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# Spatial and Temporal Variations of Nutrients and Physiochemical Parameters in relation to Phytoplankton in Lake Edku, Egypt

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**Abstract** Lake Edku is one of the northern Delta lakes, connected with the Mediterranean Sea through El-Boughaz opening. The main objective of the present work is to study the spatial and temporal variations of nutrients and physiochemical parameters of the lake water and its relation with the phytoplankton communities, chlorophyll-a as well as diversity index. Water samples were collected seasonally during 2016. The results of hydrographic and nutrient salts revealed that the pH values lie slightly on the alkaline side, with a range of (7.47-9.07), Electrical conductivity (EC) showed a wide range from 0.59 mS/cm in spring to 5.13 mS/cm in winter with an average 1.87mS/cm. Salinity ranged between 0.29 and 2.92 PSU. Chlorophyll-a revealed a wide range (17.20–300.20 μg/l) with an average value of 13.60±18.85 μg/l. The values of dissolved oxygen (DO) and Biological oxygen demand (BOD) ranged (1.56 to 18.10 $mgl^{-1}$) and (0.91 and 15.90 $mgl^{-1}$), respectively. Suspended particulate matter ranged between 16 and 122 with an average 37.81±34.54 mg/l. The range and the average values of nutrients (μM) were; 0.22- 67.3 (11.36±10.96), 1.54 - 80.04 (18.65±18.66), 0.11 - 37.29 (10.72±1.41), 1.33 - 108.38 (31.63±26.17), 1.36–70.97 (19.17±11.20) for $PO_4$/P, $NH_4$/N, $NO_2$/N, $NO_3$/N, $SiO_4$/Si, respectively. In general, the amounts of the dissolved inorganic nitrogen forms could be arranged in the following order; $NO_3$/N> $NH_4$/N > $NO_2$/N. A total of 30 species belonging to four Phyla of phytoplankton were record, Chlorophyceae (18 species) dominated followed by Bacillariophyceae (10 species). There were 9 predominant species. Distribution of phytoplankton arranged as follow autumn<winter< spring<summer, respectively. The total abundance of phytoplankton ranged between $46\times10^5$ cells/l and $414\times10^5$ cells/l with an average $142x10^5$ cells/l. The Shannon-Wiener diversity index varied between 1.36 and 2.85 with an average 2.26, that revealing moderated biodiversity in the phytoplankton community.

**Keywords** Lake Edku, Phytoplankton, Abundance, nutrients, diversity index

## Introduction

Lake Edku is considered as important fishing area in Egypt receives its water from two sources, the main source is the drainage water of Kom Belag and Berzek drains where it is annually supplied with $1836.55 \times 10^6 m^3$ of water. The sea water of Abu Qir Bay enters the lake sometimes through the lake sea connection as subsurface water current under the action of wind especially in winter [1]. The lake can be divided into three ill-defined basins; eastern, central and western. Lake Edku receives huge amounts of drainage water from four main drains, namely, Edku, Bousaly, El-Khairy and Berzek, which open into the eastern basin of the lake, the drainage water contains unspecified quantities of urban, industrial and agricultural chemicals from the Beheira Governorate and beyond [2].

Water quality can be assessed by various parameters such as BOD, temperature, electrical conductivity, nitrate, phosphorus, dissolved oxygen [3]. Two major nutrients are necessary for the development of aquatic life: Nitrogen (N) and phosphorus (P). A third one, silicate (Si), is necessary for the development of diatoms [4]. Phytoplankton plays a key role in the primary production and global nutrient cycles [5]. Phytoplankton respond quickly to environmental changes and are considered good indicators of water quality and trophic conditions because of their short generation time and fast population renewal [6]. Changes in the plankton community structure in relation to physicochemical parameters may be a first sign of deterioration in the water quality. The application of plankton indicators to lake water quality assessment has a long tradition [7]. Phytoplankton is the primary producers of lake ecosystems and thus not only plays a very important role in the food chain but also affect the water quality. Phytoplankton community structure is affected by multiple environmental variables and varies widely with geographical location, functional structure, and nutritional status [8, 9]. The productivity of a specific water body depends on the amount of plankton present in the same water body. The plankton growth and distribution depend on the carrying capacity of the environment, availability of the inorganic nutrients and the physicochemical characteristics of the coastal waters. Nutrient supply to phytoplankton subsequently enhances the species composition, population abundance, richness and rates of primary production [10]. With high nutrient concentrations resulting in an increase in phytoplankton biomass and even the formation of phytoplankton blooms in lakes and reservoirs [11]. The objective of this work is to evaluate the spatial and temporal variations of some physicochemical parameters of Lake Edku water and its relation with the phytoplankton communities, chlorophyll-a as well as diversity index.

## Material and Methods

### Study Area

Lake Edku lies in the north of the Nile Delta, west of the Rosetta branch between Long. 30° 8\ 30\\ & 30° 23\ 00\\ E and Lat. 31° 10\ & 31° 18\ N. It is one of four coastal deltaic lakes that are connected to the Mediterranean Sea. Its area has decreased from 28.5x $10^3$ to about 12x$10^3$ Fadden's.

