Phytoplankton population as alarming warning bioindicator of water pollution in El-Temsah Lake, Egypt

Mostafa Elshobary (mostafa_elshobary@science.tanta.edu.eg)
Jiangsu University https://orcid.org/0000-0002-2131-0679
Abdullah M. Attiah
Atomic Energy Centre
Zenhom E. Salem
Tanta University Faculty of Science
Dorya I. Essa
Tanta University Faculty of Science

Research Article

Keywords: Phytoplankton, Palmer's index, Environmental parameters, Pollution, El-Temsah Lake

Posted Date: March 23rd, 2021

DOI: https://doi.org/10.21203/rs.3.rs-305271/v1

Abstract

Relative effects of spatio-seasonal variations on the quantitative and qualitative status of phytoplankton in 20 sampling locations of Temsah Lake were examined during winter and summer 2018. The study reveals that the population structure consisted of 105 species from 69 genera, with an annual average of 924155 cell/L. Bacillariophyceae formed the most dominant group with 42.45% of total phytoplankton with an average of 372379 cell/L. Navicula creptocephala was the most abundant species representing 19.16% of total diatoms and 7.78% of the whole standing crop with an annual average of 376879 cell/L. The highest phytoplankton abundance was in the Northern locations. Phytoplankton density showed a negative correlation of pH, temperature and TDS and positively correlated with nutrient content such as nitrate and silicate. In general, summer showed high indices value compared to winter and the diversity index in the current study ranged in moderate pollution range. The polluted state of the aquatic ecosystem in El-Temsah Lake during summer is comparatively higher than winter during the study period. Palmer's and diversity indices showed that Northern sites were the most flourishing and polluted sites. The study also recorded a number of tolerate algae (13 genera and 8 species), which can be used as an indicator for different degrees of organic pollution. Genus and species Palmer's Index scores of the northern site were in the range of ≥20 during summer, indicating most of the sampling locations showed probable to confirmed high level of organic pollution.

1. Introduction

Water is the secret of life. It is more important than energy because there are alternative energy sources, but there are no other water sources. World faces rapid deterioration of its owning water. Global population growth and rising living standards contribute to the discharging of tremendous amounts of waste and nutrients into water bodies worldwide (Elshobary et al. 2020). Therefore, it is fundamental to find environmentally sustainable ways to preserve and protect the valuable water resource. Indeed, continuous monitoring and evaluation of water quality is a crucial concern for sustainable conservation and management. Lakes are often exposed to abrupt environmental vagaries caused by various anthropogenic activities and tourism along their banks. El-Temsah Lake is one of the most common lakes in the Suez Canal of Egypt that receives an immense amount of raw waste discharges (industrial, farming, domestic, leisure, etc.) and tourism activities along its shores. El-Temsah lake is considered a transitional zone connecting two mainly different basins (Red Sea and Mediterranian Sea), affecting flora and fauna distribution (Nassar and Shams El-Din 2006).

Consequently, El-Temsah Lake exhibits serious water quality problems. It is noteworthy that excessive nutrient loading and disruption of water ecological parameters can contribute to eutrophication, resulting in substantial qualitative and quantitative variations in phytoplankton populations and water quality (Xiao et al. 2013; Haque et al. 2019). Phytoplankton blooms cause serious problems in the whole aquatic ecosystems, economy and human survival (Diodato et al. 2005; Hokimoto and Kiyofuji 2014). Furthermore, phytoplankton is directly influenced by different discharges in addition to human activities and agricultural runoff (Collavini et al. 2001). Also, they have a short life span and rapidly react to any modifications in the ecosystem, so provide an early warning sign of water deterioration condition and may be helpful for water quality evaluating (El-Kassas and Gharib 2016). Therefore, evaluation of water quality is a critical issue to balance ecological and socio-economic benefits. Since water quality summarized and defined forcing variables related to the aquatic ecosystem to be used as a key task for administering water resources on a scientific basis (Parparov and Hambright 2007). Physicochemical and biological indices are usually used for the assessment of water quality. The former is based on the determination of different physico-chemical parameters in a water sample, whereas the biological indices are dependent on biological evidence such as phytoplankton. Many studies investigated the water quality of Lake El-Temsah till 2016 (Nassar and Shams El-Din 2006; Said and El Agroudy 2006; Donia 2011; Hamed et al. 2012; Kamel 2013; Gaballa 2014; El-Serehy et al. 2018; El-Shoubaky and Hamed 2018; Soliman et al. 2019). All these studies established that the worsening of the lake ecosystem and water quality had been reached a critical level. Thus an urgent action is therefore needed urgently to recover the El-Temsah ecosystem. Therefore, the present study aims to quantify the lake's water quality during 2018 through the physiochemical and biological phytoplankton index. This aim was performed through the numerically mathematical indices of species richness, species diversity, equitability, and Palmer indices to assess these indices' suitability for the maintenance and management of water resources.

2. Materials And Methods

2.1. Study Areas and sampling locations

This study was carried out in two seasons in August (dry summer season), and February (wet winter season) 2018, where the difference in climate changes was significant in these two seasons in Egypt. El-Temsah lake is located near the middle of the Suez Canal about mid-way between the northern city of Port Said and the southern city of Suez at 30°35'46.55"N and 32°19'30.54"E (Fig. 1). El-Temsah lake is the largest lake of Ismailia city, Egypt, with a total surface area of 14 km with 80 million m^3. It is a saline shallow water body (3 and 16 m in depth). The lake is connected to a small, shallow lagoon by a narrow passage on the west side. This lagoon is connected with El-Mahsama drains (industrial, agriculture, and sewage effluent). On the north side, the lake occasionally receives input from the Ismailia freshwater canal and agricultural drainage water from the El-Forsan drain. The lake is connected with the Suez Canal from eastern and southern areas (Abd El Samie et al. 2008). Twenty sampling locations were carefully chosen to cover different regions of the lake (Fig. 1).

2.2. Environmental Data Collection Water

Water temperature and pH value were measured in situ, using Hydrolab, Model (Multi Set 430i WTW). For the other chemical analysis, water samples were collected in polyethylene bottles and were stored in an icebox upon returning to the laboratory. The collected samples were sieved and filtered through zooplankton net (100 µm mesh size) and Whatman® GF/F (0.7 µm pore diameter), respectively, and used for chemical analysis. Total Dissolved Solids (TDS), silicate (Si), phosphate (PO3-P), and nitrate NO3-N were measured according to the standard methods of the American Public Health Association (APHA 1998).

2.3. Phytoplankton Collection and Enumeration

Triplicate phytoplankton samples with 2 L each were collected in a clean polyethylene bottle from the water surface of the sampling locations. The samples were fixed at the sampling site using 10 mL acidic Lugol's iodine and transferred in an icebox to the laboratory. In the laboratory, samples were kept to settle for 48 h. The supernatant was carefully siphoned off via sterilized plastic tubes with plankton net (5μ) and concentrated lower samples stored into 100 mL tight capped bottles in the dark place to prevent light degradation before counting identification. Phytoplankton enumeration in triplicate was done by transferring 1 mL into Sedgewick-Rafter counting chamber at 100 and 40 × magnification using a compound microscope Nikon Eclipse E400 (Nikon, Japan). Phytoplankton was counted (cell/L) and estimated by counting all phytoplankton, whether single cells, colonies, or filaments (LeGresley and McDermott 2010). The algal species were identified according to standard references (Smith 1950; Desikashary 1959; Hendy 1964; Bourrelly 1981; Prescott 1987). The identified species were compared with the latest website of AlgaeBase (http://www.algaebase.org).

2.4. Data analysis

Analysis of variance (ANOVA) was assessed to determine the degree of seasonal variation and spatial variation at ≤ 0.05 level of significance. Duncan's multiple comparison test was used to compare the average biological and physicochemical parameters using SPSS v.23. The significant dissimilarities of phytoplankton communities and environmental conditions in sample locations were tested using one-way Analysis of Similarity (ANOSIM) (Clarke 1993). Similarity percentage analysis (SIMPER) was used to examine genus influence in the sampling locations using Paleontological Statistics (PAST3). Phytoplankton richness, equitability indices and biodiversity indices were calculated using Shannon–Wiener diversity index (*H'*), Margalef (*D*) and Equitability index (*J'*) to characterize the species diversity in a community across seasons and sampling locations using PAST3. Spatial and temporal physical/chemical patterns were illustrated using contour graphics generated using SURFER 13 (Surfer®, Golden Software, LLC).

