 17.2 mg/L at S1 to 20.8 mg/L at S2 whereas for the Rainy season, the mean total alkalinity values varied from 14.2 mg/L at S5 to 17.8 mg/L at S4. The mean values of total hardness for the Dry season ranged from 42.0 mg/l at S2 to 53.4 mg/lat S3 while the mean values for the Rainy season varied from 36.2 mg/L at S4 to 45.7 mg/L at S5.

The mean calcium values during the Dry season ranged from 8.02 mg/L at S1 to 10.52 mg/l at S3 whereas for the Rainy season, the mean calcium values varied from 7.31 mg/L at S1 to 8.88 mg/L at S6. The mean values of chloride for the Dry season varied from 5.22 mg/L at S1 to 6.01 mg/L at S3 while the mean values for the Rainy season varied from 3.24 mg/L at S4 to 4.86 mg/L at S6.

The mean dissolved oxygen values for the Dry season ranged from 8.2mg/L at S3 to 14.3 mg/L at S1 whereas for the Rainy season, the mean dissolved oxygen values varied from 5.0 mg/L at S6 to 8.7 mg/L at S4. The mean values of COD during the Dry season varied from 2.8 mg/L at S1 to 5.7 mg/L at S2 while the mean values during the Rainy season varied from 6.4 mg/L at S4 to 8.6 mg/L at S6.

Table 3.1 Mean values of the physicochemical characteristics of Agulu Lake.

Parameters / Locations	Sampling Points					
	Dry season			Rainy Season		
	S 1	S 2	S 3	S 4	S 5	S 6
Temperature ^{0}C	28.8	28.5	28.3	29.9	29.4	29.6
pH	7.24	7.80	7.52	7.38	7.14	7.21
Turbidity (FTU)	20.06	14.62	10.42	10.48	10.66	9.42
Conductivity µohmCm^{-1}	26.6	29.2	32.3	36.2	48.0	44.4
TDS mg/L	88.03	64.22	47.56	40.14	28.64	23.08
TSS mg/L	41.60	24.01	16.86	20.20	22.17	10.42
TS mg/L	129.63	88.23	64.42	60.34	50.81	33.5
Total Alkalinity mg/L	17.2	20.8	19.5	17.8	14.2	16.9
Total Hardness mg/L	43.8	42.0	53.4	36.2	45.7	38.9
Calcium mg/L	8.02	8.97	10.52	7.31	8.26	8.88
Chloride mg/L	5.22	5.72	6.01	3.24	4.62	4.85
DO mg/L	14.3	12.8	8.2	8.7	5.7	5.0

COD mg/L	2.8	5.7	4.2	6.4	6.9	8.6
BOD mg/L	10.65	14.43	18.22	18.04	20.12	24.06
Phosphate mg/L	0.02	0.01	0.02	0.01	0.01	0.00
Potassium mg/L	2.26	2.10	2.42	1.77	2.08	2.03
Nitrate mg/L	0.02	0.01	0.005	0.003	0.02	0.01
Sodium mg/L	2.87	3.22	3.36	2.06	2.72	2.75

The mean values of BOD during the Dry season ranged from 10.65 mg/L at S1 to 18.22 mg/L at S3 whereas for the Rainy season, the mean values of BOD varied from 18.04 mg/L at S4 to 24.06 mg/L at S6. The mean values of phosphate during the Dry season varied from 0.01 mg/L at S2 to 0.02 mg/L at S1 while the mean values of phosphate during the Rainy season varied from 0.00 mg/L at S6 to 0.01 mg/L at both S4 and S5.

The mean values of potassium during the Dry season ranged from 2.10 mg/L at S2 to 2.42 mg/L at S3 whereas for the Rainy season, the mean values of potassium varied from 1.77 mg/L at S4 to 2.08 mg/L at S5. The mean values of nitrate during the Dry season varied from 0.005 mg/L at S3 to 0.02 mg/L at S1 while the mean values for the Rainy season varied from 0.003 mg/L at S4 to 0.02 mg/L at S5. The mean values of sodium in Agulu Lake during the Dry season varied from 2.87 mg/l at S1 to 3.36 mg/l at S3 while the mean values of sodium during the Rainy season varied from 2.06 mg/l at S4 to 2.75 mg/l at S6.