### Sampling and water analysis

Ten surface water samples to determination of physiochemical and nutrients salts were collected seasonally from Lake Edku during 2016 (Table 1&Fig. 1), using plastic Rottener Sampler of 2 liters capacity. Trips for sampled collection were carried out on a boat. Five stations for estimation of the phytoplankton standing crop were carried out by sedimentation method as reported in standard method in American Public Health Association [13], identification to species and counting will be done, and counting was expressed as units $l^{-1}$. Species diversity index (H) was estimated according to Shannon and Weaver (1963) [14] as follows:

$$H = -\sum_{i=1}^{n} Pi \ln\ Pi$$

Where *P*i = importance probability for each species (*n/N* is the proportion of *i*, the *ni* species) to the total number of phytoplankton cells (N), the results were expressed as nats. Estimation of quantitative phytoplankton analysis counting chamber were done by Sedgewick-Rafter cell according to Karlson *et al*., (2010) and Ortiz and Selene (2015) [15,16]. The different species were counted and the results expressed as unit per liter various key books and taxa were consulted for identification of phytoplankton species. Diversity H' (Shannon–Wiener index) was used to describe the numerical structure of the zooplankton and phytoplankton community. The water temperature was measured with an ordinary thermometer graduated from 0-$100^o$ C. The pH value was measured using a pocket pH meter (Orion research, model211 digital pH meter). Electrical conductivity was measured using an ordinary conduct meter by using (Jenway 4510 Conductivity/TDS Meter), Salinity was measured using an induction salinometer (Beckman; model RS7-C). Dissolved oxygen was estimated according to the Winkler method. Samples for dissolved nutrient were immediately filtered through Whatman GF/C filters and kept frozen until analysis. Samples of ammonium were fixed in the field without filtration. Dissolved inorganic nitrogen compounds ($NH_4$/N, $NO_2$/N and $NO_3/N$), reactive phosphate ($PO_4$-P) and reactive silicate ($SiO_4$) were determined according to Grasshoff (1979)[17]. Chlorophyll-*a* in the surface water was extracted with 90% acetone and measured spectrophotometrically using the SCORE UNESCO equation given in [18]. The measurements of dissolved nutrient salts and Chlorophyll-*a* were performed using Jenway 6800 Double-Beam Spectrophotometer. Shannon-Weaver diversity index usually ranges from 1.5 to 3.5 and only rarely exceeds 4.5.

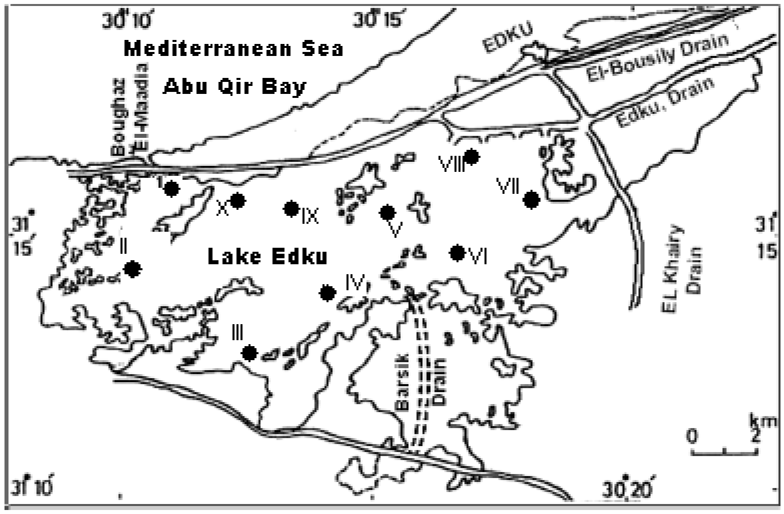


Figure 1*:* Sampling stations, lake Edku,Egypt.

**Table 1:** Sampling stations, Lake Edku

| Station | Station name | Latitude | Longitude | Plankton stations |
|---|---|---|---|---|
| I | Al-Tarfaya drain | 31°15'20.64"N | 30°10'18.92"E | S1 |
| II | Hantour Gate | 31°14'53.55"N | 30°10'33.66"E | |
| III | Churches gate | 31°14'9.46"N | 30°11'54.28"E | S2 |
| IV | AL-Tawila gate | 31°14'21.25"N | 30°12'43.67"E | |
| V | AL-charaship | 31°15'13.63"N | 30°13'54.63"E | S3 |
| VI | AL-Berka | 31°15'9.55"N | 30°12'42.18"E | |
| VII | AL-Throua drain (Edku drain) | 31°15'48.15"N | 30°13'57.94"E | S4 |
| VIII | Allbany mosque | 31° 15' 46.1082"N | 30° 12' 45.921"E | |
| IX | International road | 31° 15' 46.2096" N | 30° 11' 29.6592"E | S5 |
| X | Albogaz | 31° 16' 0.4902"N | 30° 10' 46.3182"E | To start point |

**Results & Discussion**

**Hydrographic Conditions**

The absolute values of temperature are illustrated in Fig. 2. The minimum, maximum and the average values are fluctuated between 18.80 and 31.00 °C with an average 23.92±4.41 (Table 2). The dominant species of phytoplankton, abundance and biomass are changed considerably with increasing in water temperature [19]. The variations of water temperature are affected by air temperature [20].

The pH value of nature water varied between 6.5 and 8.5. If the pH value of marine water or freshwater is greater than 9.6 or lesser than 4.5, the water-living organisms will be killed [21]. The spatial and temporal variation of pH values are illustrated in Fig. 2, it lies on the alkaline side, ranging between 7.47 and 9.07 (Table 2). There are many factors that may be affected on pH values, interactions with surrounding rock (particularly carbonate forms) and other materials, $CO_2$ concentrations [22] and Photosynthetic activity of aquatic plants, respiration of aquatic organisms [21].

Electrical Conductivity (EC) was relatively stable, as shown in Table 2, the absolute value ranged between a minimum value 0.59 mS/cm at station VII during spring and a maximum 5.13mS/cm at statin IV during winter with an average 1.87±0.65mS/cm. variation of Electrical Conductivity may be due to natural flooding, evaporation or man-made pollution.

The spatial and temporal distribution of salinity (Fig. 2) ranged between a minimum value of 0.29 at station VII during spring and a maximum value of 2.92 at station IV during winter with an average of 0.97±0.85. Summer season is the highest concentration of salinity followed by autumn and spring respectively. Stations IV, II, and III that are located between Tarfaya drain and Boghaz recorded the highest concentration. This can be explained by saltwater from the sea is pushed into the lake, raising salinity value. Stations VIII and IX recorded the lowest concentration may be due to inflow of freshwater that decrease salinity values.