3. Results

3.1. Hydrology

Knowledge about different physico-chemical parameters provides a biological activity to assess the ecological quality of an ecosystem. Physicochemical factors play a crucial role in guiding biodiversity in the aquatic environment, contributing to a shift in the diversity and population of aquatic biota (Ramírez et al. 2005; Elshobary et al. 2020). Fig 2 displays the average value of six physicochemical parameters for the twenty locations in Temsah Lake.

The hydrogen ion value (pH) is the leading factor that directs both the chemical and biological activity of the aquatic ecosystem. The pH was slightly alkaline around the year within the standard pH ranged from 6.5 to 8.5 (WHO 2011). The annual mean was 7.55 and fluctuated between 6.63 at location 3 during winter to 8.17 at location 13 during summer (Table 1). pH is affected by CO_2 circulation and organic and inorganic contaminants in the water body (Rahman and Huda 2012). The high reported pH value may be owing to the impact of increased biological activity, CO_2 consumption (Govindasamy et al. 2000) and the high photosynthetic rate during summer (Saravanakumar et al. 2008; Sankar et al. 2010).

The water temperature is a key factor as it controls various abiotic and biotic activities of an aquatic ecosystem (Radhika et al., 2004). Stenseth et al. (2005) stated that temperature variation could lead to changes in marine and estuarine ecosystems at all food chain levels, from primary producers (phytoplankton) to top predators. The surface temperature (SWT) fluctuated from 24.9 at location 3 to 27.85 °C at location 13 (Table 1). The summer season showed the highest SWT might be owing to the intensity of solar radiation, evaporation and water influx (Kumar et al. 2006; Saravanakumar et al. 2008; Sankar et al. 2010). It was reported that most phytoplankton prefers moderate temperature ranged from 20-35 (Elshobary et al. 2020). Therefore, five groups of algae were recorded in this study.

Concentrations of total dissolved solids (TDS) in water vary considerably in different geological regions due to differences in minerals' solubilities. The annual TDS fluctuated between 2070 ppm at location 2 during summer to 51239 ppm at site 15 during summer (Table 1). The high concentration of TDS is caused mainly by the remnants of inorganic materials and wastewater molecules due to the anthropogenic activities around the water body (Sulistiawati et al. 2020). The winter season is the leading season, while the concentrations dropped a little bit in the summer. High TDS values during the winter season are attributed to the rains that carry soil and other organic matter from the wetlands to the lake (Sharma and Tiwari 2018). The same finding was observed in the Ismailia canal connected with the lake in 2018 (Elshobary et al. 2020). Ali et al. (2020) demonstrated that TDS in winter exceeded spring, summer and autumn values, respectively. TDS concentrations are very high near the southwestern locations due to the outfall of domestic and industrial wastewater that agreed with previous studies in the same lake during 2011 (Donia 2011) and 2015 (El-azim et al. 2018).

Silicate concentration is one of the vital environmental indicators that impact the phytoplankton productivity in the aquatic environment, especially diatoms (Cui et al. 2018). Silicate value was ranged from 0.5 ppm at location 19 during summer to 9.19 ppm at location 3 during winter (Table 1). The availability of silicate in El-Temsah Lake is due to the mixing of agriculture runoff discharged in the lake and connected canals such as Ismailia and Suez canals as well as Bitter Lake. The highest silicate values were observed in winter and reduced in summer; this could be due to the high density of phytoplankton in summer and its high silicate consumption for their biological activity and flourishing during summer (Sankar et al. 2010). These results agreed with (Habib et al. 1997; Elshobary et al. 2020), who showed that silicate concentration in winter was higher than in summer during their studies.

In contrast, autumn is the leader season, followed by spring and summer in Bitter lake (Nassar and Fahmy 2016). These differences have been addressed by Bharathi et al. (2018), who reported that silicate concentration could be varied from season to season according to sampling locations and studying periods in the same water body. Generally, the amount of silica is attributable to the weathering of silicate rocks, in addition to its absorption by diatoms (Wang et al. 2013; El-Otify and Iskaros 2015).

With regards to the trophic conditions of the Temsah lake, nitrate (NO_3- N) and phosphorus (PO_4-P) covered a wide range of concentrations, from 1.5 ppm to 4.7ppm and 0.009 ppm to 0.89 ppm, respectively (Table 1). Summer is the leader season in NO_3- N and PO_4-P. This finding is agreed with (Abdel-Satar et al. 2017), who demonstrated that NO_3- N and PO_4-P values were the maxima in summer compared to winter seasons in the river Nile and Bitter Lakes of Egypt (Nassar and Fahmy 2016). The highest NO_3- N and PO_4-P concentrations were observed at location 3 during summer (4. 7 ppm) for nitrate and location 7 during summer (0.89 ppm) for phosphate. The reported highest summer NO_3- N and PO_4-P concentration may be mainly due to the organic materials received from the catchment zone (Ashok Prabu et al., 2008). Significant spatial and seasonal differences were found for all abiotic variables ($p \leq 0.05$) (Table 1).

3.2. phytoplankton composition and percentage frequencies of phytoplankton groups

The quantitative and qualitative status of phytoplankton in Temsah Lake during winter and summer 2018 revealed that its community structure was belonging to five divisions, namely: Bacillariophyceae, Chlorophyceae, Cyanophyceae, Dinoophyceae and Euglenophyta. A total of 105 species belonging to 69 genera were identified during the studying period at different 20 locations covering the whole area of El-Temsah Lake with an annual average of 924155 cell/L. Among those, Bacillariophyceae (26 genera and 39 spp.), Chlorophyceae (24 genera and 33 spp.), Cyanophyceae (9 genera and 15 spp.), Dinophyceae (5 genera and 8 spp.) and Euglenophyceae (3 genera and 10 spp.) as shown in Table (2). This finding is slightly lower than that reported in the recent survey in Temsah lake of Gaballa (2014), who found 116 different genera during 2012. These differences may be associated with spatial and temporal variations in the physiochemical and biological parameters of water bodies (Zhang et al. 2011; Demir et al. 2014; Napiórkowska-Krzebietke and Hutorowicz 2014; Elshobary et al. 2020). The low number of species recorded in the lake can generally be attributed to the persistent discharge of wastewater, leading to increased nutrient supplements hence decreasing predominant species. This finding was affirmed by Ludsin et al. (2001) and Prepas and Charette (2005), who showed that the biodiversity of many aquatic microorganisms reversibly proportions with nutrient content due to increase eutrophication state of the water body.

Bacillariophyceae was the most dominant group and formed about 42.45% of total phytoplankton standing crop with an average of 372379 cell/L. *Navicula creptocephala* was the most recorded species representing 19.16% of total diatoms and 7.78% of the total standing crop with an annual average of 376879 cell/L. *Cyclotella kutzingiana* and *Diatoma vulgare* were also highly recorded during the study period, with an average of 44217.5 and 39460 cell/L, respectively. In a previous study, diatoms were the dominant group in El-Temsah lake, representing 56 and 58%, respectively (Gaballa 2014; El-Serehy et al. 2018). Chlorophyceae occupied the second predominant position with an annual average of 336547 cell/L comprising 36.24% of the total standing crop. *Scenedesmus quadricauda* was the most dominant with a yearly average of 24162.5 cell/L followed by *Chlorella vulgaris* and *Chlorobotrus regularis* with an average of 25212.5 and 24568.5, respectively. While, Cyanophyceae represented 19.09% of the phytoplankton with an annual average of 196088 cell/L. *Oscillatoria planktonica* was the most dominant, representing 20.19% of total Cyanophyceae. Dinophyceae and Euglenophyceae were rarely recorded and representing only 1.50 and 0.72 % of the whole standing crop with an annual average of 14605 and 4537 cell/L, respectively (Table 2). These taxonomic groups and species abundance showed more or less consistent with prior studies in the same lake (Nassar and Shams El-Din 2006; Gaballa 2014; El-Serehy et al. 2018).

Diatoms exhibit the most dominant group in this study because of their ability to survive under a wide range of environmental factors, such as salinity, temperature and nutrient availability (Huang et al. 2004; Kouhanestani et al. 2019). The same conclusion was observed by Gaballa (2014), who mentioned that phytoplankton's structure was dominated by diatoms followed by Cyanophyta, Dinophyta and Chlorophyta in the same lake during 2012. Elshobary et al. (2020) have shown that diatoms occupy the first dominant group, followed by Chlorophyta, Cyanophyta, and Dinophyta in the Ismailia canal connected with Temsah. Otherwise, Euglenophyta, represented by ten species and constituting 0.72% of the total phytoplankton community, is probably represented in this way due to the increase in organic matter pollution in El- Temsah Lake (El-Serehy et al. 2018).

