



Research Article

Distribution and Diversity of Phytoplankton in Lake Alau,  
Maiduguri, Northeast Nigeria

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ABSTRACT

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Phytoplankton provides the fundamental stage in energy flow through primary production in aquatic ecosystems. Season and physicochemical parameters play a significant role in their distribution and abundance. This study determined the relationship between phytoplankton diversity and Spatio-temporal changes in physicochemical parameters of Lake Alau, Maiduguri, Nigeria. Samples were collected for 12 months (dry and wet seasons) at some stations. A total of 40 species belonging to 6 taxa were identified. Chlorophyceae was the dominant taxa for both seasons. Nitrate–nitrogen and phosphate-phosphorous limit the growth of phytoplankton in the reservoir. Effects of season on phytoplankton composition and abundance of each station varied with months. Phytoplankton abundance and distribution show three phases, separated by a shift in nutrient concentration, physicochemical factors, and season. The abundance of phytoplankton in the lake depends on nutrient availability. They were within the ranges of allowable limits recommended by regulatory agencies on water bodies.

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## INTRODUCTION

Freshwater Lakes are large masses of standing water, created by impounding the run-off water or major streams or rivers as a reservoir. Often, this entails building a dam at the end of the river valley. The Lakes then form inundating large tracts of land. Lakes epitomize positive development which can result in negative in the long run if not properly planned before establishing them. The creation of a large dam in a riverine environment could affect the socio-economic problems both at the upstream and downstream sectors of the entire catchment basin (Blackmore, 2000). The foundation of aquatic food webs that support the stability and functionality of reservoir ecosystems is phytoplankton. Therefore, in order to evaluate the consequences of anthropogenic influences and climate change on reservoir ecosystems and to develop strategies for adaptively managing water quality in a changing world, it is imperative to understand how environmental forces affect phytoplankton communities (Znachor *et al.*, 2020).

One of the most important components of the aquatic ecosystem for preserving stability and providing a way to adapt to changes in the environment is phytoplankton. Thus, the observation of phytoplankton community structure can be a useful and trustworthy method for biological monitoring studies that evaluate the level of pollution in aquatic environments. The majority of the aquatic body's producers and the base of the ecological pyramids are phytoplankton (Hossain *et al.*, 2017).

The quantity and assemblage structure of phytoplankton populations are primarily governed by a range of inorganic nutrients and water quality parameters. Plankton species are utilized as indicators of water quality because they are highly sensitive to changes in their habitat and react promptly to any disturbance (Sharma *et al.*, 2020).

Primary productivity is a measure of new organic matter created in the water body (Wetzel, 2001). Species composition, diversity

and distributions are influenced by geographical locations and quality, which can be adversely affected by human activity (Bell, 2012). Every water body's physico-chemical characteristics and phytoplankton diversity are correlated, and the surrounding land use and land cover pattern play a major role in determining the water quality at point sources that feed into freshwater streams (Sharma *et al.*, 2020).

This study aimed to provide some aspects of water quality status and phytoplankton composition and distribution for monitoring the health of Lake Alau and its biodiversity.

## MATERIALS AND METHODS

### Study area

Lake Alau reservoir is the largest impounded water body in Borno state, North-eastern Nigeria. It was constructed in 1987 by the Borno State Government, through a World Bank-assisted project, with the primary aim of providing domestic water supply to Maiduguri Metropolis. The intervention of a large dam in the riverine environment could affect the catchments around the entire basin (Blackmore, 2000). Alau Dam (11°41'43.8"N, 13°16'19.0"E) reservoir is located about 19 km from Maiduguri, along Maiduguri – Bama Road (Borno State Ministry of Land and Survey [BSMS], 2020). It has a total surface area of 56 Km<sup>2</sup> with two distinct seasons; a rainy season with mean annual rainfall of about 600 mm from July to October, and a hot dry season from March to July. The dry season is preceded by a period of harmattan with very low temperatures and dry harmattan wind between November and February. It has a maximum depth of 10m with an effective storage capacity of 54,000 ha (Chad Basin Development Authority [CBDA], 1984).

### Sampling Stations

Sampling stations were selected after the preliminary surveys of the reservoir, based on factors such as lake volume or size of water, flushing rate, accessibility, security, and human activities around the catchment. Four sampling stations were chosen and sampling

was conducted every month, covering both the dry season and wet season (Table 1)

**Table 1:** Description of the sampling station in Lake Alau, Maiduguri, Northeast Nigeria

| Station   | Description  |
|-----------|--|
| Station 1 | Near the dam; the spillway and outlet; the pumping station by the Borno State Water Board  |
| Station 2 | Adjacent to the school of fisheries; surrounded by thick macrophytes vegetation (submerged and emergent). The runoff from a canal in the school empties into this station. It is a regular site for irrigation farming for vegetables.   |
| Station 3 | Around Alau Ngaufere, fishing village's close to the limit of reservation. The water body is ~102 m wide and supported by a big dyke surrounded by heavy stones, which act as a pathway for farmers and villagers surrounding the area. The water is used for all sorts of domestic activities (washing, bathing, drinking) and irrigation.  |
| Station 4 | At Abari village, the nucleus of the fish camps for Maiduguri metropolis and its environs. The water body and the beds in this station widen considerably. The width of the water body is ~2 Km. The station is also a major fish landing site, it is the biggest among the four stations. Numerous outcrops of rocks appear within the water course sometimes forming barriers that create fast currents above the average flow rate. There is a great deal of human interference across the lake with fishermen padding and littering the littoral edge with their fishing gear. |

### Sample collection

The period of study was from October 2020 to October 2021. Three water samples per station were collected monthly in a 2 L sampling bottle during the dry season and wet season. Samples were transported in a cooler until analysis.

### Determination of physicochemical parameters

Water temperature and transparency were determined *in situ*, and other parameters (Total dissolved solute (TDS), pH, colour, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), conductivity, magnesium, iron, manganese, copper, phosphorous, chromium and nitrogen) were determined as described by APHA (1998) at the research laboratory of Department of Biological Sciences, University of Maiduguri.

### Identification of phytoplankton

Water samples from the surface of the lake were collected monthly using 2L sampling bottles from the stations. Sub-sample (100 mL) was immediately fixed with lugols solution iodine to preserve the phytoplankton.

Phytoplankton was identified using standard guidelines under the Olympus stereo microscope as described by Belcher and Swale (2008).

### Statistical analysis

Data on physicochemical parameters were analyzed using one-way analysis of variance (ANOVA). Phytoplankton occurrence was analysed using simple descriptive statistics. Means were compared using Fisher's LSD. Correlation was used to determine the relationship between water quality parameters and the abundance and diversity of phytoplankton. All data were significant at  $p < 0.05$ .

### RESULTS

The periodic atmospheric temperature mean showed significant differences between months and stations. The lowest pooled mean value of  $29.1 \pm 0.01^\circ\text{C}$  was recorded in November, (range 29.5 – 30.2) while the highest value of  $42.2 \pm 0.03^\circ\text{C}$  was recorded in May (range 42.0 – 42.3) (Table 2). There were no significant differences between all the stations ( $p < 0.05$ ) in these months. The lowest pooled mean value of  $33.3 \pm 0.02^\circ\text{C}$  was recorded in station 2 (range 28.1- 42.2), while

the highest value of  $33.6 \pm 0.01^\circ\text{C}$  (range 29.0 – 42.1) was recorded in station 4. Other higher values were obtained in March, April and May, while lower values were obtained from June to October (Table 3). The lowest pooled mean of  $23.7 \pm 0.16^\circ\text{C}$  (range 23.3 – 24.1) was recorded in February, while the highest value of  $31.0 \pm 0.14^\circ\text{C}$  was recorded in May (range 30.5 – 31.8). Although other higher values were recorded in May, September and October with no significant difference, ( $p < 0.05$ ). Also, lower values were recorded in January, February, March and April, ( $p < 0.05$ ) (Table 2). In terms of stations, the lowest pooled mean value of  $27.1 \pm 0.10^\circ\text{C}$  (range 20.8 – 30.5) was recorded in station 1, while the highest value of  $28.1 \pm 0.20^\circ\text{C}$  was recorded in station 4 (range 22.1 – 31.8). There was no significant difference between all the stations ( $p < 0.05$ ) (Table 3).