**Table 2:** Minimum, Maximum and an average of physiochemical parameters in Lake Edku during 2016

| | | **Temp. (ºC)** | **pH** | **DO (mg/l)** | **BOD (mg/l)** | **TSS (mg/l)** | **EC(mS/cm)** | **Salinity (%)** | **Chl-a (µg/l)** |
|---|---|---|---|---|---|---|---|---|---|
| Winter | Min. | 21.1 | 7.47 | 11.30 | 7.10 | 16.00 | 1.44 | 0.77 | 18.96 |
| | Max. | 23.3 | 9.07 | 18.10 | 15.90 | 66.00 | 5.13 | 2.92 | 73.47 |
| | Ave. | 21.94 ±0.58 | | 14.26 ±2.02 | 11.96 ±2.82 | 35.08 ±14.85 | 2.14 ±1.08 | 1.18 ±0.63 | 38.16 ±20.38 |
| Spring | Min. | 23.00 | 7.85 | 7.48 | 3.83 | 26.40 | 0.59 | 0.29 | 18.90 |
| | Max. | 25.00 | 8.61 | 14.02 | 7.25 | 122.00 | 1.96 | 1.02 | 300.20 |
| | Ave. | 24.20 ±0.63 | | 11.65 4±2.40 | 5.63 ±1.33 | 52.92 ±27.51 | 1.39 ±0.55 | 0.71 ±0.29 | 132.54 ±75.32 |
| Summer | Min. | 29.00 | 7.69 | 1.56 | 0.91 | 16.00 | 1.82 | 0.85 | 29.60 |
| | Max. | 31.00 | 8.70 | 9.35 | 6.76 | 54.67 | 3.53 | 1.67 | 100.50 |
| | Ave. | 29.90 ±0.88 | | 5.607 ±2.76 | 3.614 ±2.10 | 26.534 ±10.40 | 2.256 ±0.58 | 1.19 ±0.28 | 56.58 ±26.83 |
| Autumn | Min. | 18.80 | 8.07 | 4.99 | 1.87 | 23.60 | 0.63 | 0.33 | 17.20 |
| | Max. | 20.20 | 8.74 | 13.09 | 4.05 | 55.80 | 1.86 | 1.07 | 76.12 |
| | Ave. | 19.62 ±0.55 | | 8.911 ±2.49 | 2.866 ±0.67 | 36.7 ±10.08 | 1.40 ±0.49 | 0.79 ±0.29 | 33.23 ±20.78 |

The minimum, maximum and the average values of DO concentration are shown in Table 2. The results as shown in Fig.2 revealed that the average value was 10.11±4.19 mg/l and ranged between a minimum1.56 mg/l at station VII during summer and a maximum 18.10 during winter at station II, the highest seasonal average value of 14.26 ±2.13mg/l recorded during winter, and the lowest seasonal average value of 5.61±2.90 mg/l during summer. DO concentrations during the four seasons can be arranged as the following: winter> spring >autumn> summer. Decreasing of DO concentration during summer may be due increasing of temperature [23].

As showed in Table 2 and graphically in Fig. 2, the average $BOD_5$ content fluctuated between 0.91 mg/L at station VII during summer and 15.90 mg/l at station III during winter with an average 60.2±3.56 mg/L. Seasonal averaged ranged between 2.87±0.70 mg/l during autumn and 11.96±2.97 mg/l during winter. The average spatial variation ranged between 4.40±3.12 mg/l at station I and 7.10±5.59 mg/l at station III.

Concentration of total suspended solids (TSS) illustrated in Table 1 and graphically in Fig. 2. The lowest concentration of TSS was receded at station V (16.00 mg/l) during winter, while the highest concentration was recorded during spring at station X (122.00 mg/l). with annual average of 37.81±34.54 mg/l. Most suspended solids are made up of inorganic materials, though bacteria and algae can also contribute to the total solids concentration.

These solids include anything drifting or floating in the water, from sediment, silt , and sand to plankton and algae [24].

Chlorophyll-a is the primary molecule responsible for photosynthesis [25]. Chlorophyll-a is found in every single photosynthesizing organism, from land plants to algae and cyanobacteria [26]. Chlorophyll-a concentration illustrated in Table2 and Fig.2. Seasonal average concentration varied between 33.23±20.78 $\mu gl^{-1}$ during autumn and 132.54±75.32 $\mu gl^{-1}$ during spring. The lower value during autumn may be due to distribution of immersed and emerged plants, which shading by emerged plants counteracts the development of algae in the lake. Stations IIV and IIIV showed the highest concentration of Chlorophyll-a, this may be due to the effect of wastewater from Edku and Barzek drainage which are considered the most important of sewage lake supply.

