EGYPTIAN JOURNAL OF BOTANY (EJBO)

Print ISSN: 0375-9237
Online ISSN: 2357-0350

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PUBLISHED BY
THE EGYPTIAN
BOTANICAL SOCIETY

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Finding a connection between frequency and abundance of phytoplankton to abiotic components is an interesting issue for current research. The main objective of the ongoing research is to illustrate how environmental factors, such as the concentrations of abiotic components including pollutants in the water of drains, fish farms, treatment stations and Lake Burullus, affect the distribution and classification of phytoplankton populations. Samples of surface water were taken during spring 2020 at ten sites that represented four ecological locations to identify the algae and analyze. The microalgae species were recognized morphologically via light microscopic characterization. Thirty-eight phytoplankton species were found and identified in different locations representing four Bacillariophytes, nine Chlorophytes, and twenty-five Cyanophytes. *Oscillatoria* contributed the most, followed by *Anabaena*, and *Chroococcus*. *Scenedesmus bijuga* and *Chlorella vulgaris*. Besides, the largest number of colonies was observed in Lake Burullus, followed by pump stations, fish farms, and drains. Using detrended correspondence analysis (DCA) and two-way indicator species analysis (TWINSPAN), it was recognized that 4 groups (communities) were segregated at the 4th classification level. Total algal richness exhibited a positively significant link with NH_3 and PO_4, but a negatively significant correlation with TDS, EC, Zn, and Cd. The richness of Chlorophyta exhibited a negative correlation with Fe, while the richness of Cyanophyta exhibited a strong positive correlation with PO_4 and a negative correlation with zinc. However, there are notable differences in TDS, NH_3, and zinc between the water from various places. The greatest values of water pH, TDS, EC, COD, and heavy metals (Zn, Cu, Ni, Pb, Zn, and Cd) were found in Lake Burullus. Conversely, the drains showed the greatest levels of NH_3 and DO and the lowest levels of nearly all water variables. The present study concluded that abiotic components showed a direct relationship in distributing the microalgae, where ammonia, phosphate, iron, Zinc, cadmium, TDS and EC exhibited influence on algal abundance.

Keywords: Microalgae distribution, heavy metals, sewage drainage, wastewater, TWINSPAN, DCA

ARTICLE HISTORY
Submitted: July 17, 2024
Accepted: December 14, 2024

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DOI: 10.21608/ejbo.2024.304948.2918

EDITED BY: A. Hegazy

INTRODUCTION

Phytoplankton (microalgae) are microscopic, photosynthetic aquatic creatures and widely distributed organisms that grow quickly in different conditions (Suthers *et al.,* 2019). They can be found in a variety of environments including freshwater, brackish water, saline water, and wastewater (Neto and Pinto 2018). This phytoplankton can break down and/or biosorb several pollutants from wastewater, such as heavy metals, organic and inorganic compounds, and other nutrients such as Na, K, Ca, Mg, N, S and P, that may be necessary for their growth (Supeng *et al.,* 2012). In this regard, microalgae cultures can be used to support quaternary and tertiary wastewater cleanup since they can break down complex contaminants (Srimongkol *et al.,* 2022). According to Venkatachalapathy *et al.* (2013), the predominant species found in the mildly polluted regions are from the genera *Nitzschia* and *Gomphonema*. *Cocconeis* and *Chamesiphon* were previously found in quite clean habitat. While *Gamophema* was found in severely polluted water, *Navicula accomda* is considered a good predictor of organic pollution (Archibald 1972). Small-scale algae treatment of wastewater is a conventional method that improves pH, salt content, and other factors. It also fixes carbon dioxide and produces biomass more profitably. Any metal or related metalloid that is highly dense, nonbiodegradable, hazardous at low concentrations, and pollutes the environment is considered a heavy metal (Herrera-Estrella et. Al., 2001). Growth of plants and phytoplankton requires a few heavy metals including Fe, Zn, Ni, Cu, Mn, and Co., which play an important physiological or biochemical role in them. When the amounts of these necessary heavy metals are high, they become poisonous. Other elements, such as Pb, Hg, and Cd, have no physiological or biochemical function and have harmful effects at low concentrations; therefore, they are not necessary for plants (Gaur and Adholeya 2004). Phytoremediation, the removal or mitigation of heavy metals such as Cr, Pb, Hg, and Cd that are extremely harmful to living things, is commonly applied by cyanobacteria and microalgae. The phytoremediation process may be mediated by a variety of mechanisms, contingent on the nature of the treated heavy metal, the type of algae involved, and the treatment parameters (Gonzalez-dkila 1995; John 2003; Kumar *et al.,* 2015). Adsorption is the process by which algae absorb metals. Physical adsorption is the initial process by which the metal ions are adsorbed across the cell surface; this might happen in a matter of seconds or minutes. Then, through a process known as chemisorption, these ions are gradually transferred into cytoplasm. Algal polyphosphate bodies allow unicellular freshwater algae to store more nutrients. Several studies have shown that the polyphosphate bodies found in green algae can store a variety of metals, including titanium, lead, magnesium, zinc, cadmium, cobalt, nickel, and copper. According to Dwivedi (2012), these entities in algae have two distinct purposes: they serve as a "detoxification mechanism" and a "storage pool" for metals. From heavy metal-contaminated aquatic systems, Singh *et al.,* (2021) reported the ability of algae to remove several elements, such as N that reaches (90%), P (98%), Pb (100%), Zn (99.7%), Cr (96%), etc.