Table 3.2 Species composition of Rotifera in the zooplankton communities of the Sampling Points in Agulu Lake

Species	Sampling Points					
	Dry Season			Rainy Season		
	S 1	S 2	S 3	S 4	S 5	S 6
Diurella species	+	+	+	–	+	–
Keratella quadrata	+	+	+	+	–	–
Microcodon species	+	–	+	+	+	+
Brachionuscaudatus	+	+	+	+	+	+
Gastropushyptopus	+	+	+	–	+	–
Epiphanes macrourus	+	+	+	–	–	+
Lacane bulla	–	+	–	–	+	+

Lecane aculeate	+	+	−	−	−	−
Lecaneclosterocerca	−	+	−	−	+	−
Asplachna species	+	+	+	−	+	−
Dipleuchnispropatula	+	+	+	+	−	−
Anuraeopsisnavicula	−	−	+	−	+	+
Cephalodella spp.	+	+	−	+	+	+
Collotheca spp.	+	+	−	−	−	−
Filiniaopoliensis	+	+	+	−	−	+
Ascomorpha ovalis	+	+	−	+	+	−
Encentrum sp.	+	+	+	−	+	−
Filinia terminalis	+	−	+	+	−	−
Euchlanisdilatata	+	−	+	+	−	−
Epiphanes senta	+	+	−	+	+	−
Dicranophorus sp.			+	+		

+ = Present − = Absent

Table 3.2 presents the species composition of the Rotifera in Agulu Lake during the dry and rainy seasons.The most frequently encountered zooplankton species belonging to the Rotifera group during the dry season were *Anuraeopsisnavicula,Ascomorpha ovalis,Asplachna species,Brachionuscaudatus,Cephalodella spp.,Collotheca spp.,Dipleuchnispropatula,Diurella species, Encentrum sp., Epiphanes macrourus, Epiphanes senta, Euchlanisdilatata, Filiniaopoliensis, Filinia terminalis, Gastropushyptopus, Keratella quadrata, Lacane bulla,* Lecaneclosterocerca, and *Microcodon species,* while during the Rainy season the most commonly seen were *Anuraeopsisnavicula,Ascomorpha ovalis, Asplachna species, Brachionuscaudatus, Cephalodella spp., Dicranophorus sp., Dipleuchnispropatula, Diurella species, Encentrum sp., Epiphanes macrourus, Epiphanes senta, Euchlanisdilatata, Filiniaopoliensis, Filinia terminalis, Gastropushyptopus, Lacane bulla, Lecaneclosterocerca,* and *Microcodon species.*

Table 3.3 Species composition of Cladocera in the zooplankton communities of the sampling points in Agulu Lake

Species	Sampling Points					
	Dry Season			Rainy Season		
	S 1	S 2	S 3	S 4	S 5	S 6
Paramaecium caudatum	+	+	+	+	+	+
Moina reticulata	+	−	−	+	+	+
Amoeba species	+	+	+	+	+	+
Diaphanosomaspinulosum	+	−	−	−	−	−
Diaphanosomaexcisum	+	+	+	−	−	+
Ceriodaphniasilvestrii	−	−	+	−	+	+
Carchesiumpolypium	+	+	−	−	+	+
Paramaecium Aurelia	+	+	+	+	−	+
Arcella species	+	+	−	−	−	−
Macrothrix spinosa	+	−	−	−	+	−
Daphnia gessneri	−	+	+	+	−	−
Acroperus arpae	+	+	+	−	−	−
Alona eximia	−	−	+	+	−	+
Alona davidi	+	−	+	−	−	−
Alona monacantha	+	+	+	−	+	−
Eurialonabrasiliensis	+				+	

+ = Present − = Absent

Table 3.3 presents the species composition of the Cladocera in Agulu Lake during the dry and rainy seasons. The most commonly seen zooplankton species during the dry season belonging to the Cladocera group were *Acroperus arpae*, *Alona davidi*, *Alona eximia*, *Alona monacantha*, *Amoeba species*, *Arcella species*, *Carchesiumpolypium*, *Ceriodaphniasilvestrii*, *Daphnia gessneri*, *Diaphanosomaspinulosum*, *Eurialonabrasiliensis*, *Macrothrix spinosa*, *Moina reticulata*, *Paramaecium Aurelia*, *Paramaecium caudatum*,and*Diaphanosomaexcisum*, while the most frequently encountered species during the Rainy season were *Alona eximia*, *Alona monacantha*,

Amoeba species, Carchesiumpolypium, Ceriodaphniasilvestrii, Daphnia gessneri, Eurialonabrasiliensis, Macrothrix spinosa, Moina reticulata, Paramaecium Aurelia, Paramaecium caudatum, and Diaphanosomaexcisum.