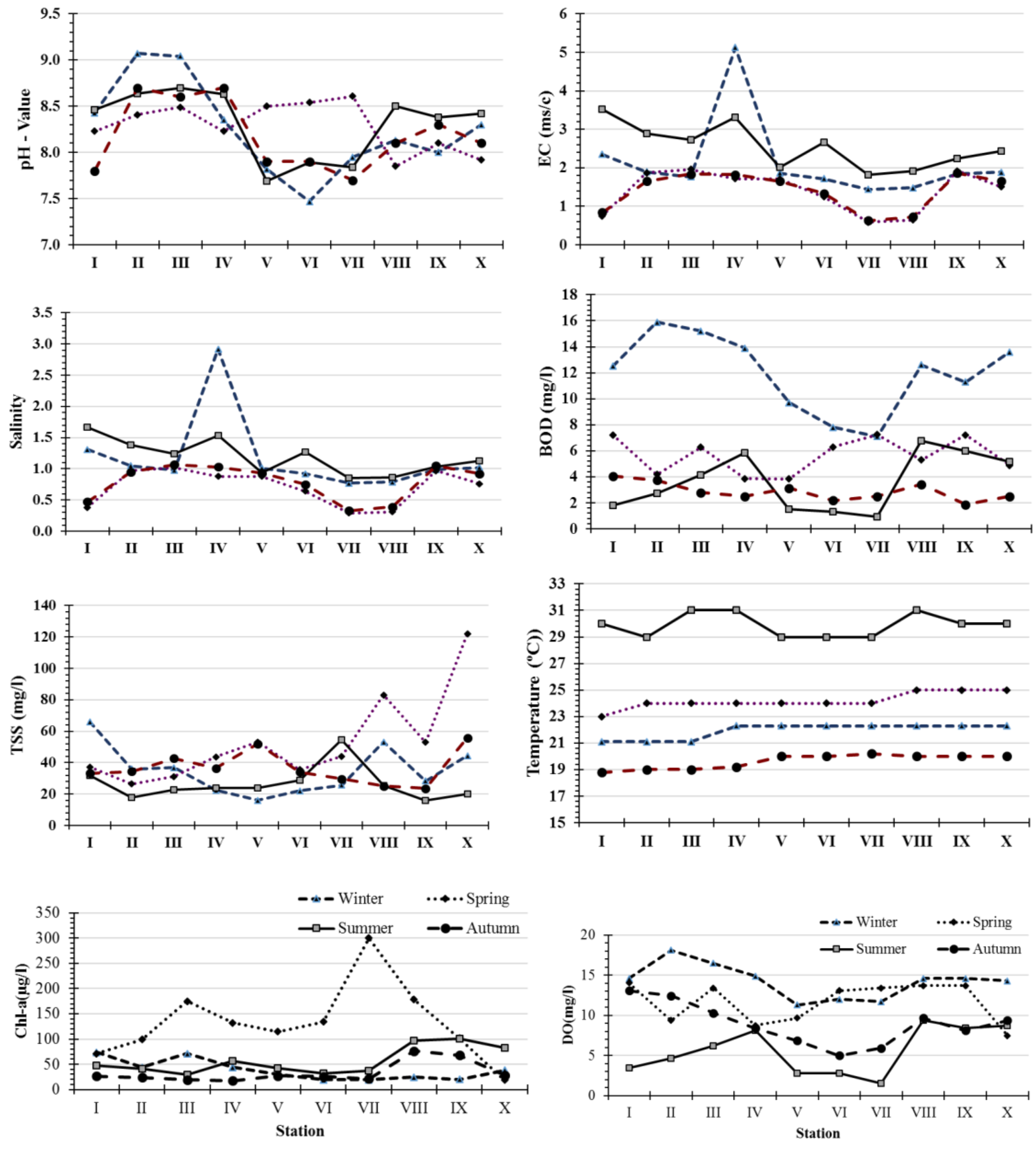


*Figure 2: Spatial and temporal distribution of physiochemical parameters during 2016*

**Nutrient Salts**

Dissolved inorganic P, N (nitrite, nitrate and ammonium) and silicate are generally considered the most critical nutrients for algal production. Nutrients are elements that are the basic atomic building blocks of living tissues [27]. Inorganic nitrogen compounds ammonium, nitrite and nitrate can be absorbed by phytoplankton living in the aquatic habitat. Ammonium is considered one of the most important pollutants in the aquatic environment not only because of its highly toxic nature, but also its ubiquity in surface water systems [28]. Ammonium is used both directly (in anhydrous form), as well as a precursor for other nitrogen-based fertilizers such as ammonium nitrate, ammonium phosphate, urea, and ammonium sulfate [29].

In the present study the concentrations of ammonium are shown in Table 3 and graphically in Fig. 3. The absolute concentration of ammonium fluctuated between 1.54µM at station II during winter and 80.04 µM at station V during autumn with an average 18.65±12.12µM. Seasonal average ranged from 6.63±3.00µM to 37.29±31.37µM. Annual average ranged between 3.67±1.60 µM at station II and 43.83±32.33 µM at station V. The concentration of ammonium during the four seasons can be arranged as the following: autumn>summer>spring>winter. These concentrations decreased gradually to reach the lowest values during winter. These decreased concentrations during summer may be due to the consumption and assimilation of ammonium by aquatic plants.

The results of nitrite $NO_2/N$ concentrations fluctuated between 0.11µM at station I during winter and 37.29µM at station X during autumn with an average 10.72±5.41µM. The seasonal average concentration ranged between 1.98±1.90µM during summer and 16.78±9.95µM during autumn, the annual average ranged from 4.45±6.89 µM at station I to 16.31±11.63 µM (Table3 and Fig. 3). The result showed decrease in the nitrite content in the summer might be due to the increase in the oxidation rate of nitrite to nitrate. Nitrate is a common form of inorganic combined nitrogen in natural waters and aquaculture systems. Most of the nitrate found in unpolluted natural waters is the end product of nitrification. Nitrate salts are also occasionally used in fertilizers applied to ponds to stimulate phytoplankton growth, and nitrate may be applied to pond bottom soils to prevent reducing conditions that lead to sulfide production [30]. Nitrate at different station during the four seasons illustrated in Table 3 and graphically in Fig. 3. The absolute concentration fluctuated between 1.33 µM at station IV during summer and 108.38µM at station III during autumn with an average 31.63±15.23µM, seasonal average varied from 7.35±6.62 µM during summer to 47.31±29.27 µM during autumn, while annual average varied between 18.02±15.53 µM at station I and 52.84±34.08 µM at station III. Factors affecting the concentration and distribution of nitrate in the lake may be related to the discharge of drainage water, dissolved oxygen, decomposition of organic remains regeneration from the bottom sediments and assimilation by aquatic plants.