For the pH, the lowest pooled mean value of  $7.0 \pm 0.00$  was recorded in October (7.5 – 7.5), while the highest mean value of 8.6 was recorded in June (range 8.0 – 9.0), which is slightly higher compared to the rest of the months. The lowest pooled mean value of  $7.5 \pm 0.00$  (range 7.0 – 8.5) was recorded in station 1, and the highest value of  $7.7 \pm 0.00$  (range 7.5 – 9.0) was recorded in stations 3 and 4. There was no significant difference ( $p < 0.05$ ) in the pooled pH of all the stations (Table 3). The highest mean transparency of  $25.6 \pm 0.02\text{cm}$  was recorded in October (range 16.5 – 17.1) and the lowest value of  $5.6 \pm 0.02\text{cm}$  (range 3.5 – 7.5) was recorded in July. Other higher values are recorded from October to May with no significant differences, ( $p < 0.05$ ) (Table 2).

The lowest pooled mean turbidity of  $34.25 \pm 0.01$  (FTU) was recorded in January (range 11.00– 61.00), while the highest value of  $62.63 \pm 0.06$  (FTU) was recorded in December (range 59.80 – 68.00) which was no significantly different, between the values recorded in November and December, ( $p < 0.05$ ) (Table 2). The lowest pooled mean value of  $24.74 \pm 0.03$  (range 11.00 – 68.00) (FTU) was recorded in station 2, and the highest value of  $73.58 \pm 0.02$  (range 57.60 – 88.50) (FTU) was recorded in station 4. The values obtained in stations 3 and 4 are significantly higher ( $p < 0.05$ ), compared to the rest of the stations (Table 3).

The lowest pooled mean conductivity value of  $141.9 \pm 0.00$   $\mu\text{m/cm}$  was recorded in October

(range 92.6 – 189.8) and the highest value of  $217 \pm 0.01$  (range 152.0 – 268.0)  $\mu\text{m/cm}$  was also recorded in October, exactly a year after. In terms of stations, the lowest pooled mean value of  $123.9 \pm 0.02$   $\mu\text{m/cm}$  (range 92.6 – 152.0) was recorded in station 1, and the highest value of  $235.7 \pm 0.01$   $\mu\text{m/cm}$  was recorded in station 3 (range 189.8 – 267.1). The conductivity for stations 3 and 4 is significantly different ( $p < 0.05$ ) compared to stations 1 and 2 (Table 3).

The lowest pooled mean DO value of  $4.7 \pm 0.01$  mg/l was recorded in June (range 2.0 – 6.9) and the highest value of  $11.3 \pm 0.02$  mg/l was recorded in May (range 10.2 – 12.5). Other higher values are recorded from December to April, with no significant differences, ( $p < 0.05$ ) (Table 2).

In terms of stations, the lowest pooled mean value of  $5.6 \pm 0.01$  mg/l for DO was recorded in station 4 (range 2.0 – 10.5), and the highest value of  $9.2 \pm 0.02$  mg/l was recorded in station 2 (range 6.8 – 12.5) (Table 3). The lowest pooled mean BOD value of  $0.43 \pm 0.01$  mg/l was recorded in October (range 0.30 – 0.60) and the highest value of  $0.80 \pm 0.03$  mg/l was recorded in September (0.50 – 0.80). Other higher values were recorded in November and December (Table 2). The lowest DO value of  $0.55 \pm 0.02$  mg/l was recorded in station 4 (0.20 – 0.80), and the highest value of  $0.65 \pm 0.03$  mg/l was recorded in station 2 (0.40 – 0.90). There was no significant difference between all the stations ( $p < 0.05$ ) (Table 3). The lowest pooled mean TDS value of  $63.6 \pm 0.02$  mg/l was recorded in November (range 42.0 – 85.0) and the highest value of  $117.8 \pm 0.05$  mg/l was recorded in October (range 79.4 – 148.0). Other higher values were recorded in June, July, August and September (Table 2). The lowest pooled mean value  $63.0 \pm 0.02$  mg/l was recorded in station 1 (range 43.4 – 79.5), and the highest value of  $124.8 \pm 0.02$  mg/l was recorded in station 3 (range 84.0 – 147.2). Stations 3 and 4 are significantly different compared to stations 1 and 2 ( $p < 0.05$ ) (Table 3).