Table 3.4 Species Composition of Copepoda in the zooplankton communities of the different sampling points in Agulu Lake

Species	Sampling Points					
	Dry Season			Rainy Season		
	S 1	S 2	S 3	S 4	S 5	S 6
Mesocyclops species	+	+	−	+	+	−
Nuplius larvae	−	−	−	+	+	−
Zoea larvae	+	+	+	+	−	+
Macrocyclops species	+	+	−	−	+	−
Cathocamptus sp.	+	+	+	+	−	+
Helobdella	−	−	+	−	+	+
Limnocalanussp	+	+	−	−	−	+
Nauplius species	+	+	−	−	−	−
Cyclops species	+	+	+	−	+	−
Diaptomus	+	+	−	+	+	−
Diacyclops sp.	−	−	−	+	−	−
Argyrodiaptomus furcatus	+	+	+	+	−	−
Paracyclopsfimbriatus	−	+	−	−	−	−
Thermocyclopsdecipiens	+	+	+	−	−	+
Thermocyclops minutes	+	+	+	+	+	−
Mesocyclopslongisetus	+	−	−	−	+	−
Mesocyclopsbrasilianus	+	−	+		+	+

+ = Present − = Absent

Table 3.4 revealed that the most frequently encountered zooplankton species during the Dry season belonging to the Copepoda group were *Argyrodiaptomus furcatus, Cyclops species, Cathocamptus*

sp., Limnocalanussp, Diaptomus, Helobdella, Macrocyclops species, Mesocyclops species, Nauplius species, Paracyclopsfimbriatus, Thermocyclopsdecipiens, Thermocyclops minutes, and *Zoea larvae*; while the most frequently encountered during the Rainy season were *Argyrodiaptomus furcatus,Diacyclops sp. species, Cyclops species, Cathocamptus sp., Limnocalanussp, Diaptomuspps,Helobdellaspp, Macrocyclops species, Mesocyclops species, Nuplius larvae, Paracyclopsfimbriatus, Thermocyclopsdecipiens, Thermocyclops minute and Zoea lar*

Table 3.5 Number of species of Rotifera, Cladocera and Copepoda in the sampling points of Agulu Lake

GROUP	SAMPLING POINT							
	Dry Season				Rainy Season			
	S1	S2	S3	Total	S4	S5	S6	Total
Rotifera	17	16	14	47	10	12	7	29
Cladocera	13	9	10	32	6	8	8	22
Copepoda	13	12	8	33	8	9	6	23
Total	43	37	32	**112**	24	29	21	**74**

A total of 112 species of zooplankton were encountered during the Dry season, consisting of 47 species of Rotifera, 32 species of Cladocera and 33 species of Copepoda. This is in line with the finding of Emmanuel *et al.* (2008) who reported three taxa of Zooplankton in Calabar River. 43, 37 and 32 zooplankton species were encountered in S1, S2 and S3 respectively. S1 had the highest number of Rotifera (17), Cladocera (13) and Copepoda (13); S3 had the lowest number of Rotifera (14) and Copepoda (8), while S2 had the lowest number of species of the Cladocera (9) group (Table 3.2). However, during the Rainy season, a total of 74 species of zooplankton were encountered, consisting of 29 species of Rotifera, 22 species of Cladocera and 23 species of Copepoda. 24, 29 and 21 zooplankton species were encountered in S4, S5 and S6 respectively. S5 had the highest number of Rotifera (12) and Copepoda (9) while S6 had the lowest number of both Rotifera (7) and Copepoda (6); S5 and S6 both had the same number (8) of Cladocera while S4 had the lowest number (6) of species of the Cladocera group. More zooplankton species (115) were encountered in the Dry season than in the Rainy season (64). The result revealed that Rotifera was the most dominant group in both the Dry and Rainy seasons, while Cladocera was the least encountered in both seasons.