The absolute reactive phosphate ($PO_4/P$) concentration varied between a lowest value 0.22 µM and a highest value 67.30 µM with an average 11.36±7.73 µM. Seasonal average fluctuated between 3.08±1.80 µM during spring and 20.15±18.90 µM during summer. Spatial average ranged between 3.62±4.20 µM at station I and 25.56±5.45 µM at station VIII, based on the annual average concentration of $PO_4/P$, the results can be arranged as the following order: summer < autumn < spring <Winter, owing to distribution decreasing of concentration may be due to Plant uptake is a major factor controlling concentrations of soluble reactive phosphate in water, and much of the total phosphorus in water is contained in phytoplankton cells, chemical combination of P with Mn and Fe dependent on oxidation and pH condition, absorption of phosphorus by particle and organ material and sediment while Increasing of the concentration of reactive phosphate may be associated with the biological uptake and or additional phosphate source [31&32].

The reactive silicate concentration ranged between a minimum 1.36µM at station I during autumn and 70.97µM at station V during winter with an average 19.17±9.61 µM. Seasonal average varied between 8.26±5.20µM during summer and 29.16±12.45µM during autumn. Annual averaged ranged from 7.95±6.26µM to 44.41±17.30 µM at stations VIII and V, respectively. Variation of silicate concentrations may be due to variation in the activity of diatoms, and other microorganisms.

**Table 3**: Minimum, Maximum and an average of nutrients content in Lake Edku during 2016

| | $NH_4/N$ | $NO_2/N$ | $NO_3/N$ | $PO_4/P$ | $SiO_4/Si$ |
|---|---|---|---|---|---|

| | | (µM) | (µM) | (µM) | (µM) | (µM) |
|---|---|---|---|---|---|---|
| Winter | Min. | 1.54 | 0.11 | 2.90 | 1.07 | 3.64 |
| | Max. | 10.67 | 28.71 | 71.33 | 7.74 | 70.97 |
| | Ave. | 6.63 ±3.16 | 12.61 ±10.74 | 30.67 ±20.88 | 4.30 ±2.46 | 28.29 ±24.96 |
| Spring | Min. | 1.96 | 0.36 | 9.10 | 0.22 | 4.28 |
| | Max. | 26.88 | 31.21 | 84.05 | 6.30 | 40.40 |
| | Ave. | 9.26 ±7.66 | 11.49 ±9.92 | 41.19 ±29.45 | 3.08 ±1.90 | 10.97 ±11.20 |
| Summer | Min. | 1.88 | 0.21 | 1.33 | 2.63 | 3.24 |
| | Max. | 72.00 | 5.07 | 19.95 | 67.30 | 22.60 |
| | Ave. | 21.4 ±27.53 | 1.98 ±2.00 | 7.35 ±6.98 | 20.15 ±19.92 | 8.26 ±5.48 |
| Autumn | Min. | 3.00 | 6.25 | 16.76 | 1.33 | 1.36 |
| | Max. | 80.04 | 37.29 | 108.38 | 25.70 | 47.88 |
| | Ave. | 37.29 ±33.06 | 16.78 ±10.49 | 47.31 ±30.85 | 17.93 ±8.43 | 29.16 ±13.12 |