**Table 2: Mean monthly physicochemical parameters of Lake Alau, Maiduguri, Nigeria**

| Parameters                 | Oct. 2020                | Nov 2020                 | Dec 2020                 | Jan 2021                 | Feb 2021                 | Mar 2021                 | Apr 2021                 | May 2021                 | Jun 2021                 | Jul 2021                 | Aug 2021                 | Sept 2021                | Oct. 2021                |
|----------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| Atm. Temp (°C)             | 30.0±0.00 <sup>a</sup>   | 29.1±0.01 <sup>b</sup>   | 29.9±0.02 <sup>b</sup>   | 35.4±0.02 <sup>a</sup>   | 38.4±0.03 <sup>a</sup>   | 40.1±0.02 <sup>a</sup>   | 40.1±0.02 <sup>a</sup>   | 42.2±0.03 <sup>a</sup>   | 29.7±0.01 <sup>b</sup>   | 29.4±0.02 <sup>b</sup>   | 29.4±0.02 <sup>b</sup>   | 30.1±0.03 <sup>a</sup>   | 31.1±0.02 <sup>a</sup>   |
| Water Temp (°C)            | 28.0±0.12 <sup>b</sup>   | 28.0±0.12 <sup>b</sup>   | 28.6±0.13 <sup>b</sup>   | 21.9±0.05 <sup>c</sup>   | 23.7±0.16 <sup>c</sup>   | 26.2±0.09 <sup>c</sup>   | 27.1±0.15 <sup>c</sup>   | 31.0±0.14 <sup>a</sup>   | 28.7±0.06 <sup>b</sup>   | 28.1±0.15 <sup>b</sup>   | 28.3±0.14 <sup>b</sup>   | 29.1±0.12 <sup>a</sup>   | 30.1±0.08 <sup>a</sup>   |
| pH                         | 7.0±0.00 <sup>b</sup>    | 7.3±0.00 <sup>b</sup>    | 7.5±0.00 <sup>b</sup>    | 7.5±0.00 <sup>b</sup>    | 7.5±0.01 <sup>b</sup>    | 7.5±0.00 <sup>b</sup>    | 7.5±0.00 <sup>b</sup>    | 7.5±0.00 <sup>b</sup>    | 8.6±0.00 <sup>a</sup>    | 7.9±0.00 <sup>b</sup>    | 7.6±0.00 <sup>b</sup>    | 7.6±0.00 <sup>b</sup>    | 7.5±0.00 <sup>b</sup>    |
| Transp. (Cm)               | 25.6±0.02 <sup>a</sup>   | 17.9±0.01 <sup>a</sup>   | 18.1±0.03 <sup>a</sup>   | 30.1±0.02 <sup>a</sup>   | 20.3±0.03 <sup>a</sup>   | 22.3±0.01 <sup>a</sup>   | 22.5±0.02 <sup>a</sup>   | 25.1±0.01 <sup>a</sup>   | 7.1±0.02 <sup>b</sup>    | 5.6±0.02 <sup>b</sup>    | 7.8±0.01 <sup>b</sup>    | 8.5±0.02 <sup>b</sup>    | 8.4±0.0 <sup>b</sup>     |
| Turbidity (FTU)            | 41.0±0.03 <sup>b</sup>   | 60.58±0.03 <sup>a</sup>  | 62.63±0.06 <sup>a</sup>  | 34.25±0.01 <sup>c</sup>  | 42.65±0.05 <sup>b</sup>  | 46.73±0.09 <sup>b</sup>  | 48.88±0.07 <sup>b</sup>  | 53.05±0.03 <sup>b</sup>  | 49.25±0.05 <sup>b</sup>  | 46.18±0.02 <sup>b</sup>  | 46.45±0.03 <sup>b</sup>  | 47.18±0.01 <sup>a</sup>  | 46.77±0.00 <sup>b</sup>  |
| Condc. (µr/cm)             | 141.9±0.00 <sup>b</sup>  | 143.2±0.02 <sup>b</sup>  | 153.2±0.03 <sup>b</sup>  | 161.2±0.02 <sup>b</sup>  | 143.6±0.01 <sup>b</sup>  | 181.6±0.02 <sup>a</sup>  | 185.3±0.01 <sup>a</sup>  | 190.7±0.02 <sup>a</sup>  | 207.1±0.01 <sup>a</sup>  | 208.9±0.03 <sup>a</sup>  | 210.0±0.03 <sup>a</sup>  | 215.0±0.02 <sup>a</sup>  | 217.0±0.01 <sup>a</sup>  |
| DO (mg/L)                  | 6.0±0.01 <sup>b</sup>    | 6.0±0.02 <sup>b</sup>    | 7.0±0.03 <sup>a</sup>    | 7.3±0.02 <sup>a</sup>    | 8.6±0.02 <sup>a</sup>    | 9.4±0.01 <sup>a</sup>    | 9.5±0.03 <sup>a</sup>    | 11.3±0.02 <sup>a</sup>   | 4.7±0.01 <sup>b</sup>    | 5.7±0.02 <sup>b</sup>    | 7.2±0.01 <sup>a</sup>    | 8.6±0.02 <sup>a</sup>    | 8.6±0.02 <sup>b</sup>    |
| BOD (mg/L)                 | 0.43±0.01 <sup>c</sup>   | 0.70±0.03 <sup>a</sup>   | 0.75±0.04 <sup>a</sup>   | 0.58±0.04 <sup>c</sup>   | 0.65±0.05 <sup>b</sup>   | 0.63±0.05 <sup>b</sup>   | 0.53±0.06 <sup>c</sup>   | 0.45±0.05 <sup>c</sup>   | 0.55±0.05 <sup>c</sup>   | 0.58±0.04 <sup>c</sup>   | 0.65±0.05 <sup>b</sup>   | 0.80±0.03 <sup>a</sup>   | 0.50±0.03 <sup>c</sup>   |
| TDS (mg/L)                 | 71.8±0.01 <sup>c</sup>   | 63.6±0.02 <sup>c</sup>   | 86.2±0.03 <sup>b</sup>   | 82.0±0.02 <sup>b</sup>   | 89.3±0.04 <sup>b</sup>   | 92.5±0.02 <sup>b</sup>   | 94.7±0.01 <sup>b</sup>   | 98.1±0.02 <sup>b</sup>   | 105.3±0.01 <sup>a</sup>  | 109.0±0.02 <sup>a</sup>  | 111.2±0.03 <sup>a</sup>  | 116.4±0.04 <sup>a</sup>  | 117.8±0.05 <sup>a</sup>  |
| Colour (P <sup>h</sup> Co) | 154.50±0.05 <sup>c</sup> | 177.75±0.02 <sup>b</sup> | 178.35±0.03 <sup>b</sup> | 177.28±0.01 <sup>c</sup> | 183.35±0.02 <sup>b</sup> | 199.43±0.01 <sup>b</sup> | 201.13±0.02 <sup>b</sup> | 212.00±0.02 <sup>b</sup> | 370.00±0.01 <sup>a</sup> | 462.25±0.02 <sup>a</sup> | 361.25±0.02 <sup>a</sup> | 360.28±0.02 <sup>a</sup> | 362.48±0.02 <sup>a</sup> |
| Chromium (mg/L)            | 0.13±0.01 <sup>c</sup>   | 0.13±0.01 <sup>c</sup>   | 0.14±0.02 <sup>c</sup>   | 0.09±0.00 <sup>c</sup>   | 0.13±0.03 <sup>c</sup>   | 0.27±0.04 <sup>b</sup>   | 0.25±0.02 <sup>b</sup>   | 0.21±0.02 <sup>b</sup>   | 0.12±0.01 <sup>c</sup>   | 0.11±0.01 <sup>c</sup>   | 0.30±0.02 <sup>b</sup>   | 0.85±0.02 <sup>a</sup>   | 0.83±0.01 <sup>a</sup>   |
| Copper (mg/L)              | 0.40±0.00 <sup>b</sup>   | 0.45±0.01 <sup>b</sup>   | 0.43±0.03 <sup>b</sup>   | 0.58±0.04 <sup>a</sup>   | 0.40±0.05 <sup>b</sup>   | 0.55±0.04 <sup>a</sup>   | 0.48±0.02 <sup>a</sup>   | 0.50±0.03 <sup>a</sup>   | 0.28±0.02 <sup>c</sup>   | 0.50±0.03 <sup>c</sup>   | 0.25±0.03 <sup>c</sup>   | 0.23±0.04 <sup>c</sup>   | 0.23±0.03 <sup>c</sup>   |
| Sulphate(mg/L)             | 1.00±0.02 <sup>b</sup>   | 1.43±0.03 <sup>b</sup>   | 1.68±0.02 <sup>b</sup>   | 0.50±0.03 <sup>c</sup>   | 1.00±0.02 <sup>b</sup>   | 0.70±0.05 <sup>c</sup>   | 1.45±0.04 <sup>c</sup>   | 0.40±0.03 <sup>c</sup>   | 10.00±0.02 <sup>b</sup>  | 10.38±0.01 <sup>a</sup>  | 9.88±0.02 <sup>a</sup>   | 9.18±0.02 <sup>a</sup>   | 9.25±0.02 <sup>a</sup>   |
| Phosphate (mg/L)           | 0.37±0.01 <sup>b</sup>   | 0.37±0.02 <sup>b</sup>   | 0.41±0.04 <sup>b</sup>   | 0.43±0.05 <sup>b</sup>   | 0.37±0.04 <sup>b</sup>   | 0.40±0.03 <sup>b</sup>   | 0.28±0.05 <sup>c</sup>   | 0.28±0.04 <sup>c</sup>   | 0.52±0.03 <sup>a</sup>   | 0.54±0.02 <sup>a</sup>   | 0.52±0.03 <sup>a</sup>   | 0.47±0.03 <sup>b</sup>   | 0.43±0.03 <sup>b</sup>   |
| Chlorate (mg/L)            | 1.60±0.08 <sup>a</sup>   | 0.90±0.06 <sup>b</sup>   | 0.88±0.05 <sup>b</sup>   | 0.70±0.13 <sup>c</sup>   | 1.60±0.17 <sup>a</sup>   | 0.68±0.10 <sup>c</sup>   | 0.75±0.08 <sup>c</sup>   | 0.55±0.08 <sup>c</sup>   | 0.95±0.10 <sup>b</sup>   | 0.99±0.12 <sup>b</sup>   | 1.26±0.04 <sup>a</sup>   | 0.74±0.09 <sup>b</sup>   | 0.74±0.05 <sup>c</sup>   |
| Iron (mg/L)                | 1.02±0.20 <sup>a</sup>   | 1.11±0.18 <sup>a</sup>   | 1.12±0.10 <sup>a</sup>   | 0.92±0.14 <sup>b</sup>   | 1.02±0.08 <sup>a</sup>   | 0.83±0.10 <sup>b</sup>   | 0.83±0.09 <sup>b</sup>   | 0.84±0.12 <sup>b</sup>   | 0.49±0.06 <sup>a</sup>   | 0.48±0.04 <sup>c</sup>   | 0.46±0.16 <sup>c</sup>   | 0.45±0.08 <sup>c</sup>   | 0.50±0.23 <sup>c</sup>   |
| Manganese (mg/L)           | 0.52±0.01 <sup>a</sup>   | 0.50±0.03 <sup>a</sup>   | 0.40±0.03 <sup>b</sup>   | 0.15±0.10 <sup>c</sup>   | 0.53±0.05 <sup>a</sup>   | 0.40±0.06 <sup>b</sup>   | 0.38±0.07 <sup>c</sup>   | 0.30±0.05 <sup>c</sup>   | 0.18±0.02 <sup>c</sup>   | 0.13±0.13 <sup>c</sup>   | 0.15±0.04 <sup>c</sup>   | 0.20±0.08 <sup>c</sup>   | 0.23±0.11 <sup>c</sup>   |
| Nitrate (mg/L)             | 40.70±0.01 <sup>a</sup>  | 31.23±0.02 <sup>a</sup>  | 32.00±0.02 <sup>b</sup>  | 37.95±0.02 <sup>a</sup>  | 40.70±0.03 <sup>a</sup>  | 38.50±0.03 <sup>a</sup>  | 39.15±0.04 <sup>a</sup>  | 58.30±0.03 <sup>a</sup>  | 11.00±0.02 <sup>c</sup>  | 11.25±0.03 <sup>c</sup>  | 13.00±0.02 <sup>c</sup>  | 14.13±0.03 <sup>c</sup>  | 14.3±0.02 <sup>c</sup>   |

Means with the same superscript in the same row are not significantly different at  $p < 0.05$ .