When compared to other biosorbents, microalgae have the most potential for biosorption of heavy metals, according to previous studies (Sweetly 2014; Mustapha and Halimoon 2015). Compared to bacteria and fungi, algae are around 15.3%–84.6% more efficient in the biosorption of heavy metals. According to a recent study by Priya *et al.,* (2022), the use of microalgal-based bioremediation strategies in wastewater treatment has become more important than traditional methods because of their capacity to create huge amounts of biomass over a short period through assimilating great amounts of CO_2. Green algae, blue-green algae, and diatoms were the most common types of algal communities in the Nile (Shehata and Bader 1985). Talling *et al.,* (2009) also looked at the abundance and composition of the phytoplankton community in different parts of the Nile system and found that diatoms predominate in seasonal cycles that terminate in highly turbid floodwater that is rich in nutrients. Designing future phytoremediation tactics under the current water circumstances will require creating a map of the distribution, abundance, and frequency of the algal population in response to the heavy metal toxicity tolerance in the current study. The objective of the ongoing research is to illustrate how environmental factors, such as the concentrations of abiotic components including pollutants in the water of drains, fish farms, treatment stations, and Lake Burullus, affect the distribution and classification of phytoplankton populations. Two-way indicator species analysis (TWINSPAN) and detrended correspondence analysis (DCA) approaches were employed in statistical analysis to find the relationship between the distribution of algal communities and different water-heavy metals.

MATERIALS AND METHODS

Study area

The study area was in Egypt's northern Nile Delta. Three shallow brackish lakes, Manzalla, Burullus, and Idku, are located east to west in the northern section of the Nile Delta and are connected to the Mediterranean Sea by small openings in the sandbars. Lake Burullus is a shallow brackish lake with an area of roughly 57,426 hectares that stretches 47 km along Egypt's deltaic Mediterranean coast. Also, some Fish farms were included, since Kafr El-Sheikh Governorate plays a significant role in fish production. El-Gharbia Main Drain (Kitchener Drain), which is 68.3 km long, empties into the Mediterranean Sea, and Lake Burullus is included. Water for this drain is collected from the south Nile Delta in the east of El-Gharbia Governorate and flows via Kafr El-Sheikh Governorate to Lake Burullus in the north Nile Delta (Table 1, Figure 1). The biological community is severely stressed due to the combination of several pollution sources that provide it with home, industrial, and agricultural waste. The worry that it impacts numerous significant ecosystems, and that fresh water may become a scarce resource in the future has evaluated its water quality as a crucial issue and demand.

Samples collection

Samples of surface water from the lake and drains were taken in April 2020 during the spring season in four-liter plastic bottles at ten sites that represented four ecological locations (Lake Burullus, fish farms, agricultural drains, and pump stations (Table 1). The samples were taken 10 cm below the surface of the water. Samples were taken in the morning (9–11 am) at the 10 chosen sites.