3.3. Seasonal variation of total phytoplankton standing crop in El-Temsah Lake

Phytoplankton density recorded in El-Temsah Lake varied greatly from winter to summer, as represented in Table (2). Summer was reported as the most productive season during the study period of 1499563 cell/L representing 80.08% of the total standing crop with phytoplanktonic diversity of 105 species, while winter recorded 348747 cell/L representing only 19.02% of total phytoplankton. Five species (*Amphora coffeaeformis, Biddulphia favus, Tetraedron muticum, Scrippsiella spinifera* and *Trachelomonas hispida*) were recorded in summer, which were not represented in winter (Table S1). Elshobary et al. (2020) observed new 11 species were present in summer that were absent in winter in the Ismailia canal. Bacillariophyta was the most dominant phylum in both seasons with 584666 cell/L during summer and 160092 cell/L of winter count. All presented phyla showed the same trend where the maximized productivity was recorded in summer and decreased in winter. While Dinophyta and Euglenophyta showed the lowest community, respectively (Table 2). Adesalu and Nwankwo (2005) demonstrated that Bacillariophyta is flourished in nutrients rich environments of temperate areas. The total phytoplankton and phyla communities at both seasons were significantly different at $p \leq 0.001$ (Table 2).

3.4. Spatial variations

Commonly, the north locations, especially locations 1, 2, 3, and 6, showed the maximum flourishing followed by the central locations (7-13), and the lowest community was observed in the south locations (14-20). Locations 6 and 3 were the most productive and flourishing locations (204,006 and 202,755 cell/L , respectively) followed by locations 2 and 1, respectively. While, the lowest crop was observed at locations 18 and 20 with total average counts of 43,708 and 44,520 cell/L, respectively (Fig. 3). On the other hand, the highest species diversity was recorded in location 6 of the maximum crop with 64 sp. and location 2 with 61 sp. However, the lowest species diversity was detected at site 16 (38 sp.) (Fig. 3). Regarding the phyla diversity, Bacillariophyta was the leading phyla at the most sampling location. Chlorophyta was clearly dominant at 1,2,4,5,6 and 14 locations. While, Cyanophyta was the dominant phyla at location 3 only. The highest Dinophyta community was recorded in location 17, followed by 10. However, the highest Euglenophyta crop was observed at location 16, followed by locations 2 and 3. The ANOVA results show a significant spatial difference between the average phytoplankton crop and the number of species at $p \leq 0.001$, respectively. The analysis of similarities among 20 locations has been analyzed by One-Way ANOSIM, which pointed out highly significant differences ($R = 0.982$; $p = 0.0002$), while SIMPER analysis showed overall average dissimilarity of 61.32% among the 20 locations. The most contributing genera with a percentage contribution ≥ 3% were *Navicula creptocephala* (5.15%), *Fragilaria crotonensis* (3.39%), *Diatoma vulgare* (3.18%) and *Stephanodiscus astraea* (3%). It has been observed that Bacillariophyceae includes most of the contributing taxa. This finding imitates the dominance of these phyla and its direct effect on spatial variation during this study.

3.5. Phytoplankton abundance in relation to some physico-chemical parameters

Some physico-chemical parameters were measured, which was observed to be varied spatially and seasonally. Significant correlations were observed between phytoplankton abundance and different physico-chemical parameters (Fig.4). Each species inclines to become dominant when the growth conditions meet its specific requirement. Phytoplankton density showed a negative correlation of pH, temperature and TDS (r = -0.71, -0.62 and -0.56). It was observed that TDS was negatively correlated with total phytoplankton, all algal groups and species diversity. This finding was agreed with previous studies that showed the same negative correlation between phytoplankton population and TDS concentration (Rahi et al. 2013; Elshobary et al. 2020), illustrating the negative effect of inorganic remains materials of TDS on the phytoplankton growth. While Phytoplankton density positively correlated with nutrient content such as Nitrate and silicate. This is due to inorganic nitrogen is one of the main nutrients for algal growth that can improve phytoplankton's growth either in Temsah lake (El-Serehy et al. 2018) or in the connected canals (Elshobary et al. 2020). On the other hand, diatom is the main phytoplankton that can cycle silicon via absorption, dissolution and deposition (Wang et al. 2007). Because the diatom is the dominant group in this study, the total phytoplankton and species number were also correlated positively with silicate content.

3.6. Species diversity indices

The diversity indices were proposed to calculate the species richness, species variation, and degree of equitability of relative abundance species (Table 3). In general, summer showed high indices value compared to winter. The diversity index (Shannon–Weaver) of phytoplankton in summer was 2.34–3.61, with an average of 3.0. The high-value area was located in the north of the lake. The value was higher in the north, followed by the middle and the lowest value was located in the south. The highest value was found at locations 2 and 6. This finding is matching with phytoplankton diversity. Noteworthy, Shannon-Weiner diversity index was used as a water pollution indicator, where Wilhm and Dorris (1968) set diversity index<1 for greatly polluted water, intermediate polluted at 1–4 and >4 for unpolluted water. The diversity index in the current study ranged in a moderate pollution range. The richness index (Margalef) of phytoplankton was quite correlated to the diversity index, where the maximum-value was also observed in the north of the lake and the highest value was found at location 2 and 6. This finding is reflecting the phytoplankton cell abundance. Equitability Index (*J'*) was used by Pielou (1966) to measure species distribution ranged from 0 to 1. However, the average evenness ranged from 0.68 at location 20 to 0.86 at location 6. These values demonstrated that phytoplankton's distributions were quite uniform, and the community structure was unstable (Mahmoud et al. 2018).

3.7. Cluster analysis

In order to reveal the similarities among the sampling locations and cluster analysis were done based on the total abundance of the phytoplankton and classes communities as well as environmental parameters (Fig. 5). The results showed the presence of two main clusters with a 100 bootstrap. The first cluster consists of the northern locations (1-6) and is divided into two subclades of 1-3 locations with 72 bootstraps and 4-6 locations. The second main clade subdivided to first subclade consisted mostly of middle locations of 7-13 with 91 bootstraps and the second subclade grouped the southern sites of 14-20. This finding reflected that the highest phytoplankton abundance of the northern locations, where these sites are more exposed to pollution discharge than in the middle of the lake, such as oil contamination, domestic outfall, agricultural discharge, and wastewater discharge (El-Serehy et al. 2018). According to the cluster analysis (Fig. 5), a maximum similarity of 93.5% was recorded between locations 1 and 2 followed by 16 and 17. In contrast, the lowest similarity of 72.5% was recorded at locations 1 and 2 and site 3.

3.8. Palmer's pollution index

Palmer has published a comprehensive rating of organic pollution tolerate algae, collected by 165 authors, and developed a pollution-tolerant algal index, including 60 most pollution-tolerant algal genera (Palmer 1969). Palmer's index has been calculated seasonally and spatially for genus (AGPI) and species (ASPI). Among these, 13 genera and 8 species were found in El-Temsah Lake (Table 4). Five genera belonging to Bacillariophyta, four genera belonging to Chlorophyta, two genera belonging to Cyanophyta and two genera belonging to Euglenophyta have been recorded. In general, the summer season showed the highest AGPI ranged from 13 to 33 than winter (9–27). Therefore, summer reported the highest pollution levels due to higher pollution loads in summer than winter, indicating the large population and variety of phytoplankton during summer.

The highest AGPI was observed at the north locations and decreased to the south. In winter, 7 location (1, 5, 7, 9, 14, 15 and 16) showed probable high pollution of score 15-20 and 10 locations (2, 3, 6, 8, 10, 11, 12, 13, 18 and 20) showed confirmed high organic pollution with score > 20. Two location (4,17) was in moderate organic pollution range (10-15) and location 19 show lack organic pollution (<10). Location 3, 20, 2, 6 and showed the greatest score.

In summer, 8 locations (10, 11, 12, 13, 16, 17, 18 and 20) showed probable high pollution and 11 locations (1-9, 14 and 19) showed confirmed high organic pollution most of them are in the north area which showed the highest population and diversity of phytoplankton. Location 15 only showed moderate pollution with score 13. Location 6, 2 and 4 showed the greatest score. These findings may be due to the fact that northern locations are the closet to people communities, leaving them facing a number of agriculture and industrial contaminations over other locations (El-Serehy et al. 2018).

On the other hand, 8 tolerant species were reported according to ASPI, Bacillariophyta was contributed 4 species (*Cyclotella meneghiniana, Navicula cryptocephala, Nitzschia acicularis* and *Synedra ulna*), 2 chlorophytes (*Chlorella vulgaris*, and *Scenedesmus quadricauda*), one species of Cyanophyta (*Oscillatoria tenuis*) and another one of Euglenophyta (*Euglena viridis*). Total ASPI ranged from 4 at location 1 during winter to 23 at location 6 during summer (Table 5).