**TABLE 3:** Mean physicochemical parameters for different stations in Lake Alau, Maiduguri, Nigeria

| Parameters                   | Station 1                | Station 2                | Station 3                | Station 4                |
|------------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| Atm. Temp ( <sup>0</sup> C)  | 33.4±0.03 <sup>x</sup>   | 33.3±0.02 <sup>x</sup>   | 33.4±0.02 <sup>x</sup>   | 33.6±0.01 <sup>x</sup>   |
| Water temp ( <sup>0</sup> C) | 27.1±0.01 <sup>x</sup>   | 27.4±0.05 <sup>x</sup>   | 27.9±0.12 <sup>x</sup>   | 28.1±0.20 <sup>x</sup>   |
| pH                           | 7.5±0.00 <sup>x</sup>    | 7.6±0.00 <sup>x</sup>    | 7.7±0.00 <sup>x</sup>    | 7.7±0.00 <sup>x</sup>    |
| Transp (Cm)                  | 18.9±0.01 <sup>x</sup>   | 14.1±0.02 <sup>y</sup>   | 15.8±0.02 <sup>y</sup>   | 15.6±0.03 <sup>y</sup>   |
| Turbidity (FTU)              | 28.34±0.01 <sup>y</sup>  | 24.74±0.03 <sup>y</sup>  | 65.97±0.04 <sup>x</sup>  | 73.58±0.02 <sup>x</sup>  |
| Cond. (µr/cm)                | 123.9±0.02 <sup>y</sup>  | 138.6±0.01 <sup>y</sup>  | 235.7±0.02 <sup>x</sup>  | 227.6±0.01 <sup>x</sup>  |
| DO (Mg/L)                    | 9.1±0.01 <sup>x</sup>    | 9.2±0.02 <sup>x</sup>    | 6.2±0.02 <sup>y</sup>    | 5.6±0.01 <sup>y</sup>    |
| BOD (Mg/L)                   | 0.58±0.04 <sup>x</sup>   | 0.65±0.03 <sup>x</sup>   | 0.60±0.03 <sup>x</sup>   | 0.55±0.02 <sup>x</sup>   |
| TDS (Mg/L)                   | 63.0±0.02 <sup>y</sup>   | 70.0±0.03 <sup>y</sup>   | 124.8±0.02 <sup>x</sup>  | 123.1±0.02 <sup>x</sup>  |
| Colour (P <sup>t</sup> Co)   | 171.98±0.03 <sup>y</sup> | 164.67±0.03 <sup>y</sup> | 332.94±0.02 <sup>x</sup> | 345.81±0.03 <sup>x</sup> |
| Chromium (Mg/L)              | 0.39±0.02 <sup>x</sup>   | 0.19±0.02 <sup>y</sup>   | 0.24±0.02 <sup>x</sup>   | 0.27±0.01 <sup>y</sup>   |
| Copper (ppm)                 | 0.45±0.01 <sup>x</sup>   | 0.55±0.02 <sup>x</sup>   | 0.27±0.04 <sup>y</sup>   | 0.29±0.03 <sup>y</sup>   |
| Sulphate (Mg/L)              | 4.35±0.02 <sup>x</sup>   | 3.72±0.03 <sup>y</sup>   | 4.54±0.04 <sup>x</sup>   | 4.57±0.02 <sup>x</sup>   |
| Phosphate (Mg/L)             | 0.39±0.03 <sup>y</sup>   | 0.49±0.04 <sup>x</sup>   | 0.42±0.02 <sup>x</sup>   | 0.35±0.03 <sup>y</sup>   |
| Chlorate (Mg/L)              | 0.59±0.06 <sup>y</sup>   | 0.94±0.17 <sup>y</sup>   | 1.15±0.08 <sup>x</sup>   | 1.11±0.17 <sup>x</sup>   |
| Iron (Mg/L)                  | 0.57±0.12 <sup>y</sup>   | 0.49±0.10 <sup>y</sup>   | 1.06±0.13 <sup>x</sup>   | 0.96±0.28 <sup>y</sup>   |
| Manganese (Mg/L)             | 0.32±0.12 <sup>x</sup>   | 0.40±0.03 <sup>b</sup>   | 0.38±0.04 <sup>x</sup>   | 0.28±0.03 <sup>y</sup>   |
| Nitrate (Mg/L)               | 37.45±0.06 <sup>x</sup>  | 24.90±0.04 <sup>y</sup>  | 27.12±0.03 <sup>y</sup>  | 28.07±0.01 <sup>y</sup>  |

Means with the same superscript in the same row are not significantly different at  $p < 0.05$ .

The lowest pooled mean colour value of  $154.50 \pm 0.05$  p<sup>t</sup> Co (range 44.00 – 236.00) was recorded in October and the highest ( $462.25 \pm 0.02$  p<sup>t</sup> Co) (range 265.00 – 460.00) was recorded in July. Other higher values were obtained between June and October (Table 2). Station 2 recorded the lowest pooled mean value of  $164.67 \pm 0.03$  p<sup>t</sup> Co (range 44.00 – 274.00) and station 4 recorded the highest value of  $345.81 \pm 0.03$  p<sup>t</sup> Co (range 225.00 – 467.00). The values obtained in stations 3 and 4 are significantly different ( $p < 0.05$ ) compared to stations 1 and 4 (Table 3).

The lowest pooled mean chromium of  $0.09 \pm 0.02$  mg/l (range 0.04 – 0.1) was recorded in January and the highest value of  $0.85 \pm 0.02$  mg/l (range 0.80 – 0.90) was recorded in September. The values obtained in October are significantly different compared to the rest of the months ( $p < 0.05$ ) (Table 2). The lowest pooled mean value of  $0.19 \pm 0.02$  mg/l (range 0.80 – 0.90) was recorded in station 2 and the highest value of  $0.39 \pm 0.02$  mg/l (range 0.10 – 0.90) was recorded in station 1. Station 1 appeared to be significantly different ( $p < 0.05$ ) compared to the rest of the

stations (Table 3). The lowest pooled mean copper of  $0.23 \pm 0.04$  ppm (range 0.20 – 0.30) was recorded in September and October, while the highest value of  $0.55 \pm 0.04$  ppm (range 0.11 – 0.80) was recorded in March. The values obtained in June, July, August, September and October are significantly different compared to the rest of the months ( $p < 0.05$ ) (Table 2). In terms of stations, the lowest pooled mean value of  $0.27 \pm 0.04$  ppm (range 0.10 – 0.70) was recorded in station 3 and the highest value of  $0.55 \pm 0.02$  ppm (range 0.11 – 0.90) was recorded in station 2 (Table 3).

The lowest pooled mean sulphate of  $0.40 \pm 0.03$  mg/l (range 0.30 – 0.50) was recorded in May and the highest value of  $10.38 \pm 0.01$  mg/l (range 8.50 – 12.50) was recorded in July. The following months also recorded higher values, June, July, August, September and October, with no significant difference ( $p < 0.05$ ). The value obtained in March, April and May is significantly different compared to other months ( $p < 0.05$ ) (Table 2). Station 2 recorded the lowest pooled mean value of  $3.72 \pm 0.03$  mg/l, (range 0.00 – 8.50) while the highest value of  $4.57 \pm 0.02$  mg/l (range 0.00 – 12.50) was recorded in station 4. There was no

significant difference in the values obtained in stations 1, 3 and 4 ( $p < 0.05$ ) (Table 3).

The lowest pooled mean phosphate of  $0.28 \pm 0.05$  mg/l (range 0.27 – 0.30) was recorded in April and May and the highest value of  $0.52 \pm 0.03$  mg/l (range 0.50 – 0.54) was recorded in June and August. The values obtained in June, July and August are significantly different compared to the rest of the months ( $p < 0.05$ ) (Table 2). Station 1 recorded the minimum pooled mean value of  $0.35 \pm 0.03$  mg/l (range 0.15 – 0.53), while station 2 recorded the maximum value of  $0.49 \pm 0.04$  mg/l (range 0.28 – 0.70). The values obtained in stations 2 and 3 are significantly different compared to station 1 and station 4 ( $p < 0.05$ ) (Table 3).