Abiotic analysis

Field analysis

Using portable field meters, pH meter (model Hanna Instrument, made in Romania), a digital electrical conductivity meter (model Hanna Instrument, made in Europe, Romania), a TDS meter (Milwaukee, made in Europe), and a dissolved oxygen DO (Milwaukee MW600 PRO), the pH, electrical conductivity (EC), total dissolved salts (TDS), and dissolved oxygen (DO) values of various wastewater samples were directly recorded in sampling locations.

Lab analysis

Analysis of Chemical Oxygen Demand (COD) by using dichromate oxidation and photometry method, while

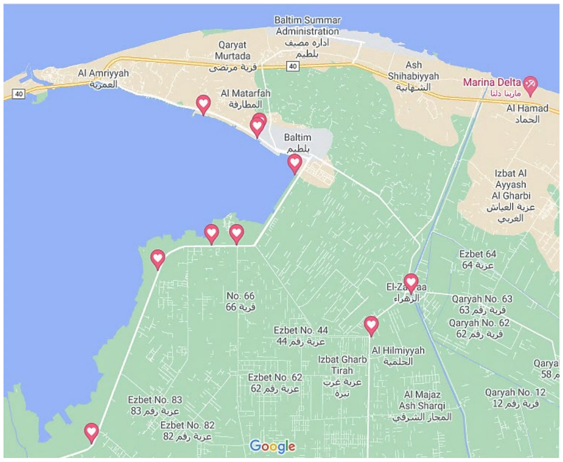

Figure 1. Map of the studied locations.

Table 1. Studied locations.

Location Number and Name	Latitude (N)	Longitude (E)
(1) Burullus drainage pump station	31°33'33.4"N	31°04'34.6"E
(2) Lake Burullus A	31°33'58.4"N	31°03'00.6"E
(3) Lake Burullus B	31°33'26.9"N	31°04'31.5"E
(4) Lake Burullus C	31°32'34.9"N	31°05'33.9"E
(5) Baltim drain station	31°30'56.0"N	31°03'56.5"E
(6) Agricultural drain	31°28'46.5"N	31°07'43.0"E
(7) Kitchener Drain	31°29'46.6"N	31°08'49.9"E
(8) Fish farm A	31°30'55.8"N	31°03'14.5"E
(9) Fish farm B	31°30'20.1"N	31°01'44.5"E
(10) Fish farm C	31°26'16.3"N	30°59'53.5"E

gravimetrical methods were used for the determination of sulphate content by using a 5% solution of $BaCl_2$ as described by UNEP (2004) and APHA (1975). Analysis of nitrite (NO_2^-), nitrate (NO_3^-), ammonia (NH_4^+), and phosphate(PO_4^{-3}) determination in water have been carried out using spectrophotometry (Reis et. al,1992; Joaquim and Antonio 1995; Ahmed et al.1996). Six heavy metals, iron (Fe), zinc (Zn), lead (Pb), nickel (Ni), cupper (Cu), and cadmium (Cd) were measured using Atomic Absorption Spectrometry type (GBC Avanta E, Victoria, Australia) according to instrument manual (Allen 1974).

Phytoplankton Identification

For refreshing the algal strains, one milliliter of each sample was mixed with 10 milliliters of KC medium in a sterile 25 milliliter flask, then they were incubated at light intensity 80µE/m2, 24-hour white, fluorescent light, and 30°C, green, yellowish green, and/or blue-green colors were detected for a week (El-Naggar *et al.,* 1999). The microalgae species were recognized morphologically via light microscopic characterization (Hegewald and Schmidt 1992; Khaybullina *et al.,* 2010; Komarek *et al.,* 2013). The names of the distinct algal morphospecies were verified using taxonomy by the Algae Base global database (Guiry and Guiry 2013).

Data and Statistical Analysis

TWINSPAN for classification technique was used as a multivariate analyze to identify microalgal communities in the study area using the percent occurrence of 38 microalgal species at 10 sites (Hill 1979a, 1979b; Hill and Gauch 1980, Gauch and Whittaker 1981). Beta-diversity (species turnover) is evaluated as a ratio of the total number of species recorded in a certain site to its alpha diversity (Whittaker 1972). Relative evenness or equitability (Shannon–Weaver index) was expressed as $\hat{H} = -\Sigma s\ Pi\ (Log\ Pi)$, where s is the total number of species and Pi is the presence percentage of the species. The relative concentration of dominance (Simpson's index) is expressed as: $C = \Sigma s\ (Pi)2$, where s is the total number of species and Pi is the percentage of species (Pielou 1975; Magurran 1988). Canonical correspondence analysis (CCA) according to Ter Braak and Smilauer (2002) was carried out with species recorded in different sites of 4 locations (Burlus Lake, fish farms, drains, and bump station) variables using the second matrix (Al-Sodany *et al.,* 2018) to detect correlations between microalgae parameters and environmental data. To evaluate the heterogeneity of samples around their means, means, standard deviations, and one-way analysis of variance (ANOVA) were computed for the water variable means relative to sites. These techniques were according to IBM SPSS statistics 20 (IBM Co., Armonk, NY, USA).