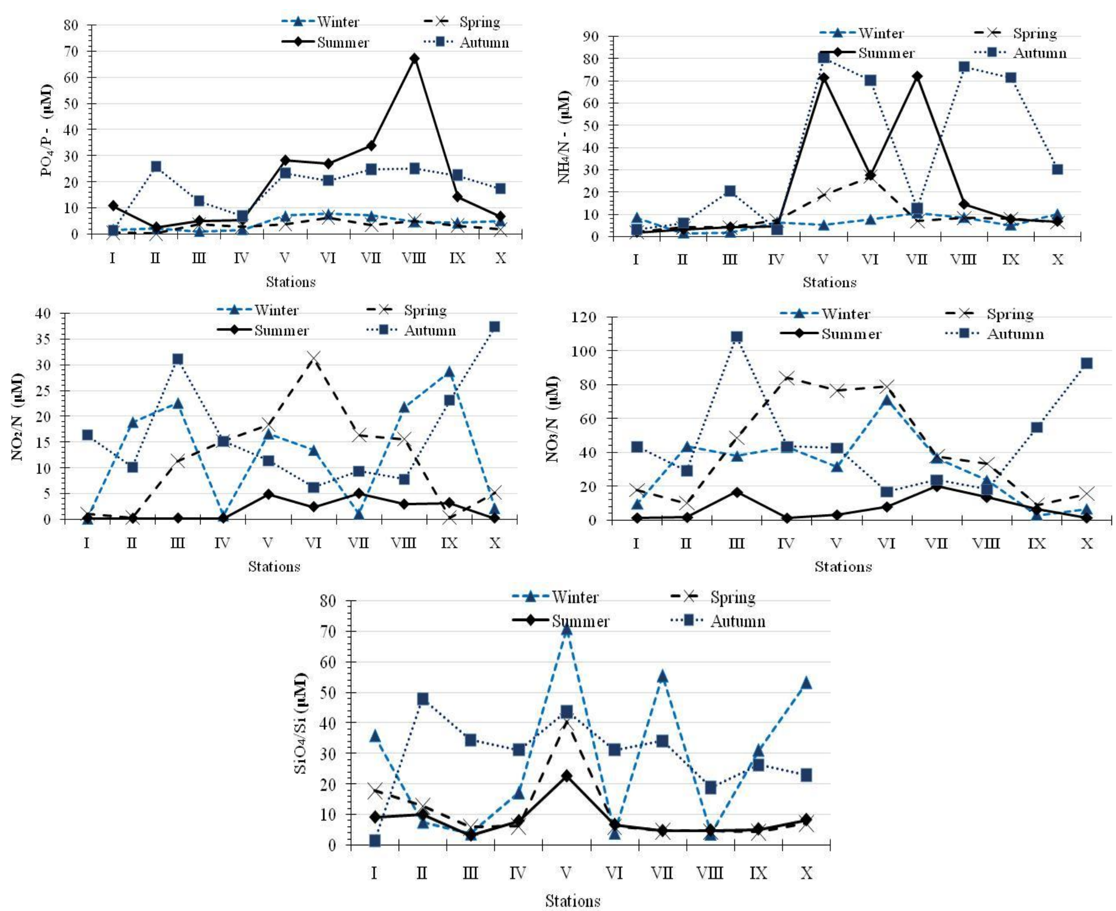


*Figure 3: Spatial and temporal distribution of nutrients salts*

**Biological Parameters**

**Phytoplankton Community**

The Phytoplankton community in the investigated area during the period of study, this work was not only productive but also diversified. A total of 30 phytoplankton taxa were identified belonging to four genera represented by nine groups (Tables 4&5). During this study, Chlorophyta comprised the highest abundance 51.67 % represented by common 13 species, while Bacillariophyceae 32.19 % comprised six species. Euglenozoa represented with abundance 10.87%. Cyanobacteria were rarely recorded contributing about 1.27 % to the total counts. The most dominant species during spring of study were represented 60% for chlorella with an average 60x $10^5$ cells $l^{-1}$, (*closterium*) with an average 9 x $10^5$ cells $l^{-1}$ and percentage 9% during summer was the most dominant species*(thalassiosira*), with an average 15 x $10^5$ cells $l^{-1}$and percentage 17.5%. *(Ankistrodesmus, thalassiosira and Nitzschiathe*) most dominant species during autumn with an average 8 x $10^5$ cells $l^{-1}$, 8 x $10^5$ cells $l^{-1}$, 6 x $10^5$ cells $l^{-1}$ with percentage 9.6 %, 9.13% and 7.7 % respectively. During autumn, winter and summer the dominant species were mostly of the phylum Bacillariophyta and Chlorophyta, while in the spring Chlorophyta was the most dominated phyla.

**Table 4:** Phytoplankton species composition and predominant species or genera in Lake Edku, during 2016

| Phyla | number of Species | Predominant species or genera |
|---|---|---|
| **Chlorophyta** | 18 | *Chlorella, Westellam, Eudorina, Pandorina, Pediastrum, Scenedesmus, Cosmarium, Desmidium, Oedogonium, Oocystis, Volvox, Actinastrum, Closterium, Dictyosphaerium, Ankistrodesmus, Botryococcus, Tetraedron, Sphaerocystis* |
| **Bacillariophyceae** | 9 | *Thalassiosira, Pinnularia, Cyclotella, Surirella, Melosira, Nitzschia closterium, Bacillaria sp, Navicula* |
| **Cyanobacteria** | 2 | *Merismopedia, Spirulina* |
| **Euglenozoa** | 1 | *Euglenaceae* |

**Phytoplankton Abundance**

The regional and seasonal variation of phytoplankton abundance is shown in Fig.'s 4 and 5. The average abundance ranged between a minimum 46 $\times 10^5$cells/l at station IV during winter and was made up of Bacillariophyta species and Chlorophyta species, and a maximum $414\times10^5$cells/l at station V during summer with an average $142\times10^5$cells/l. was $278.84\times10^5$cells/L, ranging from $3.66\times10^5$ to $867.93\times10^5$cells /l. Seasonal average abundance varied between $83\times10^5$cells/l during autumn and $300\times10^5$cells/l during summer increasing of phytoplankton abundance during summer, this may be due to water temperature and nutrient salts abundant. Spatial average recorded a minimum value of $98\times10^5$cells/l at station III and a maximum value of $173\times10^5$ cells/l at station IV. Seasonal abundant can be arranged as the following summer>spring>winter>autumn (Fig.6). The decreasing in phytoplankton abundance might be due to the drastic change in water depth and the increasing in food consumption by phytophagous fish [33].

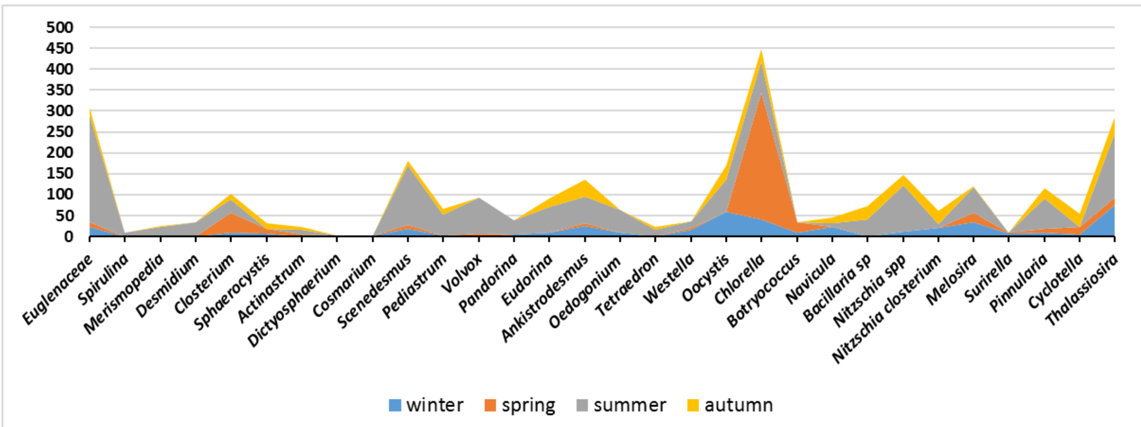


*Figure 4: Temporal variation of total Phytoplankton abandance ($\times10^5$units $l^{-1}$) in Lake Edku during 2016*