The lowest pooled mean chloride of  $0.55 \pm 0.08$  mg/l (0.23 – 1.20) was recorded in May, while the highest value of  $1.60 \pm 0.08$  mg/l (0.49 – 2.40) was recorded in October and February. There was no significant difference in values obtained in October, February and August with ( $p < 0.05$ ) (Table 2). In terms of the station, the lowest pooled mean value of  $0.59 \pm 0.06$  mg/l (0.23 – 1.52) was recorded in station 1, while the highest value of  $1.15 \pm 0.08$  mg/l (range 0.50 – 2.10) was recorded in station 3. The values obtained in stations 3 and station 4 are significantly different compared to stations 1 and 2 ( $p < 0.05$ ) (Table 3). The lowest pooled mean iron of  $0.45 \pm 0.08$  mg/l (0.38 – 0.51) was recorded in September and the highest value of  $1.12 \pm 0.10$  mg/l (range 0.71 – 1.51) was recorded in December. Other highest values were obtained in October, November, December and January with no significant differences ( $p < 0.05$ ) (Table 2). In terms of the station, the lowest, the pooled mean value of  $0.49 \pm 0.10$  mg/l (range 0.23 – 0.78) was recorded in station 2, while the highest value of  $1.06 \pm 0.13$  mg/l (range 0.38 – 1.71) was recorded in station 3. The value obtained in station 3 was significantly different compared to the rest of the station ( $p < 0.05$ ) (Table 3). The lowest pooled mean manganese of  $0.13 \pm 0.13$  mg/l (0.10 – 0.20) was recorded in July, while the highest pooled mean value of  $0.53 \pm 0.50$  mg/l (range 0.20 – 0.90) was recorded in February. The values obtained in October, November and February were significantly different compared to the rest of the months ( $p < 0.05$ ) (Table 2). Station 4 recorded the minimum pooled mean value of  $0.28 \pm 0.03$  mg/l (range 0.00 – 0.80), while

station 3 recorded the highest mean value of  $0.38 \pm 0.04$  mg/l (range 0.10 – 0.90). There was no significant difference between stations 1, 2, and 3 ( $p < 0.05$ ) (Table 3).

The lowest pooled nitrate-nitrogen of  $11.0 \pm 0.02$  mg/l (8.50 – 13.50) was recorded in June, while the highest pooled mean value of  $58.30 \pm 0.03$  mg/l (range 31.50 – 79.50) was recorded in May. The values obtained in October and May was significantly different from values obtained from all other months ( $p < 0.05$ ). There was no significant difference with values obtained from June to October, but it is different from values obtained from all other months. (Table 2). The lowest pooled mean value of  $24.90 \pm 0.04$  mg/l (range 8.80 – 78.90) was recorded in station 2 and the highest value of  $37.45 \pm 0.06$  (range 13.0 – 9.50) was obtained in station 1. Station 1 was significantly different from the values obtained from the remaining station ( $p < 0.05$ ) (Table 3).

#### **Phytoplankton composition and abundance**

The monthly occurrence of phytoplankton species obtained is presented in Tables 4 to 5. The occurrence of phytoplankton in October shows that there were significant differences in the number of the species of the taxa encountered. The number of Chlorophyceae was significantly higher than any other taxa, ( $p < 0.05$ ). The number of species for Bacillariophyceae was also significantly higher compared to the others. Myxophyceae also had a significantly higher number of spp. than Chlorophyceae, Xanthophyceae and Rhodophyceae, which did not differ significantly among them. These results were similar in respect of the number of organisms (Table 5). The number of organisms was significantly higher for Chlorophyceae (38.9%) than the others, except Bacillariophyceae (31.7%). Similarly, the number of organisms was significantly the same for Bacillariophyceae (31.7%) and Myxophyceae (21.9%). However, all the aforementioned had significantly higher numbers of organisms than Chrysophyceae (4.86%), Xanthophyceae (0.00%) and Rhodophyceae (2.43%)

**TABLE 4:** Mean number of Phytoplankton collected between October 2020 to October 2021 from Lake Alau, Maiduguri Nigeria

| Taxa              | Oct.<br>2020 | Nov<br>2020 | Dec<br>2020 | Jan<br>2021 | Feb<br>2021 | Mar<br>2021 | Apr<br>2021 | May<br>2021 | Jun<br>2021 | Jul<br>2021 | Aug<br>2021 | Sept<br>2021 | Oct.<br>2021 |
|-------------------|--------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|--------------|--------------|
| Chlorophyceae     | 4.25a        | 0.50b       | 2.75a       | 3.50a       | 4.75a       | 4.25a       | 3.00a       | 4.00a       | 6.0a        | 3.50a       | 3.50a       | 3.75a        | 4.00a        |
| Bacillariophyceae | 3.25b        | 0.75b       | 1.50c       | 3.00b       | 2.50b       | 3.00b       | 3.00a       | 3.75a       | 0.0d        | 3.00b       | 2.50b       | 3.00b        | 2.00b        |
| Chrysophyceae     | 0.50d        | 0.50b       | 0.00f       | 0.00c       | 1.00c       | 0.00d       | 0.50d       | 0.00d       | 0.0d        | 0.00e       | 1.00cd      | 0.00d        | 0.00c        |
| Xanthophyceae     | 0.00d        | 0.50b       | 1.00d       | 0.50d       | 1.00c       | 0.00d       | 0.00d       | 1.00c       | 0.50c       | 0.00e       | 1.00cd      | 1.00d        | 0.00c        |
| Rhodophyceae      | 0.25d        | 0.50b       | 0.50c       | 0.00c       | 1.00c       | 0.00d       | 1.00c       | 0.50d       | 0.0d        | 1.00d       | 0.50d       | 1.00d        | 0.50c        |
| Myxophyceae       | 2.25c        | 1.75a       | 2.00b       | 4.00a       | 4.50a       | 2.00c       | 1.50b       | 3.00b       | 3.5d        | 2.50c       | 2.00b       | 1.50c        | 2.0b         |
| Mean              | 1.75         | 1.75        | 1.29        | 1.83        | 0.44        | 1.54        | 1.50        | 2.04        | 1.67        | 1.67        | 1.71        | 0.39         | 0.64         |

Means with the same letter in the same row are not significantly different at  $p < 0.05$ .



**Table 5:** Density (mean number of organisms/L) of phytoplankton collected between October 2020 and October 2021 from Lake Alau, Maiduguri, Nigeria. Means (months) with the same superscript in the same row are not significantly different at  $p < 0.05$

| Taxa              | 2020   |      |        |      |       |      |       |      |       |      |        |      | 2021   |      |       |      |       |      |       |      |       |      |        |      |        |      |
|-------------------|--------|------|--------|------|-------|------|-------|------|-------|------|--------|------|--------|------|-------|------|-------|------|-------|------|-------|------|--------|------|--------|------|
|                   | Oct.   | %    | Nov.   | %    | Dec.  | %    | Jan.  | %    | Feb.  | %    | Mar.   | %    | Apr.   | %    | May   | %    | Jun.  | %    | Jul.  | %    | Aug.  | %    | Sept.  | %    | Oct.   | %    |
| Chlorophyceae     | 20.0a  | 38.9 | 12.3a  | 19.0 | 12.3a | 22.4 | 15.0a | 35.4 | 16.3b | 19.8 | 20.8a  | 41.6 | 20.0a  | 37.1 | 27.8a | 33.5 | 30.8a | 59.1 | 35.0a | 37.6 | 37.5a | 33.5 | 37.3a  | 32.2 | 24.00a | 38.9 |
| Bacillariophyceae | 16.3ab | 31.7 | 11.3bc | 17.5 | 13.3b | 24.2 | 12.5a | 29.5 | 22.5a | 27.4 | 17.5b  | 35.0 | 16.3b  | 30.4 | 24.3b | 29.3 | 0.00d | 0.00 | 20.3b | 21.8 | 15.0c | 13.4 | 31.8a  | 27.4 | 19.50b | 31.7 |
| Chrysophyceae     | 2.50d  | 4.86 | 12.8b  | 19.8 | 0.00d | 0.00 | 0.00b | 0.00 | 6.25c | 7.61 | 0.00d  | 0.00 | 2.50e  | 4.64 | 0.00e | 0.00 | 0.00d | 0.00 | 0.00d | 0.00 | 14.0c | 12.5 | 8.75c  | 7.55 | 0.00d  | 0.00 |
| Xanthophyceae     | 0.00d  | 0.00 | 8.00cd | 12.4 | 9.50d | 17.3 | 2.50b | 5.91 | 8.50c | 10.3 | 0.00d  | 0.00 | 0.00f  | 0.00 | 5.00c | 6.0  | 3.75c | 7.20 | 0.00d | 0.00 | 19.5b | 17.4 | 12.5bc | 10.8 | 0.00d  | 0.00 |
| Rhodophyceae      | 1.25c  | 2.43 | 6.25d  | 9.68 | 7.25c | 13.2 | 0.00b | 0.00 | 8.50c | 10.3 | 0.00d  | 0.00 | 4.75d  | 8.81 | 2.25d | 2.71 | 0.00d | 0.00 | 15.3c | 16.4 | 8.25d | 7.35 | 10.0bc | 8.63 | 5.75c  | 9.33 |
| Myxophyceae       | 11.3b  | 21.9 | 13.8b  | 21.3 | 12.5b | 22.7 | 12.3a | 29.0 | 20.0b | 24.3 | 11.50c | 23.0 | 10.30c | 19.1 | 23.5b | 28.3 | 17.5b | 33.6 | 22.5b | 24.2 | 17.8b | 15.9 | 15.5b  | 13.4 | 12.3b  | 19.9 |
| <b>Total</b>      | 51.4   |      | 64.5   |      | 54.9  |      | 42.3  |      | 82.1  |      | 50.0   |      | 53.9   |      | 82.9  |      | 52.1  |      | 93.1  |      | 112.1 |      | 115.9  |      | 61.6   |      |