4. Conclusion

This study demonstrated that environmental and seasonal fluctuations mostly shaped the phytoplankton community of El-Temsah Lake. Bacillariophyta formed the most dominant phyla in both seasons, contributing 42.45% of the total phytoplankton. The polluted state of the aquatic ecosystem in El-Temsah Lake during summer is comparatively higher than winter during the study period. Northern sites were the most fertile and polluted sites followed by middle and southern locations of the lowest phytoplankton population. According to Palmer's index and diversity index, most of the sampling locations showed probable to confirmed high level of organic pollution. The study recorded a number of tolerant algae (13 genera and 8 species) which can used as an indicator for different degrees of organic pollution. Therefore, in order to fully understand the response mechanisms associated with phytoplankton flourishing to the climate change phenomenon, the continuity of phytoplankton population research should be considered. These communities could be used as organic pollution indicators for controlling and biomonitoring organic pollution in aquatic environments.

Declarations

Ethical Approval: Not applicable
Consent to Participate: Not applicable
Consent to Publish: Not applicable
Authors Contributions:

Conceptualization: ME, ZS; Methodology ME, AA and DE; Formal analysis and investigation: ME, DE; Writing - original draft preparation: ME, DE; Writing - review and editing: ME; Supervision: ME, ZS. All authors read and approved the final manuscript.

Funding: Not applicable
Competing Interests: The authors declare that they have no competing interests

Availability of data and materials: Not applicable

References

Abd El Samie SG, Hassan HB, Hamza MS (2008) Estimation of the Pollution Level in El Timsah Lake, Egypt. Proc 9 Int Conf Nucl Sci Appl 1239

Abdel-Satar AM, Ali MH, Goher ME (2017) Indices of water quality and metal pollution of Nile River, Egypt. Egypt J Aquat Res 43:21–29. https://doi.org/10.1016/j.ejar.2016.12.006

Adesalu TA, Nwankwo DI (2005) Studies on the phytoplankton of Olero creek and parts of Benin River, Nigeria. Ekolologia 3:21–30

Ali EM, Falts SR, Rasmey AHM (2020) Quality assessment of water along suez freshwater canal and drinking water in Suez governorate, Egypt. Egypt J Aquat Biol Fish 24:65–81. https://doi.org/10.21608/ejabf.2020.68025

APHA (1998) Standard methods for the examination of water and wastewater, 19th edition.

Bharathi MD, Sarma VVSS, Ramaneswari K (2018) Intra-annual variations in phytoplankton biomass and its composition in the tropical estuary: Influence of river discharge. Mar Pollut Bull 129:14–25. https://doi.org/10.1016/j.marpolbul.2018.02.007

Bourrelly P (1981) Fresh Water Algae: Chrysophyceae, Phaeophyceae, Xanthophyceae and Diatoms. N. Boubes and Co. Paris

Clarke KR (1993) Non-parametric multivariate analyses of changes in community structure. Aust J Ecol 18:117–143

Collavini F, Zonta R, Bettiol C, et al (2001) Metal and nutrient loads from the drainage basin to the Venice lagoon. In: Ministero Lavori Pubblici, Consorzio Venezia Nuova, CNR Istituto per lo studio della dinamica delle Grandi masse(Eds.), Determination of the Pollutant Load Discharged into the Venice Lagoon by Drainage Basin. Venice, July. pp 48–55

Cui L, Lu X, Dong Y, et al (2018) Relationship between phytoplankton community succession and environmental parameters in Qinhuangdao coastal areas, China: A region with recurrent brown tide outbreaks. Ecotoxicol Environ Saf 159:85–93

Demir AN, Fakioğlu Ö, Dural B (2014) Phytoplankton functional groups provide a quality assessment method by the Q assemblage index in Lake Mogan (Turkey). Turk J Botany 38:169–179. https://doi.org/10.3906/bot-1301-60

Desikashary T (1959) Cyanophyta. Indian Council Agric. Res., New Delhi,

Diodato N, Ceccarelli M, Diodato N CM (2005) Environinformatics in ecological risk assessment of agroecosystems pollutant leaching. Stoch Environ Res Risk Assess 19:292–300

Donia N (2011) Water quality management of lake Temsah, Egypt using geographical information system (GIS). 2:1–8

Edition F (2011) Guidelines for drinking-water quality. WHO Chron 38:104–108

El-azim HA, Belal AA, El-salam ETA, et al (2018) Water Pollution by Heavy Metals in The Western Lagoon and its Effect on Timsah Lake and Consequently on Suez Canal. 17:71–76

El-Kassas HY, Gharib SM (2016) Phytoplankton abundance and structure as indicator of water quality in the drainage system of the Burullus Lagoon, southern Mediterranean coast, Egypt. Environ Monit Assess 188:1–14

El-Otify AM, Iskaros IA (2015) Water quality and potamoplankton evaluation of the Nile River in Upper Egypt. Acta Limnol Bras 27:171–190. https://doi.org/10.1590/S2179-975X4014

El-Serehy HA, Abdallah HS, Al-Misned FA, et al (2018) Assessing water quality and classifying trophic status for scientifically based managing the water resources of the Lake Timsah, the lake with salinity stratification along the Suez Canal. Saudi J Biol Sci 25:1247–1256. https://doi.org/10.1016/j.sjbs.2018.05.022

El-Shoubaky G, Hamed A (2018) The Characteristic Algal Mats and Flora of El-Timsah Lake. Catrina Int J Environ Sci 1:75–80

Elshobary ME, Essa DI, Attiah AM, et al (2020) Algal community and pollution indicators for the assessment of water quality of Ismailia canal, Egypt. Stoch Environ Res Risk Assess 34:1089–1103. https://doi.org/10.1007/s00477-020-01809-w

Gaballa MM (2014) Phytoplankton and environmental variables as water quality indicators for El-Temsah lake, Suez canal, Egypt. Egypt J Exp Biol 10:79–85

Govindasamy C, Kannan L, Azariah J (2000) Seasonal variation in physico-chemical properties and primary production in the coastal water biotopes of Coromandel coast, India. J Environ Biol 21:1–7

Habib OA, Tippett R, Murphy KJ (1997) Seasonal changes in phytoplankton community structure in relation to physico-chemical factors in Loch Lomond, Scotland. Hydrobiologia 350:63–79

Hamed MA, El-Sawy MA, AbuEl-Naga EH (2012) Hydrochemistry and nutrients of Bitter and Temsah Lakes, Suez Canal, Egypt. Egypt J Aquat Biol Fish 16:1–12

Haque MA, Jewel MAS, Zinat A, et al (2019) Phytoplankton Community Structure and Environmental Variables as Indicators of Organic Pollution in Padma River, Bangladesh. Int J Ecol Environ Sci 45:19–29

Hendy NI (1964) An introductory account of the smaller algae of British Coastal Waters. V. Bacillariophyceae (Diatoms) 1–317

Hokimoto T, Kiyofuji H (2014) Effect of regime switching on behavior of albacore under the influence of phytoplankton concentration. Stoch Environ Res Risk Assess 28:1099–1124. https://doi.org/10.1007/s00477-013-0816-9

Huang L, Jian W, Song X, et al (2004) Species diversity and distribution for phytoplankton of the Pearl River estuary during rainy and dry seasons. Mar Pollut Bull 49:588–596

Kamel KA (2013) Phytoremediation potentiality of aquatic macrophytes in heavy metal contaminated water of El-Temsah Lake, Ismailia, Egypt. Middle East J Sci Res 14:1555–1568. https://doi.org/10.5829/idosi.mejsr.2013.14.12.7441

Kouhanestani ZM, Roelke DL, Ghorbani R, Fujiwara M (2019) Assessment of Spatiotemporal Phytoplankton Composition in Relation to Environmental Conditions of Gorgan Bay, Iran. Estuaries and Coasts 42:173–189. https://doi.org/10.1007/s12237-018-0451-2

Kumar T, Thangaradjou T, Kannan L (2006) Physico-chemical and biological properties of the Muthupettai mangrove in Tamil Nadu. J Mar Biol Assoc India 48:131–138

LeGresley M, McDermott G (2010) Counting chamber methods for quantitative phytoplankton analysis-Haemocytometer, Palmer-Maloney cell and Sedgewick-Rafter cell. e. In: Karlson B, Cusack C, Bresnan E (eds) Microscopic and Molecular Methods for Quantitative Phytoplankton Analysis. Intergovernmental Oceanographic Commission, UNESCO (IOC Manuals and Guides), Paris, France, pp 25–30