Table 3.6. Pearson Correlation (r-values) calculated between zooplankton diversity and physico-chemical parameters of Agulu Lake during the Dry Season

	Temp	p H	Turb	E C	TDS	TSS	T S	T Alk	T HD	C a	Cl^-	D O	C O D	B O D	PO_4	K	NO_2	N a
R o t	0 . 2	0 . 3	0 . 2	0 . 3	0 . 2	0 . 1	0 . 2	0 . 2	0 . 7	0 . 4	0 . 2	0 . 5	0 . 1	0 . 2	0 . 2	1	0 . 2	0 . 1
C l a	0 . 5	0 . 0	0 . 5	0 . 6	0 . 5	0 . 4	0 . 5	0 . 0	0 . 9	0 . 7	0 . 5	0 . 7	0 . 4	0 . 4	0 . 4	0 . 7	0 . 4 9	0 . 4
Copepoda	0 . 0	0 . 5	0 . 0	0 . 1	0 . 0	0 . 0	0 . 0	0 . 4	0 . 5	0 . 2	0 . 0	0 . 3	0 . 0 7	0 . 0 0	9 . 0 0 1	0 . 7	9 . 0 0 3	0 . 0 3

Temp = Temperature, Turb = Turbidity, EC = Electrical Conductivity, TDS = Total Dissolved Solids, TSS = Total Suspended Solids, TS = Total Solids, T Alk = Total Alkalinity, T HD = Total Hardness, Ca = Calcium, Cl^- = Chloride, DO = Dissolved Oxygen, COD = Chemical Oxygen Demand, BOD = Biological Oxygen Demand, PO_4 = Phosphate, K = Potassium, NO_2 = Nitrate, Na = Sodium

Table 3.7. Pearson Correlation (r-values) calculated between zooplankton diversity and physico-chemical parameters of Agulu Lake during the Rainy Season

	Temp	p H	Turb	E C	TDS	TSS	T S	T Alk	T HD	C a	Cl^-	D O	COD	BOD	PO_4	K	NO_2	N a
R o t i f	0 . 0	0 . 1	0 . 9	0 . 1	0 . 5	0 . 8	0 . 7	0 . 1	0 . 1	0 . 5	0 . 4	0 .	0 . 6	0 . 6	0 . 0	0 . 2	0 . 0	0 . 3
C l a d o	0 . 1	0 . 0	0 . 9	0 . 0	0 . 3	0 . 9	0 . 5	0 . 3	0 . 3	0 . 4	0 . 2	0 . 2	0 . 4	0 . 4	0 . 2	0 . 0	0 . 2	0 . 1
Copepoda	0 . 7	0 . 8	0 . 2	0 . 8	0 . 7	0 . 2	0 .	0 . 4	0 .	0 . 7	0 . 9	0 . 8	0 . 6	0 . 6	0 . 6	0 . 9	0 . 6	0 . 9

Temp = Temperature, Turb = Turbidity, EC = Electrical Conductivity, TDS = Total Dissolved Solids, TSS = Total Suspended Solids, TS = Total Solids, T Alk = Total Alkalinity, T HD = Total Hardness, Ca = Calcium, Cl^- = Chloride, DO = Dissolved Oxygen, COD = Chemical Oxygen Demand, BOD = Biological Oxygen Demand, PO_4 = Phosphate, K = Potassium, NO_2 = Nitrate, Na = Sodium

Tables 3.6 and 3.7 show the relationship between physicochemical parameters and zooplankton biomas in Agulu Lake during the Dry and Rainy seasons respectively. The zooplanktons identified belong to three groups: Rotifera, Cladocera and Copepoda. The relationship between Physicochemical properties and zooplankton abundance revealed that there was significant correlation between zooplankton and some physicochemical parameters. This finding is in line with that of Ewa *et al.* (2017) who in their research on the effect of physicochemical parameters on zooplankton in th Brackish Coastal Vistula Lagoon reported significant correlation between the occurrence of zooplanktons and some physicochemical characteristics in the lagoon.

During the Dry season (Table 3.6) Rotifera showed high positive correlation with Total Hardness (0.76049), exhibited perfect correlation with K (1), and low positive correlation with other parameters. Cladocera showed very high positive correlation with Total Hardness (0.95856), high positive correlation with Ca (0.70193), DO (0.79597), K (0.71906) and EC (0.64649); and exhibited moderate correlation with Temperature (0.54109), Turbidity (0.56709), TDS (0.54956), TS (0.51592), Cl^- (0.51733), TSS (0.46214), COD (0.42005), BOD (0.48759), PO_4 (0.49324), NO_2 (0.49324) and Na (0.45986). Cladocera showed low positive correlation with other parameters. Copepoda showed very high positive correlation Cl^- (0.91568), K (0.90401), pH (0.81696), EC (0.8076), DO (0.88603), Na (0.97551), and showed high positive correlation with Temperature (0.73985), TDS (0.79296), Ca (0.74355), COD (0.67934), BOD (0.65821), PO_4 (0.60203), and NO_2 (0.60203). Copepoda also exhibited moderately positive correlation with TS (0.5611), Total Hardness (0.5112), and Total Alkalinity (0.48775).