Myxophyceae was the taxa with dominant species and it is significantly different compared to the rest of the taxa, ( $p < 0.05$ ). There was no significant difference between the remaining taxa ( $p > 0.05$ ). Myxophyceae replaced Chlorophyceae as in the case of October. In Table 5, Chlorophyceae (19.0%) still maintained its dominance, and it is significantly different compared to the remaining taxa, ( $p < 0.05$ ). It was followed by Chrysophyceae (19.8%) and Myxophyceae (21.3%) with no significant difference ( $p > 0.05$ ). In December, Chlorophyceae once again regained its position as the most dominant taxa with a high number of species identified. It is significantly different compared to the rest of the taxa with ( $p < 0.05$ ). It was followed by Myxophyceae. No species of Chrysophyceae was identified (Table 4). Chlorophyceae has the highest number of organisms /L (22.4%). It is significantly different compared to the rest of the taxa ( $p < 0.05$ ). It was followed by Bacillariophyceae (24.2%) and Myxophyceae (22.7%). There was no species of Chrysophyceae (0.00%)/L. (Table 5).

In January Myxophyceae replaced Chlorophyceae as the most dominant taxa, although there was no significant difference between them. These two taxa are significantly different compared to the rest of the taxa. No species of Chrysophyceae and Rhodophyceae were identified (Table 4). Chlorophyceae (35.4%), Bacillariophyceae (29.5%) and Myxophyceae (12.3%) recorded the highest number of organisms /L. It was followed by Xanthophyceae (5.91%). There were no Chrysophyceae (0.00%) and Rhodophyceae (0.00%) recorded (Table 5). Results on the mean number of phytoplankton species in February are shown in Table 4. There was a significant difference between Chlorophyceae, Myxophyceae and the rest of the taxa. These were followed by Bacillariophyceae. There were no significant differences between Chrysophyceae, Xanthophyceae and Rhodophyceae ( $p > 0.05$ ).

Bacillariophyceae has the highest number of organisms/L (27.4%). Bacillariophyceae (27.4%) and Myxophyceae (24.3%) are significantly different compared to Chrysophyceae (7.61%), Xanthophyceae (10.3%) and Rhodophyceae (10.3%) ( $p < 0.05$ ). This shows that Bacillariophyceae replaced Chlorophyceae as the most dominant organism /L. (Table 5). In March, the taxa Chlorophyceae recorded the highest number of identified species which is significantly different compared to the rest of the taxa ( $p < 0.05$ ). It was followed by Bacillariophyceae and Myxophyceae. There was no significant difference between Chrysophyceae, Xanthophyceae and Rhodophyceae ( $p < 0.05$ ) (Table 4).

Chlorophyceae recorded the highest number of organisms/L (41.6%), which was significantly different compared to the rest of the taxa ( $p < 0.05$ ). It was followed by Bacillariophyceae (35.0%) and Myxophyceae (23.0%). There was no significant difference between the remaining taxa (Table 5). In April, Chlorophyceae and Bacillariophyceae recorded the highest number of species, which means an increment in Bacillariophyceae, with no significant difference ( $p < 0.05$ ). It was followed by Myxophyceae. There was no significant difference among the remaining taxa (Table 4). In Table 5 Chlorophyceae has the highest number of organisms per litre (37.1%), and it is significantly different compared to the rest of the taxa, ( $p < 0.05$ ). It was followed by Bacillariophyceae (30.4%) and Myxophyceae (19.1%). Xanthophyceae recorded no organism /L (0.00%). In May (Table 4), Chlorophyceae and Bacillariophyceae remain with the highest number of species, with no significant difference ( $p < 0.05$ ). It was followed by Myxophyceae and Xanthophyceae, which means an increment for Xanthophyceae. There was no significant difference between Chrysophyceae and Rhodophyceae. In terms of organisms /L, Chlorophyceae (33.5%) recorded the highest and

is significantly different compared to the rest of the taxa ( $p < 0.05$ ). It was followed by Bacillariophyceae (29.3 %) and Myxophyceae (28.3 %) with no significant difference. Chrysophyceae (0.00%) recorded no organisms /L. (Table 5).

#### **Wet Season**

In June (Table 4), Chlorophyceae recorded the highest number of species, and it was followed by Myxophyceae. Chlorophyceae is significantly different compared to the rest of the taxa ( $p < 0.05$ ). Bacillariophyceae and Rhodophyceae, for the first time, recorded no identified species. In Table 5 Chlorophyceae recorded the highest number of organisms /L (59.1 %), and it is significantly higher compared to the rest of the taxa, ( $p > 0.05$ ). It was followed by Myxophyceae (33.6%) and Xanthophyceae (7.20 %). Chrysophyceae (0.00%), Bacillariophyceae (0.00 %) and Rhodophyceae (0.00%) recorded no organisms /L. In July, Chlorophyceae recorded the highest number of species and is significantly different compared to the rest of the taxa ( $p < 0.05$ ). It was followed by Bacillariophyceae. Chrysophyceae still maintained no identified species (Table 4). Chlorophyceae has the highest number of organisms /L (37.6%). It is significantly different compared to the rest of the taxa, ( $p < 0.05$ ). It was followed by Bacillariophyceae (21.8%) and Myxophyceae (24.2%). Xanthophyceae recorded no organisms/L (0.00%), as of June (Table 5).

In August Chlorophyceae still maintained its dominance. It is significantly different compared to the rest of the taxa, ( $p < 0.05$ ). It was followed by Bacillariophyceae and Rhodophyceae. There was no significant difference between the remaining taxa (Table 4). Chlorophyceae has the highest number of organisms /L (33.5%). It is significantly different compared to the rest of the taxa, ( $p < 0.05$ ). It was followed by Xanthophyceae (17.4%) and Myxophyceae (15.9%) with no significant difference ( $p > 0.05$ ) (Table 5). In September, Chlorophyceae has the

highest number of phytoplankton, and it is significantly different compared to the rest of the taxa, ( $p < 0.05$ ). It was followed by Bacillariophyceae and Myxophyceae. There was no significant difference between the remaining taxa, ( $p < 0.05$ ) (Table 4).

Chlorophyceae has the highest number of organisms /L (32.2 %), it was followed by Bacillariophyceae (27.4%) with no significant differences, ( $p > 0.05$ ). There is no significant difference between Xanthophyceae (10.8 %) and Myxophyceae (8.63 %) (Table 5). In October, Chlorophyceae still maintain the highest number of species. It is significantly different compared to the rest of the taxa, ( $p < 0.05$ ). It was followed by Bacillariophyceae and Myxophyceae. There was no significant difference between the remaining taxa (Table 4). In terms of organisms/L, Chlorophyceae maintained the highest (38.9%). It is significantly different compared to the rest of the taxa, ( $p < 0.05$ ). It was followed by Bacillariophyceae (31.7%) and Myxophyceae. (19.9%) There was no significant difference among the remaining taxa (Table 5).