Ludsin SA, Kershner MW, Blocksom KA, et al (2001) Life after death in Lake Erie: nutrient controls drive fish species richness, rehabilitation. Ecol Appl 11:731–746

Mahmoud KMAA, Sayed SSM, Habib MR, Sayed, Sara S.M. Habib MR (2018) Ecological assessment of the River Nile around Gizert El-Warrak by Phytoplankton and macroinvertebrates assemblages. bioRxiv 21:297432. https://doi.org/https://doi.org/10.1101/297432

Napiórkowska-Krzebietke A, Hutorowicz A (2014) Phytoplankton in an ecological status assessment of the vendace-type Lake Dejguny (northeastern Poland). Fish Aquat Life 22:29–40

Nassar MZ, Shams El-Din NG (2006) Seasonal Dynamics of Phytoplankton Community in the Bitter Lakes and Temsah Lake. Egypt J Aquat Res 32:198–219

Nassar MZA, Fahmy MA (2016) Effects of some environmental factors on the population density and species diversity of phytoplankton in Bitter Lakes, Egypt. Rend Lincei 27:291–298. https://doi.org/10.1007/s12210-015-0476-4

Palmer CM (1969) A COMPOSITE RATING OF ALGAE TOLERATING ORGANIC POLLUTION 2. J Phycol 5:78–82

Parparov A, Hambright KD (2007) Composite water quality: evaluation and management feedbacks. Water Qual Res J 42:20–25

Pielou EC (1966) Shannon's formula as a measure of specific diversity: its use and misuse. Am Nat 100:463–465

Prepas EE, Charette T (2005) Water Bodies: Causes, Concerns, Controls. Environ Geochemistry 9:311

Prescott GW (1987) How to know the freshwater algae., 3rd edn. Wm. C. Brown Co. Publ., Dubuque, Iowa

Rahi ML, Mahfuj SE, Islam SS, et al (2013) Assessment of the abundance and species composition of Phytoplankton of Moiur river, Khulna. J Bio-Science 21:27–34. https://doi.org/10.3329/jbs.v21i0.22516

Rahman MA, Huda ME (2012) Study of the Seasonal Variations in Physicochemical and Biological Aspects of the Padma River at Paturia Ghat, Manikganj. Jahangirnagar Univ Environ Bull 1:55–66

Ramírez T, Cortés D, Mercado JM, et al (2005) Seasonal dynamics of inorganic nutrients and phytoplankton biomass in the NW Alboran Sea. Estuar Coast Shelf Sci 65:654–670. https://doi.org/10.1016/j.ecss.2005.07.012

Said TO, El Agroudy NA (2006) Assessment of PAHs in water and fish tissues from Great Bitter and El Temsah lakes, Suez Canal, as chemical markers of pollution sources. Chem Ecol 22:159–173. https://doi.org/10.1080/02757540500526476

Sankar R, Ramkumar L, Rajkumar M, et al (2010) Seasonal variations in physico-chemical parameters and heavy metals in water and sediments of Uppanar estuary, Nagapattinam, India. J Environ Biol 31:681–686

Saravanakumar A, Rajkumar M, Serebiah JS, Thivakaran GA (2008) Seasonal variations in physico-chemical characteristics of water, sediment and soil texture in arid zone mangroves of Kachchh-Gujarat. J Environ Biol 29:725–732

Sharma R, Tiwari V (2018) Phytoplankton diversity in relation to physico-chemical environmental variables of Nachiketa Tal, Garhwal Himalaya. Biodivers Int J 2:102–110. https://doi.org/10.15406/bij.2018.02.00052

Smith G (1950) Fresh water algae of the United States., 2nd ed. Book Comp. Inc., New York

Soliman NF, Younis AM, Elkady EM (2019) An insight into fractionation, toxicity, mobility and source apportionment of metals in sediments from El Temsah Lake, Suez Canal. Chemosphere 222:165–174. https://doi.org/10.1016/j.chemosphere.2019.01.009

Stenseth NC, Ottersen G, Hurrell JW, Belgrano A (2005) Marine ecosystems and climate variation: the North Atlantic-a comparative perspective, Oxford Uni. Oxford University Press

Sulistiawati D, Ya'la ZR, Mubaraq Z (2020) Water quality study in several seaweeds culture sites in the post-earthquake-tsunami Palu Central, Sulawesi Province. In: Journal of Physics: Conference Series. IOP Publishing, p 12035

Wang B, Liu C-Q, Wang F, et al (2013) Diatoms modify the relationship between dissolved silicon and bicarbonate in the impounded rivers. J Limnol 72:40

Wang X, Chen S, Song A, et al (2007) Roles of plants in biogeochemical cycling of silicon [J]. Chinese J Ecol 4:

Wilhm JL, Dorris TC (1968) Biological parameters for water quality criteria. Bioscience 477–481

Xiao R, Su S, Ghadouani A, Wu J (2013) Spatial analysis of phytoplankton patterns in relation to environmental factors across the southern Taihu basin, China. Stoch Environ Res Risk Assess 27:1347–1357. https://doi.org/10.1007/s00477-012-0670-1

Zhang N, Fan Y, Liu Y (2011) Relationship between diatom communities and environmental conditions at Honghe wetland, China. African J Biotechnol 10:17506–17518

Tables

Table 1 Seasonal physiochemical parameters at different sampling location in El-Temsah Lake

Parameters	pH		Temperature (°C)		TDS (ppm)		Silicate (ppm)		PO4-P (ppm)		NO3-N (ppm)	
Locations	W*	S	W	S	W	S	W	S	W	S	W	S
L. 1	7.62	7.06	18.60	32.70	2100.00	2081.61	7.70	2.17	0.39	0.41	3.90	3.00
L. 2	7.38	7.11	18.70	32.60	2070.00	2037.86	4.47	4.54	0.44	0.49	2.60	3.20
L. 3	6.63	7.41	18.40	31.40	32820.00	32810.31	9.19	3.89	0.60	0.64	2.70	3.30
L. 4	6.96	7.34	19.20	31.70	31700.00	31557.04	2.14	1.80	0.65	0.66	3.20	3.50
L. 5	6.79	7.59	19.20	32.30	38200.00	38165.14	1.43	2.00	0.43	0.45	4.70	4.50
L. 6	7.09	7.51	19.50	32.30	29500.00	29231.32	3.94	2.73	0.52	0.55	3.40	3.60
L. 7	7.39	7.68	18.20	32.40	46900.00	46837.68	1.87	1.00	0.88	0.89	2.50	4.30
L. 8	7.38	7.81	18.90	34.50	42870.00	42628.03	2.02	2.00	0.33	0.35	2.70	4.20
L. 9	7.33	7.88	17.70	35.00	46900.00	46859.38	0.93	1.20	0.22	0.23	2.90	4.10
L. 10	7.30	7.58	17.80	35.20	40520.00	40483.98	1.66	1.60	0.15	0.16	2.70	3.20
L. 11	7.40	7.74	18.90	33.20	48000.00	47591.46	0.74	2.20	0.22	0.24	3.10	3.40
L. 12	7.59	7.85	21.80	33.30	39870.00	39359.34	4.17	5.50	0.36	0.42	2.20	3.20
L. 13	7.40	7.86	21.50	33.80	43182.00	43097.82	3.00	3.60	0.27	0.30	3.00	3.60
L. 14	7.54	7.93	21.30	34.40	47870.00	47071.23	2.14	2.50	0.02	0.04	3.00	3.40
L. 15	7.42	8.00	21.20	33.60	51239.00	51049.11	1.44	2.00	0.01	0.03	2.30	3.40
L. 16	7.50	7.98	20.70	34.90	42450.00	42392.75	2.39	1.90	0.08	0.10	3.40	3.50
L. 17	7.99	8.17	20.60	34.60	39790.00	39341.48	1.94	1.30	0.01	0.01	1.50	3.30
L. 18	7.52	8.10	20.00	34.50	42910.00	42231.04	2.68	0.81	0.01	0.02	3.00	3.30
L. 19	7.91	7.95	19.10	34.50	47900.00	47803.45	2.41	0.50	0.14	0.15	2.80	3.30
L. 20	7.52	7.98	19.50	34.70	39320.00	38954.70	2.90	1.30	0.01	0.03	3.30	3.00
F-value	110.51*	101.36*	69.74*	126.32*	12.54*	12.53*	1.83*	1.89*	5.05*	6.56*	20.04*	32.94*

*winter (W), summer (S)