Whereas during the Rainy season (Table 3.7) Rotifera showed very high positive correlation with Turbidity (0.91423) and TSS (0.89994), and exhibited high positive correlation with TS (0.77223), COD (0.65399) and BOD (0.67512). Rotifera also exhibited moderate positive correlation with TDS (0.54037), Ca (0.58979), Cl^- (0.41766), and DO (0.4473), and low positive correlation with other parameters. Cladocera showed very high positive correlation with Turbidity (0.90686) and TSS (0.92115), and also showed moderate positive correlation with TS (0.59332), Ca (0.41087), COD (0.47508), and BOD (0.49621). Copepoda correlated very highly positively with Na (0.97551), Cl- (0.91568), K (0.90401), pH (0.81696), EC (0.8076), and DO (0.88603), and showed high positive correlation with Temperature (0.73985), TDS (0.79296), Ca (0.74355), COD (0.67934), BOD (0.65821), PO4 (0.60203), and NO2 (0.60203); and exhibited moderate positive correlation with TS (0.5611), Total Hardness (0.5112), and Total Alkalinity (0.48775), and also showed low correlation with other parameters. The strong relationship between zooplankton and the various physicochemical parameters in the lake is in line with the findings of Suresh *et al.* (2011) who reported that different environmental factors affecting the characteristics of water have enormous impact upon the growth and abundance of zooplankton.

4.0. DISCUSSION

It has been reported that many species of zooplanktons are limited by dissolved oxygen, temperature, salinity and other physico-chemical factors (Jeje & Fernando, 1986; Esenewo, Ugwumba & Akpan, 2017). Temperature is a very important physical parameter used in determining water quality. Higher temperature regimes during the dry season coupled with high level of food in the water as a result of high primary productivity (phytoplankton), can be responsible for the high populations of zooplankton (Adadu, Omeji & Garba, 2019).There were slight variations in the mean values of temperature at all the sites in Agulu Lake during the Dry and Rainy seasons. The values of the water temperature of the lake for the two seasons were within the NESREA recommended range limits of 25^0C - 31^0C for surface water in the tropical region (Esenowo *et al.*, 2017). However, slightly lower mean values of temperature were recorded during the Dry season compared to the Rainy season. The range of pH values recorded in this study were in line with the pH range recorded in some other studies (Abdullahi, Moses and Kwaya, 2019; Odo, 2004; Attama, 2003). In this present study, the highest mean pH value in Agulu Lake during the Dry season was recorded in S2 (7.80) while the highest in during the Rainy season was recorded in S4 (7.38). This could explain the greater diversity of zooplankton during the Dry season compared to the Rainy season since planktons are known to thrive better in alkaline conditions.

The turbidity values in Agulu Lake were higher for the Dry season than the values recorded for the Rainy season. Turbid water may provide nutrients needed for primary productivity. This may have contributed to the higher zooplankton diversity during the Dry season.

Electrical conductivity is good indicator of water quality (Gaikwad *et al.*, 2008). The maximum mean conductivity value (32.3 µohmCm^{-1}) for Agulu Lake during the Dry season was recorded at S3 while the maximum value (48.0 µohmCm^{-1}) was recorded at S5 during the Rainy season. The higher electrical conductivity recorded during the Rainy season is attributed to the fact that water evaporates during the Rainy season, leading to increase in concentration of ions which result in increase in electrical conductivity. Likewise, in the Rainy season the dilution of the ions due to rainwater results in a decrease in electrical conductivity.

Higher values of TDS were recorded during the Dry season compared to the Rainy season. The highest value of TDS during the Dry season was recorded at S1 (88.03 mg/L) and the least value was recorded at S3 (47.56mg/L); while the highest value of TDS during the Rainy season was recorded at S4 (40.14 mg/L) and the lowest value was recorded at S6 (23.08 mg/L). TSS can affect zooplankton diversity by decreasing water's natural dissolved oxygen levels. The TSS values were higher during the Dry season compared to the Rainy season. The mean TSS value for the Dry season was highest at S1 (41.60mg/L) and lowest at S3 (16.86mg/L), whereas for the Rainy season, the mean TSS value was highest at S5 (22.17 mg/L) and lowest at S6 (10.42 mg/L).