RESULTS

Thirty-eight phytoplankton species, representing 18 genera, were found at various sites within the research region. Of these, 25 are classified as Cyanophytes, 4 as Bacillariophytes, and 9 as Chlorophytes (Table 2). In the study region, *Oscillatoria* (6 species) contributed the most, followed by *Nostoc* (5 species), *Anabaena* (4 species), and *Chroococcus* (4 species). *Scenedesmus bijuga* and *Chlorella vulgaris* (80 and 60% of the locations, respectively) had the largest contribution. In terms of locations, Pump stations recorded 23 algal species (5 unique species), while Lake Burullus recorded 21 species (2 unique species) (Figure 2a). However, Lake Burullus had the highest total colonies followed by drains, fish farms and pump stations (Figure 2b). However, *Chlorella vulgaris* and *Scenedesmus bijuga* (Chlorophyta) were recorded in all locations, while

Nostoc carneum, Oscillatoria polifica, Oscillatoria subbrevis, Oscillatoria limnetica and *Oscillatoria anguina* (Cyanophyta), *Chlorella ellipsoidea, Scenedesmus quadricauda and Stigeoclonium polymorphum* Chlorophyta) and *Navicula and Nitzschia* (Bacillariophyta) were recorded in 3 locations (out of 4). Site 5 at Pump stations and site 4 at Lake Burullus were characterized by high diversity in all microalgal species as compared with sites 8 and 10 at fish farms that have a low diversity (Table 3). Regarding to diversity indices (Table 4), the pump stations and Lake Burullus had the highest species richness (13.00±2.83 and 9.67±2.52 ind./site), total species (23 and 21 sp.) and Hmax (1.34 and 1.32). Fish farms had the highest species turnover (2.25) and relative evenness (0.84), while the pump stations had the lowest (1.69 and 0.76, respectively).

Using detrended correspondence analysis (DCA) and two-way indicator species analysis (TWINSPAN), it was recognized 4 groups (communities) had aggregated at the 4th classification level (Figure 3). The first group (community I) represents the drains (the most polluted sites)and dominated by 5 algal species (*Chroococcus miutus, Chlorella vulgaris, Pediastrum duplex var cohaerens, Pediastrum duplex var clathratum, Pediastrum duplex*), community II represents pump stations and dominated by 9 algal species (*Anabaena cylindrica, Arthrospira jenneri, Calothrix fusca, Nodularia spumigena, Nostoc caeruleum, Oscillatoria lutea, Oscillatoria anguina, Scenedesmus quadricauda, Scenedesmus bijug*); community III represents fish farms and dominated by 11 algal species (*Aphanocapsa endophytica, Chroococcus limneticus, Chroococcus minor, Chroococcus disperses, Nostoc carneum, Nostoc muscorum, Oscillatoria polifica, Oscillatoria limnetica, Eudorina elegans, Stigeoclonium polymorphum, Navicula*) and community IV represents Lake Burullus and dominated by 13 species (*Anabaena oscllarioides, Anabaena Azollae, Anabaena variabilis, Aphanotheca microscopica, Nostoc linckia, Nostoc microscopicum, Oscillatoria subbrevis, Oscillatoria acutissima, Oscillatoria tenuis, Chlorella ellipsoidea, Cymbella tumida, Diatomella, Nitzschia)*.