Table 2. Seasonal distribution of the recorded phytoplankton group number of species, number of cells per liter and their percentage in El-Temsah Lake during the period of study

Algal phyla	Winter			Summer			Average		
	sp.no.	Cell/L	%	sp.no.	Cell/L	%	sp.no.	Cell/L	%
Bacillariophyta	37	160092^{b}	45.90%	39	584666^{b}	38.99%	38	372379^{b}	42.45%
Chlorophyta	32	125429^{c}	35.97%	33	547664^{c}	36.52%	32	336547^{c}	36.24%
Cyanobacteria	16	54668^{d}	15.68%	16	337507^{d}	22.51%	16	196088^{d}	19.09%
Dinophyta	7	4790^{e}	1.37%	8	24420^{e}	1.63%	7.5	14605^{e}	1.50%
Euglenophyta	9	3768^{f}	1.08%	10	5306^{f}	0.35%	9.5	4537^{f}	0.72%
Total phytoplankton	101	348747^{a}	100%	106	1499563^{a}	100%	103	924155^{a}	100%
F-value	19773.87*	2.83E+11*		21681.07*	4.84E+12*		20715.20*	1.86E+12*	

Represented data are mean ± SD. Different superscript letters in each column indicate significant differences at p B 0.05 using Duncan’s test *Significant at p B 0.05

Table 3 Shannon(*H'*), richness (*D*) and equitability (*J'*) indices at different location in El-Temsal Lake during the period of study Sampling

Sampling stations	Winter			Summer			Average		
	H'	*D*	*J'*	*H'*	*D*	*J'*	*H'*	*D*	*J'*
L.1	2.39	2.66	0.72	3.27	2.92	0.92	2.83	2.79	0.82
L.2	2.72	3.56	0.76	3.61	4.18	0.92	3.16	3.87	0.84
L.3	2.38	2.80	0.71	3.38	3.88	0.87	2.88	3.34	0.79
L.4	2.39	2.19	0.76	3.45	4.10	0.90	2.92	3.15	0.83
L.5	2.31	2.59	0.70	3.14	3.81	0.83	2.72	3.20	0.77
L.6	2.86	3.15	0.82	3.52	4.20	0.89	3.19	3.68	0.86
L.7	1.85	1.66	0.65	3.18	3.14	0.89	2.51	2.40	0.77
L.8	2.45	3.14	0.71	2.79	2.88	0.80	2.62	3.01	0.75
L.9	2.53	2.43	0.79	3.08	2.84	0.89	2.80	2.63	0.84
L.10	2.25	2.32	0.72	3.29	3.58	0.88	2.77	2.95	0.80
L.11	2.39	2.41	0.74	3.01	2.62	0.89	2.70	2.51	0.81
L.12	2.49	2.37	0.77	3.02	2.92	0.86	2.76	2.64	0.82
L.13	2.34	2.64	0.70	3.00	3.18	0.84	2.67	2.91	0.77
L.14	2.41	2.48	0.76	2.84	2.51	0.85	2.62	2.49	0.81
L.15	2.32	2.72	0.70	2.08	1.67	0.72	2.20	2.19	0.71
L.16	2.38	2.09	0.80	2.78	2.40	0.84	2.58	2.24	0.82
L.17	2.86	3.37	0.81	2.77	2.07	0.88	2.82	2.72	0.85
L.18	2.81	2.76	0.84	2.34	1.48	0.84	2.57	2.12	0.84
L.19	2.08	2.18	0.66	3.00	2.39	0.92	2.54	2.28	0.79
L.20	2.04	5.40	0.53	2.46	1.70	0.83	2.25	3.55	0.68
Average	2.41	2.74	0.73	3.00	2.92	0.86	2.71	2.83	0.80

Table 4. Algal genera Palmer index (AGPI) in El-Temsah Lake during winter and summer seasons

Season	Tolerant genera	AGPI	L.1	L.2	L.3	L.4	L.5	L.6	L.7	L.8	L.9	L.10	L.11	L.12	L.13	L.14	
Winter	*Cyclotella* spp.	1	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	-	-	+(1)	+(1)
	Melosira spp.	1	+(1)	+(1)	-	-	-	-	-	-	+(1)	+(1)	+(1)	-	+(1)	-	-
	Navicula spp.	3	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)
	Nitzschia spp.	3	+(3)	-	+(3)	-	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	-
	Synedra spp.	2	-	-	+(2)	-	-	+(2)	-	-	-	-	+(2)	+(2)	-	-	-
	Chlamydomonas spp.	4	-	+(4)	-	-	-	-	-	-	-	-	-	-	-	-	-
	Chlorella spp.	3	-	-	-	-	-	-	-	-	-	-	-	+(3)	-	-	-
	Micractinium spp.	1	-	-	-	+(1)	+(1)	-	-	-	-	-	-	-	-	-	-
	Scenedesmus spp.	4	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)
	Oscillatoria spp.	5	-	+(5)	+(5)	-	+(5)	+(5)	+(5)	+(5)	+(5)	-	+(5)	+(5)	+(5)	+(5)	+(5)
	Phormidium spp.	1	+(1)	+(1)	+(1)	+(1)	-	-	-	+(1)	+(1)	+(1)	+(1)	+(1)	-	-	+(1)
	Euglena spp.	5	-	+(5)	+(5)	-	-	+(5)	-	+(5)	-	+(5)	-	-	+(5)	-	-
	Phacus spp.	2	+(2)	+(2)	+(2)	+(2)	+(2)	-	-	-	-	+(2)	+(2)	+(2)	-	-	+(2)
	Total		**15**	**26**	**27**	**12**	**19**	**23**	**16**	**22**	**18**	**21**	**22**	**23**	**21**	**17**	**16**
summer	*Cyclotella* spp.	1	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)
	Melosira spp.	1	+(1)	+(1)	-	-	-	+(1)	+(1)	+(1)	+(1)	-	+(1)	+(1)	+(1)	+(1)	+(1)
	Navicula spp.	3	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)
	Nitzschia spp.	3	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	-	+(3)	+(3)
	Synedra spp.	2	-	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	-
	Chlamydomonas spp.	4	+(4)	-	-	-	-	+(4)	+(4)	+(4)	+(4)	-	-	-	-	-	-
	Chlorella spp.	3	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	-	+(3)	+(3)	-
	Micractinium spp.	1	-	-	-	+(1)	-	+(1)	+(1)	+(1)	-	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)
	Scenedesmus spp.	4	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)
	Oscillatoria spp.	5	+(5)	+(5)	+(5)	+(5)	-	+(5)	+(5)	+(5)	-	-	-	-	-	+(5)	-
	Phormidium spp.	1	-	+(1)	+(1)	+(1)	-	+(1)	+(1)	-	-	+(1)	-	+(1)	+(1)	-	-
	Euglena spp.	5	-	+(5)	+(5)	+(5)	+(5)	+(5)	-	-	-	-	-	-	-	-	-
	Phacus spp.	2	-	+(2)	-	+(2)	+(2)	-	-	-	-	-	-	-	-	+(2)	-
	Total		**24**	**30**	**27**	**30**	**24**	**33**	**28**	**27**	**22**	**18**	**18**	**16**	**16**	**25**	

+ = present, - = absent

Table 5 Algal species Palmer index (ASPI) in El-Temsah Lake during winter and summer seasons

Season	Tolerant species	**ASPI**	**L.1**	**L.2**	**L.3**	**L.4**	**L.5**	**L.6**	**L.7**	**L.8**	**L.9**	**L.10**	**L.11**	**L.12**	**L.13**	**L.14**	**L.15**	**L.16**	**L.17**
Winter	*Cyclotella meneghiniana*	2	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	-	-	+(2)	+(2)	+(2)	+(2)
	Navicula creptocephala	1	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)
	Nitzschia acicularis	1	+(1)	-	+(1)	-	+(1)	-	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	-	-	+(1)
	Synedra ulna	3	-	-	-	-	-	-	-	-	-	-	+(3)	+(3)	-	-	-	-	-
	Chlorella vulgaris	2	-	-	-	-	-	-	-	-	-	-	-	+(2)	-	-	-	-	-
	Scenedesmus quadricauda	4	-	-	-	-	+(4)	-	-	+(4)	-	-	-	-	-	+(4)	-	-	+(4)
	Oscillatoria tenuis	4	-	+(4)	+(4)	-	-	+(4)	+(4)	+(4)	-	-	+(4)	+(4)	+(4)	+(4)	+(4)	-	-
	Euglena viridis	6	-	+(6)	-	-	-	+(6)	-	-	-	+(6)	-	-	-	-	-	+(6)	-
	Total		4	13	8	3	8	13	8	12	4	10	11	11	6	12	7	9	8
Summer	*Cyclotella meneghiniana*	2	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)
	Navicula creptocephala	1	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)
	Nitzschia acicularis	1	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	+(1)	-	+(1)	+(1)	+(1)	+(1)
	Synedra ulna	3	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	+(3)	-	+(3)	-	+(3)	+(3)	+(3)	+(3)	-	+(3)	+(3)
	Chlorella vulgaris	2	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	+(2)	-	+(2)	+(2)	-	-	-
	Scenedesmus quadricauda	4	-	-	+(4)	-	-	+(4)	-	-	-	-	-	-	-	-	-	-	-
	Oscillatoria tenuis	4	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)	+(4)	-	-
	Euglena viridis	6	-	+(6)	-	-	+(6)	+(6)	-	-	-	-	-	-	-	-	-	-	-
	Total		**13**	**19**	**17**	**13**	**19**	**23**	**13**	**10**	**13**	**10**	**13**	**11**	**10**	**13**	**10**	**7**	**7**