#### **Correlation between physicochemical parameters and abundance of phytoplankton**

The results obtained on the phytoplankton population are shown in Table 5. These results show that the highest population were obtained in the year 2021 in August (112.1) and September (115.9), followed by the population in July 2021 (93.1). The lowest populations were recorded in April (53.9), June 2021 (52.1), March (50.0), and January 2021 (42.3), followed by and with no significant difference between these months. Also, the lowest value was recorded in

In general, the results showed an increase from October and November 2020, when the work started, and then started to decrease from December to January 2021, after which there was another peak in February 2021 (82.1), followed by a decrease in March (50.0). The population of phytoplankton, thereafter started increasing from April (53.9) to May (82.9), after which it started

to decline to (52.1) in June 2021. After June, the population again started increasing through July (93.1), August (112.1) and September (115.9) when the highest population was attained. The population thereafter reduced to (61.6) in October 2021. Thus the result shows various peaks of population viz in November 2020 (64.5), February 2021 (82.1), May 2021 (82.9), July 2021 (93.1) August 2021 (112.1) and September 2021 (115.9).

The phytoplankton population was not correlated. The pH and the phytoplankton population did not indicate a relationship and hence a negative correlation. The insignificant variation in pH level throughout the year shows no affinity with the phytoplankton population. An instant increase in June 2021, showed a negative correlation with the phytoplankton population. There was no significant correlation between transparency and the phytoplankton population and thus when the degree of transparency increases, the phytoplankton population decreases. The correlation analysis did not show any relationship between turbidity and the phytoplankton population. However, there seems to be a relationship in some instances, viz in November 2020, December 2020, January 2021, February 2021 and May 2021. There was no correlation between conductivity values and the phytoplankton population as shown in the correlation analysis. The phytoplankton population and monthly DO variation showed a significant correlation. The phytoplankton population and BOD did not show a pronounced relationship however, there was a slight correlation in November 2020 and December 2020. There was also a relationship in August (2021), September (2021) and October (2021). The phytoplankton population and colour variation did not show any relationship throughout the year, except in May 2021, and July 2021.

The monthly variation in copper concentration and phytoplankton population shows a correlation

in the following months; November 2020, December 2020, May 2021, July 2021 and August 2021. There was no correlation in the remaining months. There was a correlation between chromium and phytoplankton populations in January 2021 and June 2021. The remaining months did not show any correlation between chromium and phytoplankton population. There was correlation in the following months; November 2020, December 2020, January 2021, February 2021, March 2021, April 2021, July 2021, August 2021 and October 2021. The distribution of iron concentration and phytoplankton population did not show any relationship, except in November 2020 and February 2021. The remaining months did not show any relationship.

The distribution of manganese was correlated with the phytoplankton population throughout the year. The phytoplankton population and total dissolved solids show a correlation. There seems to be a relationship in February 2021, April 2021, May 2021, July 2021, August 2021, and September 2021, and thus the population increases as total dissolved solids increase. The correlation analysis shows that the relation between nitrate-nitrogen and phytoplankton population is not significant. There was a correlation between sulphate and phytoplankton population. The phytoplankton population increases as the sulphate concentration increases, except in October 2021. The phytoplankton population and phosphate concentration show no significant relationship. The same trend in relation to the increase and decrease phytoplankton population is not affected by phosphate concentration variation.

## **DISCUSSION**

This study has revealed that the phytoplankton community and the physicochemical components of the Alau dam reservoir varied with months, stations and seasons. The temperature showed considerable fluctuation. The low temperatures recorded from October to February were due to

the harmattan and dry wind. In early May, June and July, the rains and the associated cloudy weather caused decrease in temperature. Timms (2001) suggested that climatic factors were the determining factors for the increase or decrease in temperature in the arid zone and Lake Alau shares the climate of the northeast arid zone. The water temperature range in this study falls within the normal temperature range (25– 35° C) of natural tropical waters (Alabaster and Lloyd, 2013).

Water transparency varied from 7.5 to 26.0cm in the four stations. This is very low compared to 0.45 – 2.8 meters obtained in Kanji Lake (Adeniji, 1989). The progressive decrease in water transparency from October 2020 to October 2021 has no relationship with increased phytoplankton production. The remarkable decrease from May to October after the onset of rains indicated that floods draining into the reservoir were responsible for the low water transparency within that period, rather than phytoplankton production. Biswas (1978) observed that in Lake Volta Ghana, Secchi disc transparency decreased with an increase in phytoplankton. Olaniyan (1978) suggested that transparency varies directly with rainfall in freshwater habitats and it determines the depth to which light essential for photosynthesis can penetrate.

The patterns of dissolved oxygen between stations are similar to Egborge (1979b) observed a similar pattern of variation in Lake Asejire. Oxygen levels in the four stations sampled were statistically proved to be insignificant. The relatively low level of dissolved oxygen in June may have been due to the decomposition process of organic matter brought into the reservoir through surface runoffs. The relatively higher value from March to May was due to the high phytoplankton production leading to higher photosynthetic activities, as well as reduced decaying process. Duchane (1975) considered that whereas wind is a major oxygenator in large

lakes, dissolved oxygen in smaller lakes is largely determined by the photosynthetic action of phytoplankton. Complete oxygen depletion was not observed in any of the stations in the lake, apparently because of significant water movement through the lake as a result of water release from the upstream and downstream.

The BOD exhibited the same trend as the DO. The BOD values were high in September and lower in October. There was no significant variation between the values of BOD recorded for all stations. The higher BOD recorded in station 2 could probably be due to organic matter degradation, which utilized oxygen within the lake. According to Kolo and Yisa (2000), organic matter decomposition from increased human activities can increase the BOD variation. Moore and Moore (1976) reported that BOD is a fair measure of the cleanliness of any water and classified values of less than 1.2 mg/l as clean, while 4 – 6 mg/l as fairly clean and 8 – 10 mg/l as bad and polluted. Based on these values, Lake Alau water may be considered as clean.

The reservoir is shown to be slightly alkaline. The highest value of 8.6 was recorded in June. This may be attributed to the influx of salts as a result of the rains. The value then continued on the downward trend to a neutral level again. This agrees with Beadle (1981) that the photosynthetic and respiratory process determines to a large extent the hydrogen ion, concentration in an aquatic ecosystem. Hutchinson (1975), Walnis and Toemain (1979), Holden and Green (1960) noted that in African waters, alkaline conditions are not typical. It agrees with Steeman-Nilsons (1977) that the decay of allochthonous and autochthonous organic materials in the reservoir would decrease the pH to below 7.0, the nature of the basement rocks of granite-biotite must be important in the buffering of the water pH to above 7.8. pH is positively correlated with phytoplankton abundance, indicating that an increase in phytoplankton abundance with the associated increase in their photosynthetic actions

would deplete the free CO<sub>2</sub> leading to an increase in pH. Level.

The values and the status of the pH of Lake Alau agree with the observation of Hall et al, (1970), Hall (1977) in Zambezi River; Elemi (1990) in Ona River; Atama (2021) in the RIMCO reservoir, but contradict the trend in some African lakes in which pH is lower in the wet season, but rises during the dry season (Adebisi 1981; Adeniji 1985). The pH ranges of Lake Alau were comparatively narrow and fall within the recommended range (6.5 – 9) as suitable for aquatic life (Boyd, 1979). The specific conductance of the reservoir water was less than 600µm/cm recorded from Kiri dam (Ovie et al., 2000). The maximum value of 217µm/cm recorded for Lake Alau is another indication of oligotrophy implies a low level of dissolved salts, a characteristic feature of ‘soft’ water. The low level may be associated with the bedrock of the reservoir which is known to be poor in salt regeneration. According to Hutchinson (1975) lake water classification on conductivity, the Alau Dam reservoir falls within the oligotrophic range. The result shows that conductivity is negatively correlated with phytoplankton abundance. The TDS recorded in Lake Alau started increasing during the wet seasons from May – October) and low in the harmattan. The high value of total dissolved solids during the rains has been due to flooding which brought in high concentrations of sediments into the lake.