Generally, TDS, NH_3, and Zn in water differed significantly among different sites (Table 5). Lake Burullus had the highest levels of water pH, TDS, EC, COD, and heavy metals (Zn, Cu, Pb, Ni, Cd and Zn). Besides, the drain sites exhibited the highest levels of NH_3 and DO but the lowest levels of almost all water variables. Regarding the correlation analysis between community and water variables (Table 6), it was

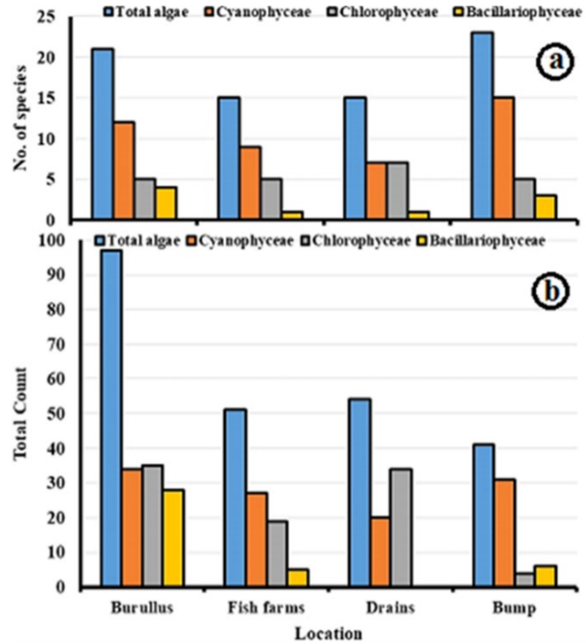

Figure 2. Number of the recorded species and total count about different sites of the studies locations

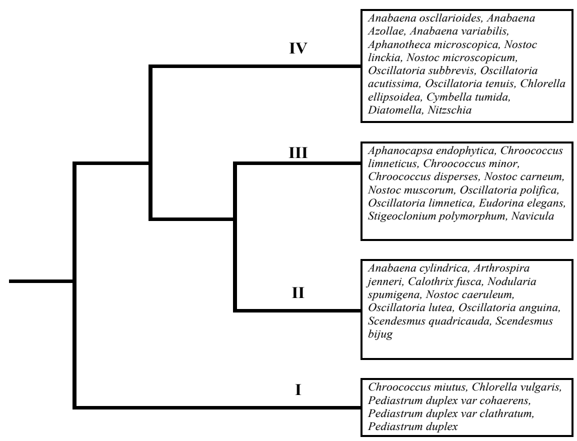

Figure 3. Dendrogram of the 4 groups or communities (I–IV) derived after the application of the two-way indicator species analysis (TWINSPAN) classification technique.

indicated that a negative significant correlation of total algae richness with TDS, EC, Cd and Zn (r= -0.681, -0.637, -0.642 at P<0.05 and -0.887 at P<0.001, respectively), but highly positively significant correlation with NH_3 and PO_4 (P<0.01). Cyanophyta richness had a negative correlation with zinc (r=-0.636, p<0.05) and highly positive correlation with PO_4 (r=0.887, P<0.01), while Chlorophyta richness had a negative correlation with Fe (r=- 0.668, p<0.05).

The correlation coefficients between environmental factors and the first and two CCA axes (Figure 4, Table 7) indicated the separation of the population parameters and the four locations. The first axis was positively influenced by the gradients of COD and Pb,

Table 2. Algal species composition and their percentage abundance in different sites of Kitchener drain and Burullus Lake, Nile Delta, Egypt