+ = present, - = absent

Figures

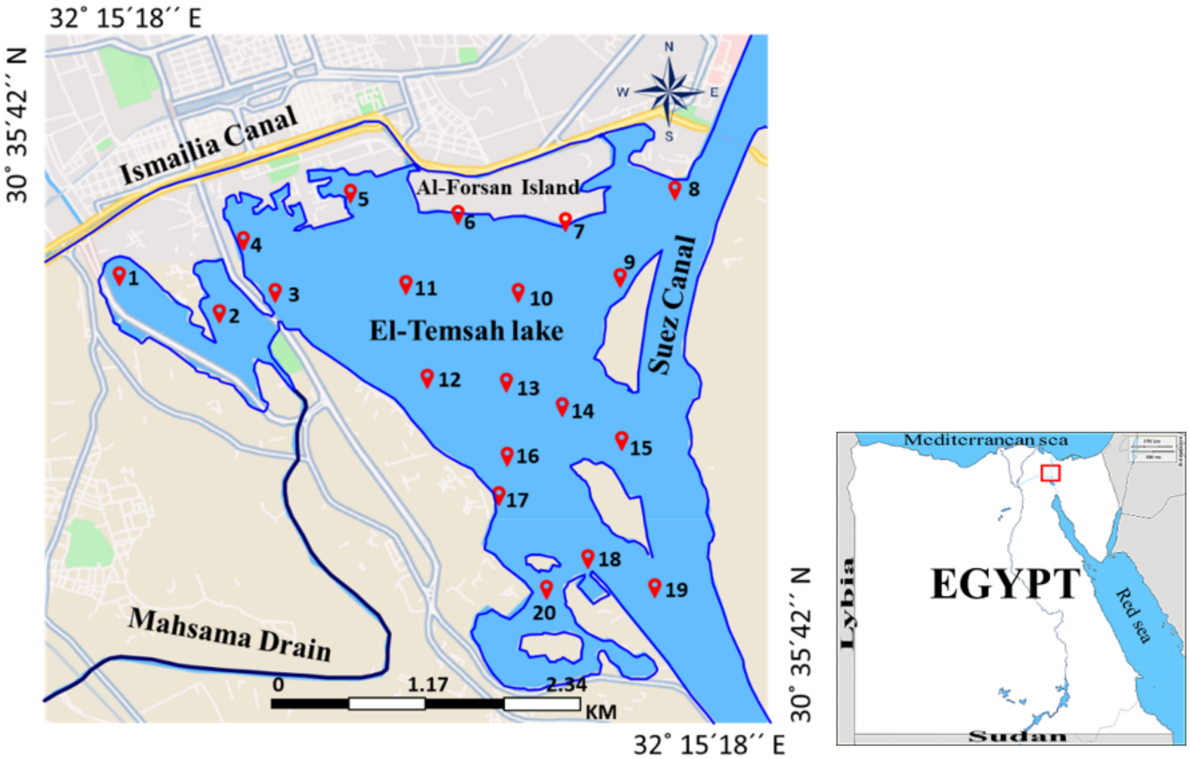

Figure 1

Map of El-Temsah canal showing the distribution of sampling sites

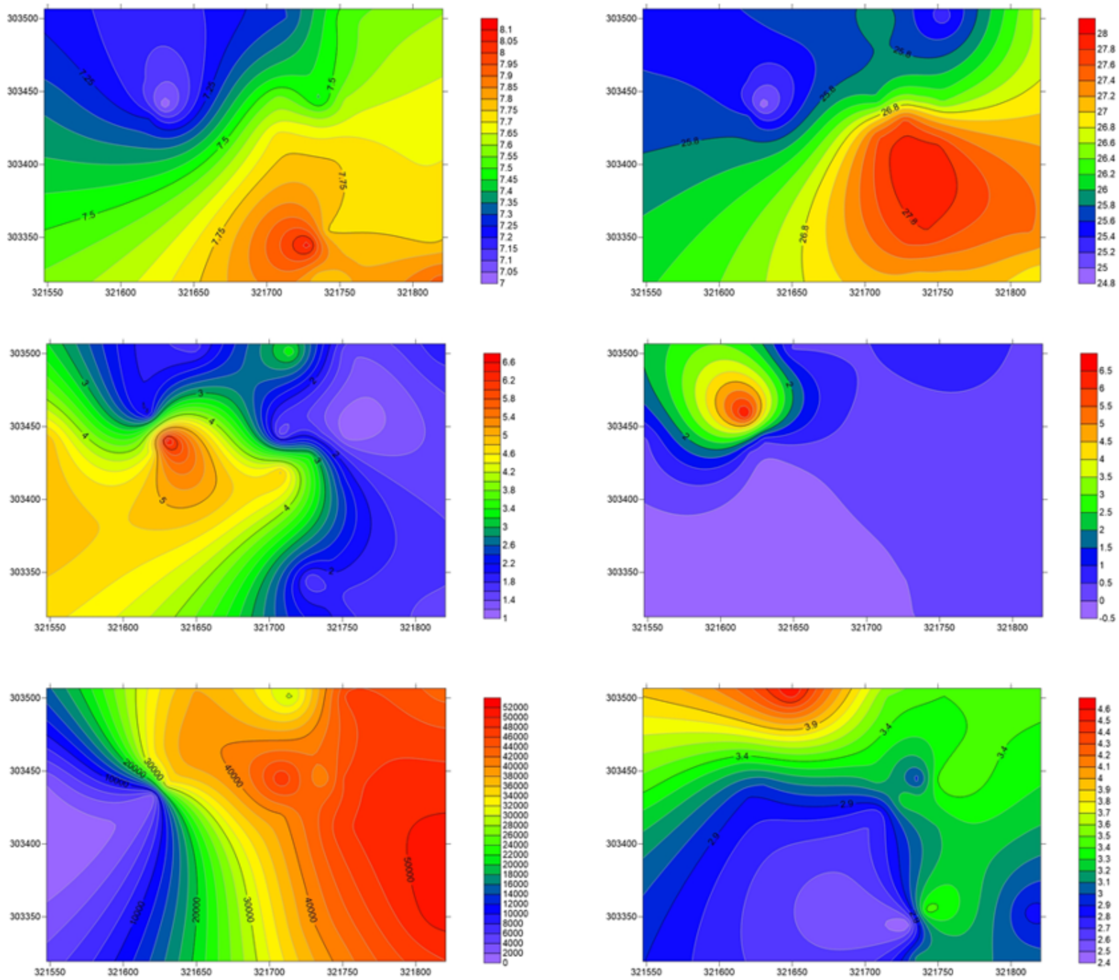

Figure 2

Average of seasonal changes of (A) pH, (B) temperature, (C) NO3-N, (D) turbidityPO4-P, (E) TDS and (F) Silicate at different sites in the El-Temsah lake during the study period.