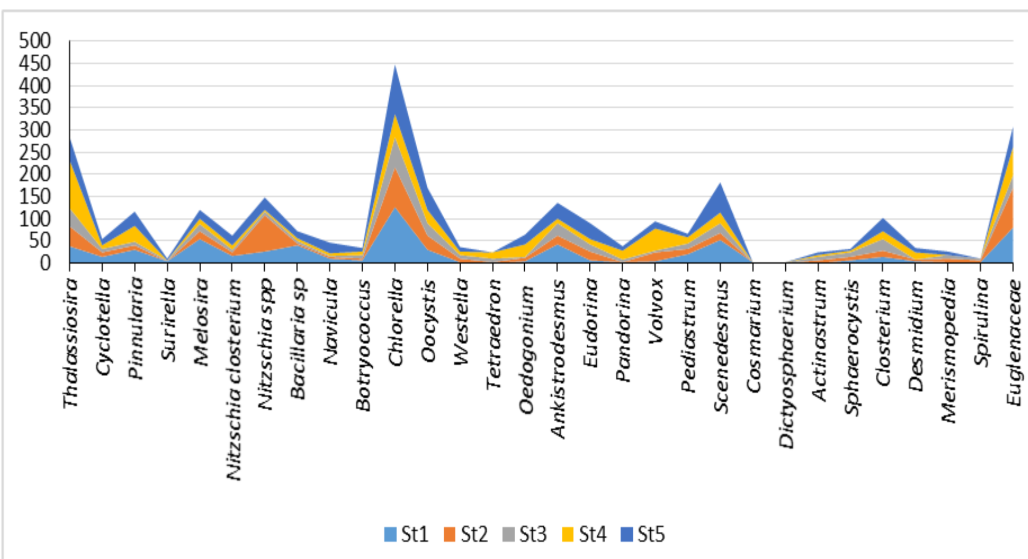


*Figure 5: Spatial variation of total phytoplankton abundance in Lake Edku during 2016*

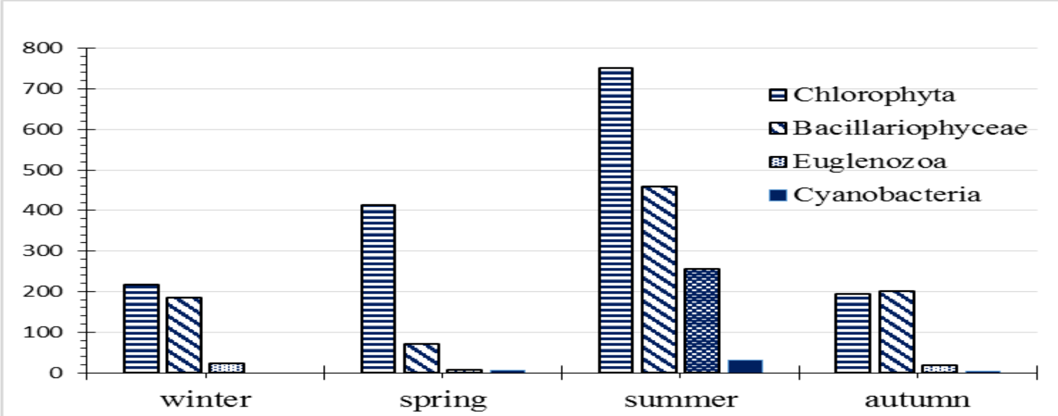


*Figure 6: Temporal variation of total phytoplankton abundance in Lake Edku during 2016*

**Table 5:** Spatial and temporal distribution of Phytoplankton abandance ($\times 10^5$units $l^{-1}$) in Lake Edku during 2016

| Phylum | | winter | spring | summer | autumn | SUM | Min. | Max. | Ave. |
|---|---|---|---|---|---|---|---|---|---|
| **Chlorophyta** | **I** | 32 | 126 | 142 | 20 | 320 | 20 | 142 | 80 |
| | **II** | 38 | 86 | 84 | 56 | 264 | 38 | 86 | 66 |
| | **III** | 70 | 56 | 72 | 58 | 256 | 56 | 72 | 64 |
| | **IV** | 50 | 36 | 186 | 40 | 312 | 36 | 186 | 78 |
| | **V** | 28 | 110 | 268 | 20 | 426 | 20 | 268 | 107 |
| | **SUM** | 218 | 414 | 752 | 194 | 1578 | 170 | 754 | 395 |
| | **Min.** | 28 | 36 | 72 | 20 | 256 | 20 | 72 | 64 |
| | **Max.** | 70 | 126 | 268 | 58 | 426 | 56 | 268 | 107 |
| | **Ave.** | 44 | 83 | 150 | 39 | 316 | 34 | 151 | 79 |
| **Bacillariophyceae** | **I** | 60 | 24 | 100 | 48 | 232 | 24 | 100 | 58 |
| | **II** | 49 | 12 | 88 | 32 | 181 | 12 | 88 | 45 |
| | **III** | 25 | 6 | 36 | 30 | 97 | 6 | 36 | 24 |
| | **IV** | 14 | 10 | 138 | 28 | 190 | 10 | 138 | 48 |
| | **V** | 37 | 18 | 96 | 62 | 213 | 18 | 96 | 53 |
| | **SUM** | 185 | 70 | 458 | 200 | 913 | 70 | 458 | 228 |
| | **Min.** | 14 | 6 | 36 | 28 | 84 | 6 | 36 | 21 |
| | **Max.** | 60 | 24 | 138 | 62 | 284 | 24 | 138 | 71 |
| | **Ave.** | 37 | 14 | 92 | 40 | 183 | 14 | 92 | 46 |
| **Euglenozoa** | **I** | 12 | 2 | 64 | 2 | 80 | 2 | 64 | 20 |
| | **II** | 8 | 4 | 72 | 6 | 90 | 4 | 72 | 23 |
| | **III** | 2 | 0 | 18 | 6 | 26 | 0 | 18 | 7 |
| | **IV** | 0 | 0 | 60 | 4 | 64 | 0 | 60 | 16 |
| | **V** | 0 | 0 | 42 | 0 | 42 | 0 | 42 | 11 |
| | **SUM** | 22 | 6 | 256 | 18 | 302 | 6 | 256 | 76 |
| | **Min.** | 0 | 0 | 18 | 0 | 18 | 0 | 18 | 5 |
| | **Max.** | 12 | 4 | 72 | 6 | 94 | 4 | 72 | 24 |
| | **Ave.** | 4 | 1 | 51 | 4 | 60 | 1 | 51 | 15 |
| **Cyanobacteria** | **I** | 0 | 0 | 4 | 0 | 4 | 0 | 4 | 1 |
| | **II** | 0 | 4 | 10 | 2 | 16 | 0 | 10 | 4 |
| | **III** | 0 | 2 | 10 | 2 | 14 | 0 | 10 | 4 |
| | **IV** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **V** | 0 | 0 | 8 | 0 | 8 | 0 | 8 | 2 |
| | **SUM** | 0 | 6 | 32 | 4 | 42 | 0 | 32 | 11 |
| | **Min.** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Max.** | 0 | 4 | 10 | 2 | 16 | 0 | 10 | 4 |
| | **Ave.** | 0 | 1 | 6 | 1 | 8 | 0 | 6 | 2 |
| **Total** | **SUM** | 425 | 496 | 1498 | 416 | 2835 | 416 | 1498 | 709 |
| | **Min.** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Max.** | 70 | 126 | 268 | 62 | 526 | 62 | 268 | 132 |
| | **Ave.** | 21 | 25 | 75 | 21 | 142 | 21 | 75 | 35 |