TS is a measure of suspended and dissolved solids in water. Agulu Lake recorded higher mean values of TS during the Dry season than during the Rainy season. The highest value of TS for the Dry season was recorded at S1 (129.63mg/L) and the lowest value was recorded at S3 (64.42mg/L), while the highest value of TS for the Rainy season was recorded at S4 (60.34 mg/L) and the lowest value at S6 (33.5mg/L).

Agulu Lake recorded higher alkalinity values during the Dry season compared to the Rainy season. Alkalinity is the buffering capacity of water body. It is a measure of the ability of water body to neutralize acids and bases and thus maintain a fairly stable pH level. The highest total alkalinity value for the Dry was recorded at S2 (20.8mg/L) and the lowest value was recorded at S1 (17.2mg/L), whereas for the Rainy season, the highest total alkalinity value was recorded at S4 (17.8 mg/L) and the lowest value was recorded at S5 (14.2 mg/L).

Total hardness is chiefly a measure of calcium and magnesium. According to Fouzia & Amir (2013), a desirable range of calcium hardness concentration in water is 75 mg/L to 250 mg/L with a minimum concentration of 20 mg/L. The water hardness of the lake during the Dry season was higher than the values recorded during the Rainy season. For the Dry season, the highest value of total hardness was recorded at S3 (53.4mg/L) and the lowest value at S2 (42.0mg/L), while for the Rainy season, the highest value of total hardness was recorded at S5 (45.7 mg/L) and the lowest at S4 (36.2 mg/L).

The calcium values recorded were higher during the Dry season compared to the values recorded for the Rainy season. The highest calcium value for the Dry season was recorded at S3 (10.52mg/L) and the lowest at S1 (8.02mg/L), whereas for the Rainy season, the highest was recorded at S6 (8.88 mg/L) and the lowest at S4 (7.31 mg/L).

Also, Agulu Lake recorded higher chloride values during the Dry season than during the Rainy season. The highest value of chloride during the Dry season was recorded at S3 (6.01mg/L) and the lowest value was recorded at S1 (5.22mg/L), while the highest value of chloride during the Rainy season was recorded at S6 (8.85 mg/L) and the lowest at S4 (3.24 mg/L).

Dissolved oxygen is the amount of oxygen that is present in water. It is an important indicator of water quality. The highest value of dissolved oxygen during the Dry season was recorded at S1 (14.3 mg/L) while the lowest value was recorded at S3 (8.2mg/L), whereas for the Rainy season, the highest dissolved oxygen value was recorded at S4 (8.7 mg/L) and the lowest was located at S6 (5.0 mg/L). The highest mean dissolved oxygen concentration of the lake during the Rainy season was greater than the limit for drinking water put at 5mg/L to 9mg/L (UNESCO, UNEP, WHO, 1996), while the lowest value was within the limit; whereas the mean values of dissolved oxygen for the Rainy season did not exceed the limit. The high dissolved oxygen content of the lake during the Dry season may have contributed to the greater diversity of zooplankton species in the lake during the Dry season. Dissolved oxygen determines the occurrence and abundance of aquatic life. According to WHO (2006), aquatic organisms are found in areas of high oxygen concentration.

COD is the amount of oxygen required to oxidize all soluble and insoluble organic compounds in water. The highest COD value during the Dry season was recorded at S2 (5.7mg/L) while the lowest COD value was recorded at S1 (2.8mg/L); whereas the highest COD value for the Rainy season was recorded at S6 (8.6 mg/L) and the lowest at S4 (6.4 mg/L). Agulu Lake recorded lower values of COD during the Dry season than during the Rainy season. High COD indicates lower amount of dissolved oxygen which can in turn lead to death of aquatic life forms.

BOD measures the amount of oxygen consumed by microorganisms in decomposing organic matter in water. The highest value of BOD in Agulu Lake during the Dry season was recorded at S3 (18.22 mg/L) and the lowest value was recorded at S1 (10.65 mg/L), whereas during the Rainy season, the highest BOD value was recorded at S6 (24.06 mg/L) and the lowest at S1 (18.04 mg/L). Higher BOD values were recorded during the Rainy season than during the Dry season. The higher BOD value recorded during the Rainy season could be due to organic matter degradation which utilized oxygen within the lake. This further explains the lower dissolved oxygen values of the lake recorded during the Rainy season. Going by the classification of water bodies according to Adakole, Balogun and Lawal (2002) and (Zakariya *et al.*, 2013): BOD < 1.0 mg/L (unpolluted); BOD < 10.0 mg/L (moderately polluted) and BOD > 10.0 mg/L (Heavily polluted), the result of the study revealed a heavily polluted water body.