Species	Code	Locations/sites										P%	Total No. of species/location			
		Burullus			Fish farms			Drains		Bump			Burullus	Fish farms	Drains	Pump
		L2	L3	L4	L8	L9	L10	L6	L7	L1	L5					
Cyanophyta																
Anabaena cylindrica	Anab cyl					3			2			20		1	1	
Anabaena oscllarioides	Anab osc		1									10	1			
Anabaena azollae	Anab azo		2								2	20	1			1
Anabaena variabilis	Anab var										1	10				1
Arthrospira jenneri	Arth jen					1						10		1		
Aphanocapsa endophytica	Apha end			1					1			20	1		1	
Aphanotheca microscopica	Apha mic										1	10				1
Calothrix fusca	Calo fus				1		5					20		2		
Chroococcus limneticus	Chro lim								1	3		20			1	1
Chroococcus minor	Chro min									2		10				1
Chroococcus dispersus	Chro dis			1						2		20	1			1
Chroococcus miutus	Chro miu							4				10			1	
Nodularia spumigena	Nodu spu				1							10		1		
Nostoc carneum	Nost car		1	3			3			2		40	2	1		1
Nostoc caeruleum	Nost cae					5						10		1		
Nostoc linckia	Nost lin	1									1	20	1			1
Nostoc muscorum	Nost mus			5						1		20	1			1
Nostoc microscopicum	Nost mic										1	10				1
Oscillatoria polifica	Osci pol			5					5	5		30	1		1	1
Oscillatoria subbrevis	Osci sub	2	2	4				3	4	3	2	70	3		2	2
Oscillatoria lutea	Osci lut				2	4						20		2		
Oscillatoria limnetica	Osci lim	2			2					3	1	40	1	1		2
Oscillatoria acutissima	Osci acu	3									1	20	1			1
Oscillatoria tenuis	Osci ten		1									10	1			
Oscillatoria anguina	Osci ang						3	2			1	30		1	1	1
Chlorophyta																
Chlorella vulgaris	Chlo vul	6	9	5		3		8			1	60	3	1	1	1
Chlorella ellipsoidea	Chlo ell	4		3		2			2			40	2	1	1	
Eudorina elegans	Eudo ele									1		10				1
pediastrum duplex var cohaerens Bohlin	Pedi coh							4				10			1	
pediastrum duplex var clathratum	Ped cla							5				10			1	
pediastrum duplex Meyen	Pedi dup							3			1	20			1	1
Scenedesmus quadricauda	Scen qua			5		4	4	4				40	1	2	1	
Scenedesmus bijugatus	Scen bij		1	2	2	2	2	5	3		1	80	2	3	2	1
Stigeoclonium polymorphum	Stig poly			1		1				2		30	1	1		1
Bacillariophyta																
Cymbella tumida	Cymb tum	8	15									20	2			
Diatomella	Diatmell		1								1	20	1			1
Navicula	Navicula			4			5			3	2	40	1	1		2
Nitzschia	Nitzschi		3						3		4	30	1		1	1

while CCA-axis 2 was positively correlated with the gradients of NO_2, NO_3, and Pb. Generally, the CCA application on the water variables and microalgal communities revealed that some of them are correlated with DO such as *Chroococcus miutus (Cyanophyacea), Chlorella vulgaris, Pediastrum duplex var cohaerens, Pediastrum duplex* var *clathratum, Pediastrum duplex* (Chlorophyceae), while others are correlated with pH and NH_3 such as *Anabaena cylindrica, Arthrospira jenneri, Calothrix fusca, Nodularia spumigena, Nostoc caeruleum, Oscillatoria lutea, Oscillatoria anguina (Cyanophyaceae), Scenedesmus quadricauda, Scenedesmus bijug* (Chlorophyaceae), others are correlated with NO_2, NO_3, SO_4 and PO_4 such as *Aphanocapsa endophytica, Chroococcus limneticus, Chroococcus minor, Chroococcus disperses, Nostoc carneum, Nostoc muscorum, Oscillatoria polifica, Oscillatoria limnetica (Cyanophyaceae), Eudorina elegans, Stigeoclonium polymorphum (Chlorophyaceae) and Navicula* (Bacillarophyaceae) and finally some are correlated with COD, EC, TDS and heavy metals (Cd, Cu, Fe, Zn, Ni and Pb) such as *Anabaena oscllarioides, Anabaena Azollae, Anabaena*

Table 3. The population density of the four different algal groups relating to the different sites of the studies locations

Divisions	Abundant	Lake Burullus			Fish farms			Drains		Pump		Total
		2	3	4	8	9	10	6	7	1	5	
Cyanophyta	Total colonies	8	7	19	6	13	11	9	13	21	11	118
	No of genera	2	3	4	3	4	3	2	4	3	4	32
	No of species	4	5	6	4	4	3	3	5	8	9	51
Chlorophyta	Total colonies	10	10	16	2	12	6	29	5	3	3	96
	No of genera	1	2	3	1	3	1	3	2	2	3	21
	No of species	2	2	5	1	5	2	6	2	2	3	30
Bacillariophyta	Total colonies	8	19	4	0	0	5	0	3	3	7	49
	No of genera	1	3	1	0	0	1	0	1	1	3	11
	No of species	1	3	1	0	0	1	0	1	1	3	11
Total	Total colonies	26	36	39	8	25	22	38	21	27	21	263
	No of genera	4	8	8	4	7	5	5	7	6	10	64
	No of species	7	10	12	5	9	6	9	8	11	15	92