The increase in TDS could influence turbidity and therefore light penetration for primary production, and affects feeding by biotic communities relying on sight. Stations 3 and 4 were more sediment-laden than stations 1 and 2. This could be a result of organic materials that were introduced from other sources through canals into the Lake. Alabaster and Llyod (2013) suggested that excessive concentration of TDS might be harmful to aquatic life. The harmful effects may include the killing or reduction of their growth rate as well as the reduction of food

available to the fauna. The correlation between the TDS and phytoplankton population in some instances might be related to the aforementioned factors.

The seasonal variations and distribution of nitrate-nitrogen followed well-known and predictive patterns, but in the case of Lake Alau reservoir, it disagrees with the predictive pattern of Chukwuma (1983). The lowest pooled mean value of 11.0 mg/l was recorded in June and the highest pooled mean value of 58.30 mg/l was recorded in April. Relatively, nitrate-nitrogen was low in Lake Alau compared to 238-300 mg/l in Lake Asejire (Egborge 1979; Biswas 1966b), and Lake and Lake Victoria (5-11mg/l) (Talling and Talling 1965).

The nitrate-nitrogen level as found in this research work is much lower than the values reported by Chidoben (1982) while working on Shen Reservoir in Plateau state. He recorded a range of 59.30-87 ppm. It is however difficult to assess the absolute value of the amount of nitrate present in the water because the concentration of the nutrient in a body of water at any one time depends on a dynamic relationship between some factors such as; the amount, which is dissolved out of the soil over which the water enters the reservoir and flows (Talling and Talling 1965).

The reasons for the high concentration level of nitrate-nitrogen from January to May be due to excessive application of fertilizer by irrigation farmers. Nwoko (1991) suggested that nitrate-nitrogen could get into the water through various sources, such as cattle dung, fertilizer run-offs, and leaching of leguminous farms. The decrease in the concentration level of the nitrate-nitrogen in other months may be connected with heterotrophic uptake by micro-organisms, sediment absorption and the complete loss of some aquatic macrophytes. There was no significant relationship between phytoplankton population and nitrogen level.

The seasonal variations of phosphate-phosphorus in the Lake Alau reservoir varied between 0.25

mg/l and 0.70 mg/l and 0.15 mg/l and 0.77 mg/l. The pattern of phosphate-phosphorus fluctuation was not in line with the temperature regimes and phytoplankton density fluctuation. Maximum phosphate concentration was obtained from June to August corresponding to the time of high runoffs. There was a subsequent decrease from September, as the rains progressed, possibly due to the dilution effect. There was a marked depletion in December. This agrees with Owens and Wood (1968) that 68% of phosphate was from run-offs and only 28% from other sources. The phosphate-phosphorous value range recorded in this study falls below the observed range of 3.8 – 6.30 mg/l observed by Beadle (1981) in some African rivers and lakes.

The sources of phosphate can be from arable agriculture. It was also observed during the study period that the intensive agricultural activities involved the use of fertilizers and pesticides to produce dry-season crops like vegetables. Some villages were using the water for domestic activities, and washing of vehicles, which could increase the phosphate level of the water. The most important limiting factor in aquatic productivity is the phosphate which can be impoverished by being used up.

The Copper concentration recorded is lower than 0.95 mg/l recorded in the Arizona desert reservoir (Olsen and Somerfield, 1977), but it is higher compared to the permissible pollution limits of 0.10 mg/l. The significant increase in copper concentration in all the stations may be linked to the activities occurring, such as excessive land runoff into the water and hence its affinity with copper sulphate which is used as fungicides in nearby tomato farms. It is also linked to activities, such as human navigating activities and washing of fishing equipment directly into the water. On the contrary, the mean value of Copper (Cu) was higher in the dry season, than in the rainy season. Wright *et al.* (1984) reported that the concentrations of Fe, Cu and Mg were higher during the rainy seasons than in the dry season.

The concentration of Fe is consistent with the low solubility of ions in desert reservoirs as reported by Olsen and Sommerfield (1977). The concentration of iron in Lake Alau may be due to direct or indirect discharges and land runoff into the Lake. The concentration of Iron (Fe) was higher in the harmattan season than in the rainy season. Entry of the heavy metals into the Lake especially during the rainy season may be through the flood and this trend increases the concentration of the metals during the rains. In the case of Iron (Fe), it agrees with the findings of Amuzu *et al.* (1990) that heavy metals occur in low concentrations in aquatic ecosystems. The values of iron for all the samples were lower than the values suggested by WHO for drinking water (Hart, 1993) classified as surface water with 1.9 mg/l of iron as slightly polluted, 2.7 mg/l as polluted and values above 2.7 mg/l as heavily polluted. Based on Harts's classification, Lake Alau can be classified as unpolluted. It was also found that iron concentration does not correlate with phytoplankton population. The concentration of manganese showed considerable variations within the Lake. The highest level of contamination in various stations could be associated with domestic washing with soap and, the effect of fertilizers, herbicides and pesticides applied to irrigated farmlands. Odiete (1999) reported that domestic sewage and agricultural effluents can precipitate manganese salts, which may exact a toxic effect on aquatic organisms. Other sources may be as a result of localized inputs and sediment transport. Most stations in Lake Alau showed low to moderate metal concentrations, which indicate a low level of pollution, which poses no environmental concern for the Lake. This is also supported by the complete absence of any relationship between phytoplankton population and manganese concentration throughout the years. This study shows that the metal concentration in Lake Alau is not high. The variation in the concentrations of heavy metals in the water may be mostly

attributed to the discharge of dumped waste, domestic activities, agricultural activities as well as direct washing in of dry and wet particles by harmattan winds and floods.

Within the study period, quantitative changes occurred among the six phytoplankton taxa identified in the Lake Alau reservoir. The progressive increase in the abundance of all taxa from June indicates that the wet season was favourable to phytoplankton production, which disagreed with Chukwuma (1983) that the dry season favoured phytoplankton production. The increasing trend after the onset of the rains and progressive decrease in abundance from October shows that the flux of nutrients, as a result of run-offs favoured phytoplankton production. A similar observation was reported for upland and lowland impoundments in Plateau state by Kemdirim (1990).

Although, Chlorophyceae showed high species diversity, only three dominant species occurred throughout the study period, an indication of a succession trend in Lake Alau reservoir. It was followed by Bacillariophyceae, which is also very significant. The replacement of Chlorophyceae by Bacillariophyceae in some instances in Lake Alau is also observed in Kainji Lake by Adeniji (1973). Chrysophyceae was the least in both species 'diversity and total abundance. The dominant species *Uroglena* spp. was constant in occurrence. Out of the 10 species of Chlorophyceae identified, *Endorina* spp. and *Chlorella* species persisted throughout the study period, however, *Enteromorpha*spp. and *Goniu* mspecies s are also common in both dry season and wet season.

About 7 species of *Bacillariophyceae* were identified. Diatom species and *Synedra* sp.

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happen to be the most dominant throughout the year, except in June. This may be a result of displacement brought about by rain onsets, which agrees with Kemdirim (1990). In chlorophyceae; *Oscillatoria* species and *Anabeana* spp. are the most dominant in both dry seasons and wet seasons. However, *Anabeana* species thrived better in the rainy seasons, while *Oscillatoria* spp. dominated the dry season, which agrees with Chukwuma (1983) and Kemdirim (1990). The taxa; chrysophyceae and rhodophyceae happen to be less prominent, with only *Uroglena* spp. and *Lemanea* spp. respectively. This may be because; they are phytobenthos that only resurface after disturbances. This agrees with Marker (1976), and Saunders and Eaton (1976). The general high species diversity shown by phytoplankton and successional trend, suggest an unstable nature of the Lake Alau reservoir, a feature characteristic of oligotrophic Lakes. The Alau Dam reservoir maintains higher species diversity when the results of the present work are compared with the results obtained by Kemdirim (1990), Chukwuma 1983, and Ovie *et al.* (2000). This suggests that based on the types of dominant species, the Alau Dam reservoir could be classified as Oligo-mesotrophic Lake.

## CONCLUSION

The phytoplankton and physicochemical variable of the Lake Alau reservoir was shown to be affected by stations and season, through their specific properties. The presence of typical eutrophic species of phytoplankton, notwithstanding other limnological features strongly suggests that the water body is maintaining an Oligo-mesotrophic status.

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