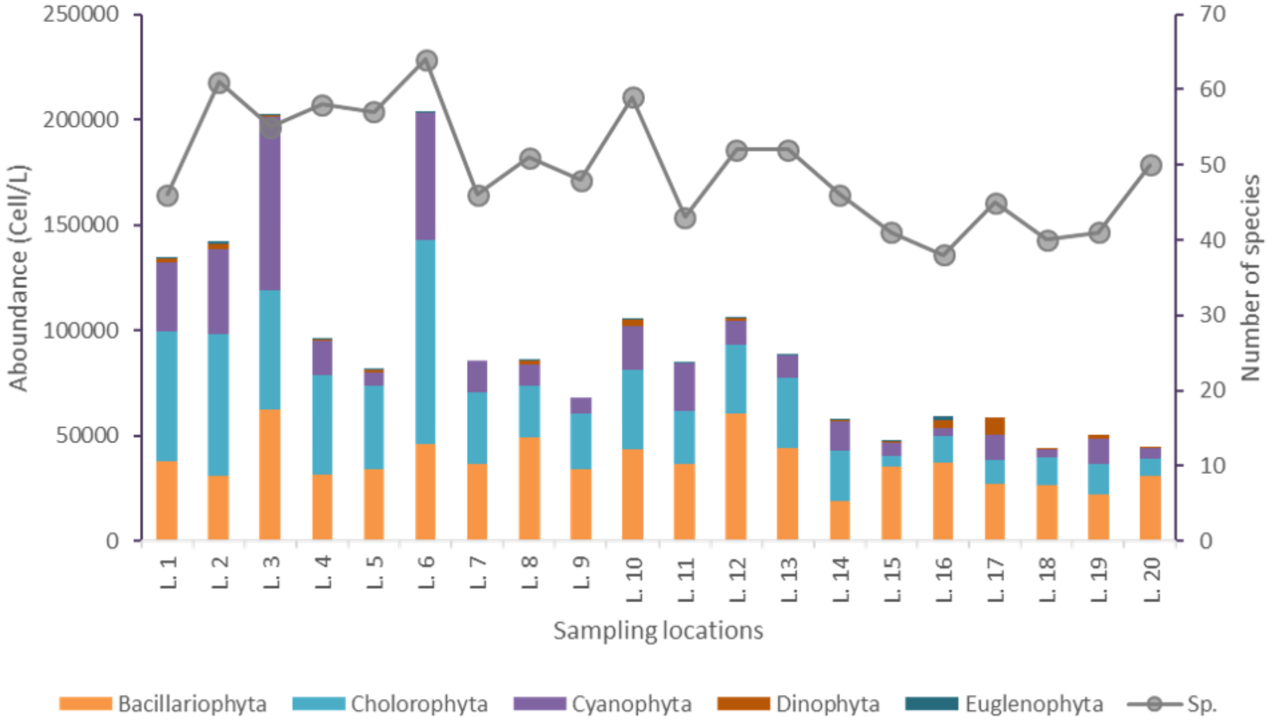

Figure 3

Total standing crop of different recorded phytoplankton divisions in El-Temsah Lake during the study period at the different locations

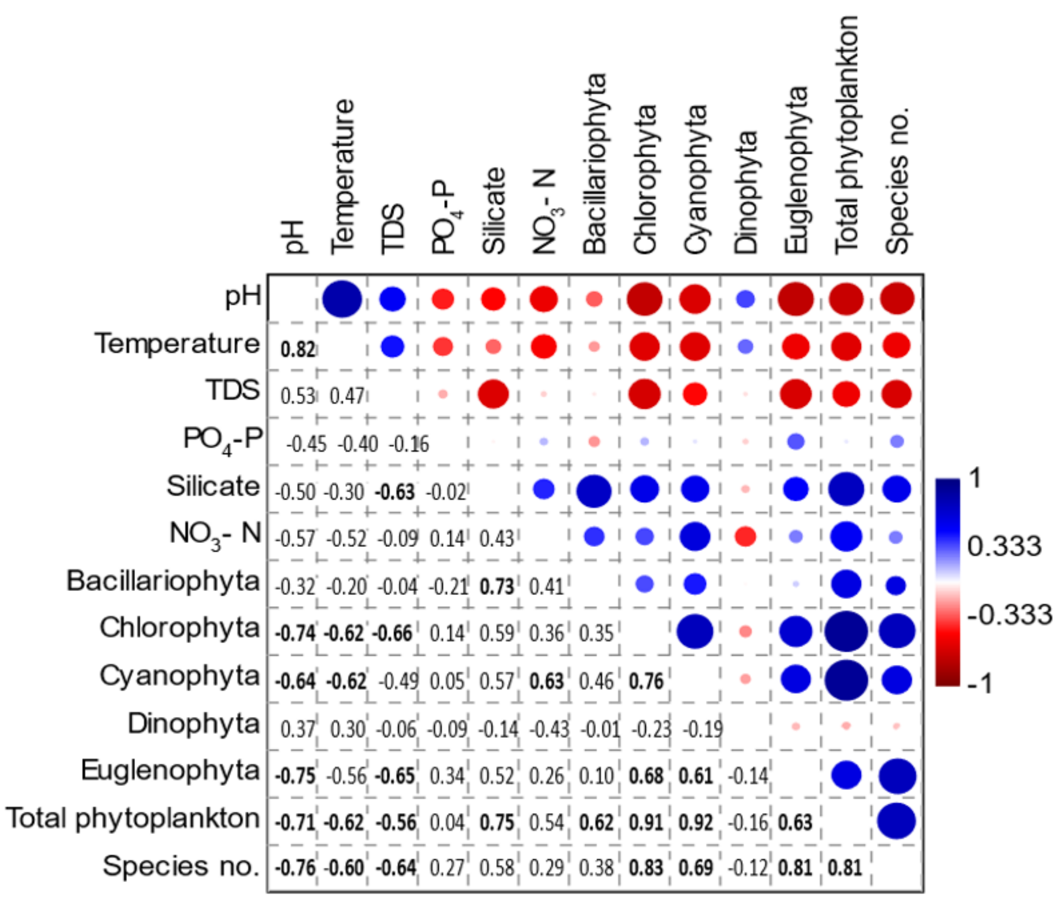

Figure 4

Pearson Correlation coefficients of different physico-chemical parameters, total phytoplankton density, and species number. The side bar indicates the probability. * Correlation is significant at the 0.05 level.

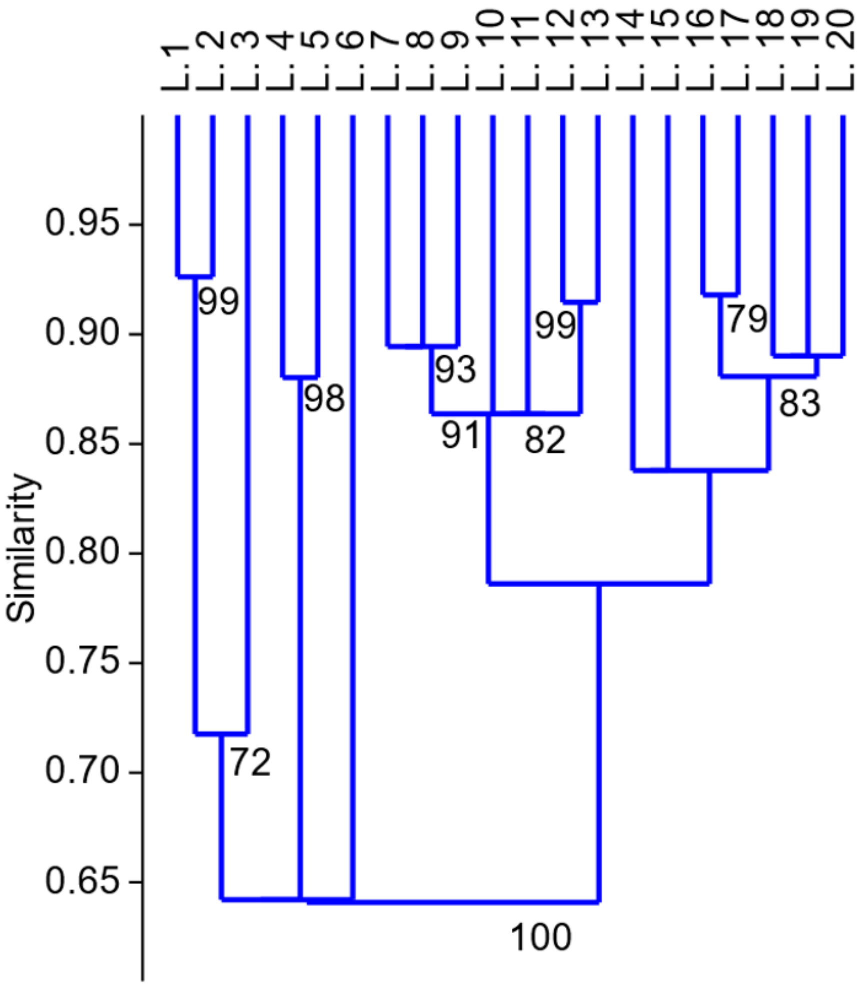

Figure 5

Dendrogram showing similarity of sampling locations on the basis of their phytoplankton structure and environmental parameters in El-Temsah Lake during the period of study

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- supp.docx