**Diversity Index of Phytoplankton Community**

The diversity index of phytoplankton in the Lake Edku (Fig.7) varied between a minimum 1.36 at station V during spring and a maximum 2.85 at the same station during summer with an average 2.26. Seasonal average ranged between a minimum1.51 during spring and a maximum 2.63 during autumn. Annual average of diversity index fluctuated between 2.27 at station V and 2.37 at station I. Diversity index can be arranged as summer>autumn>winter>spring. Respectively, and annually III>IV>V>II=I.

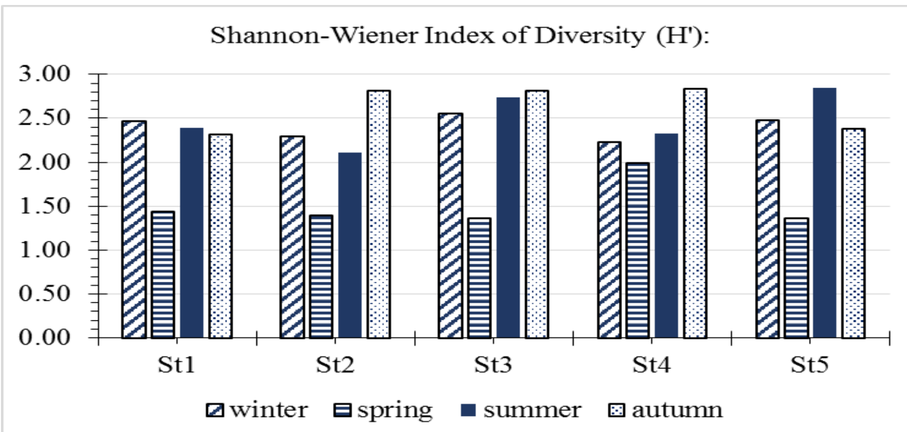


*Figure 7: Shannon- wiener Diversity index (Ȟ)*

**Correlations Matrix**

Pearson's correlation coefficients were estimated to evaluate relationships amongst all parameters. The statistical analyses were performed using SPSS computer software. Correlation coefficient showed that pH is significantly negative correlated with ammonium $NH_4/N$ (-.380). Conductivity have negative correlation with nitrite $NO_2/N$ (-0.377). Dissolved oxygen had negative correlation with reactive phosphorus ($PO_4/P$), ammonium and phytoplankton (-0.475, -0.489 and -0.463), respectively and positive correlation with nitrite (0.331). BOD had negative correlation with $PO_4/P$ and $NH_4$ /N, and phytoplankton (0.398, 0.475 and 0.385), respectively. Chlorophyll-a had negative correlation with $SiO_4$ (.355). Reactive phosphorus had a negative correlation with EC, BOD (0.475 and 0.398) and positive correlation with $NH_4/N$ (0.537). Ammonium had negative correlation with pH, DO, BOD and phytoplankton (0.390, 0.489 0.457 and 0.396), respectively. Nitrate, nitrite and silicate had negative correlation with phytoplankton (0.396, 0.500 and 0.393).

**Conclusions**

During the present study, the Lake Edku has a moderate diversity of phytoplankton species, with 30 species from 4 phyla identified during the study period. There were 9 predominant species, with substantial temporal changes in the dominant species from Bacillariophyta and Chlorophyta. The average abundance of phytoplankton in the lake was $142 \times 10^5$ cells/l.

Phytoplankton abundance showed a similar increasing trend from sprig to summer, but changes in phytoplankton abundance differed variations during winter and autumn.
The Shannon Wiener diversity index varied between 1.36 and 2.85, with an average of 2.28, revealing a moderated diverse phytoplankton community. The moderated diversity indicates good water quality.
Statistical analysis revealed that water nutrient concentration were the most significant environmental factors influencing phytoplankton community, with other environmental factors such as pH, DO, $NO^{2-}$-N, Zinc, conductivity, and crustacean zooplankton, which were also important.

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