During the Dry season, Agulu Lake recorded highest value of phosphate at S1 (0.02 mg/L) and S3 (0.02 mg/L) and lowest value at S2 (0.01 mg/L), whereas during the Rainy season, the highest value of phosphate was recorded at both S4 (0.01 mg/L) and S5 (0.01 mg/L). Nutrient enrichment stimulates phytoplankton growth (Chen *et al*., 2008) which in turn supports zooplankton community. The mean phosphate values for the Dry season were higher than the values for the Rainy season, but they were all within the concentration range of natural waters of 0.090 mg/L (UNESCO, UNEP, WHO, 1996).

The highest value of potassium for the Dry season was recorded at S3 (2.42 mg/L) and the lowest value at S1 (2.26 mg/L), whereas for the Rainy season, the highest value of potassium was recorded at S5 (2.08 mg/L) and the lowest value was recorded at S4 (1.77 mg/L).

The highest value of nitrate in the lake during the Dry season was recorded at S1 (0.02 mg/L), while the lowest value of nitrate was recorded at S3 (0.005 mg/L). The low level of nitrate detected is at variance with the findings of Wolfhard and Reinhard (1998). The highest value of nitrate during the Rainy season was recorded at S5 (0.02 mg/L) while the lowest value was recorded at S4 (0.003 mg/L). The mean values of nitrate were within the concentration range of unpolluted waters of 0.1 mg/L (UNESCO, UNEP, WHO, 1996), and far below the Nitrate concentration of 4.41 mg/L and 8.8 mg/L recorded by Odo (2004) and Anyanwu (2009) respectively in other water bodies.

The highest value of sodium in Agulu Lake during the Dry season was recorded at S3 (3.36 mg/L) and the lowest value at S1 (2.87 mg/L), while during the Rainy season, the highest value of sodium was recorded at S6 (2.75 mg/L) and the lowest value at S4 (2.06 mg/L). There was narrow variation in the sodium concentrations in the different sampling points of the lake.

Many interacting physical, chemical and biological factors can influence zooplankton species composition, in both lakes and rivers. The abundance of zooplankton depends on a number of factors such as climatic change, habitat physicochemical characteristics and biotic factors (Alexander, 2012). Dumont *et al.* (1994) reported that freshwater zooplankton may contain a diverse set of taxonomical categories. In this study**,** three groups of Zooplanktons were identified in Agulu Lake: the Rotifera, Cladocera and Copepoda. According to Hutchinson (1967), the main groups consisting of the zooplankton communities are the protozoans, rotifers and crustaceans,

particularly copepods and cladocerans. High seasonal variation of the zooplankton communities was observed in Agulu Lake. This is in line with the findings of Umi *et al.* (2018) and Sharip *et al.* (2017). There were more zooplankton species encountered during the dry season than during the rainy season. This was attributed to the high photosynthetic activity during the dry season that provides the food for zooplankton. Rotifera was the most dominant group in both the Dry and Rainy seasons, while Cladocera was the least encountered in both seasons. Also, the most abundant species of Rotifera was *Brachionuscaudatus* for both the dry and rainy seasons, and the most abundant species of *Cladocera* was *Paramaecium Aurelia* for the dry season, and *Paramaecium caudatum* during the rainy season. The most abundant species of Copepoda was *Zoealarvae* during the dry season, and *Zoea larvae* and *Daphnia species* during the rainy season.

5.0. CONCLUSION

A good number of species of zooplankton belonging to three taxa were encountered in both the dry and rainy seasons. This could be attributed to the favorable prevailing environmental conditions of the Lake.

The significant correlation between the parameters and the zooplankton species showed that the abundance of zooplankton was influenced partly by the physicochemical characteristics of the lake and by climatic factors.

Also, the seasonal variations in physicochemical parameters of the lake are reflections of the rainfall patterns and anthropogenic activities around the drainage basins of the rivers which impact significantly on the water quality and zooplankton diversity. The correlation analysis indicated that the different physicochemical parameters exert a great influence on the zooplankton distribution and abundance.

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