Table 4. Diversity of indices of the different sites of the studies location

Diversity index	Lake Burullus	Fish Farms	Drains	Pump stations
Total species	21	15	15	23
H	1.04	0.99	0.97	1.02
C	0.13	0.14	0.16	0.19
Evenness	0.79	0.84	0.82	0.76
H Max	1.32	1.18	1.18	1.34
Richness/STD	9.67±2.52	6.67±2.08	8.50±0.71	13.00±2.83
Turnover	2.17	2.25	1.77	1.69

Table 5. Physicochemical variables of collected water samples from Kitchener drain and Burullus Lake supporting the 4 algal groups resulting after the application of TWINSPAN classification. Data is the means ±SD (n=3). F-values followed with * and ** indicated significant at P ≤ 0.05 and highly significant variance at P ≤ 0.01, respectively.

Variable	Location				Total	F-value
	Burullus	Fish farms	Drains	Bumps		
pH	8.31±0.05	8.28±0.24	8.14±0.39	8.18±0.54	8.24±0.26	0.176
TDS	415.00±104.97	298.67±23.46	137.50±44.55	304.50±127.99	302.50±122.01	4.46*
EC	11.93±4.38	8.20±0.57	3.88±0.62	8.26±4.49	8.47±3.92	2.64
DO	6.07±0.21	5.67±1.46	7.45±0.21	5.65±0.49	6.14±1.01	1.99
COD	165.33±70.86	73.60±41.60	24.00±11.31	100.80±6.79	96.64±66.68	3.85
NO_2	0.16±0.27	0.02±0.03	0.09±0.12	1.12±1.27	0.29±0.62	1.95
NO_3	38.47±0.64	39.27±3.35	34.10±0.99	38.40±3.11	37.82±2.79	2.11
NH_3	1.17±0.52	0.82±0.30	4.25±1.06	2.00±1.06	1.85±1.46	10.88**
PO_4	0.06±0.07	0.02±0.02	0.53±0.45	0.63±0.48	0.26±0.36	3.19
SO_4	28.39±7.12	29.40±8.57	8.19±1.70	31.76±17.35	25.33±12.02	2.71
Fe	1.50±0.48	1.26±0.16	0.64±0.02	1.22±0.54	1.20±0.44	2.31
Cu	0.15±0.05	0.12±0.03	0.05±0.01	0.12±0.01	0.12±0.05	4.15
Ni	0.08±0.04	0.06±0.00	0.03±0.00	0.07±0.05	0.06±0.03	1.30
Pb	0.25±0.13	0.06±0.01	0.04±0.00	0.20±0.14	0.14±0.12	3.13
Zn	0.81±0.08	0.85±0.04	0.43±0.13	0.54±0.16	0.69±0.20	10.71**
Cd	0.10±0.03	0.07±0.00	0.02±0.00	0.07±0.04	0.07±0.03	4.28

Table 6. Correlation between water variables and the algal groups resulting after the application of TWINSPAN classification.

Variables	Total algae	Cyanophyta	Chlorophyta	Bacillariophyta
pH	0.036	0.318	- 0.471	0.239
TDS	- 0.681*	- 0.391	- 0.582	- 0.224
EC	- 0.637*	- 0.332	- 0.578	- 0.219
DO	0.337	0.155	0.213	0.295
COD	- 0.293	- 0.151	- 0.452	0.183
NO_2	0.274	0.490	- 0.148	0.068
NO_3	- 0.266	- 0.130	- 0.221	- 0.138
NH_3	0.806**	0.501	0.520	0.454
PO_4	0.760**	0.887***	0.003	0.417
SO_4	- 0.442	- 0.139	- 0.351	- 0.396
Fe	- 0.646*	- 0.254	- 0.668*	- 0.247
Cu	- 0.492	- 0.333	- 0.309	- 0.239
Ni	- 0.520	- 0.179	- 0.545	- 0.233
Pb	- 0.289	-0.062	- 0.427	- 0.008
Zn	- 0.887***	- 0.636*	- 0.517	- 0.428
Cd	- 0.642*	- 0.334	- 0.596	- 0.199

*** Correlation is significant at the 0.001 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

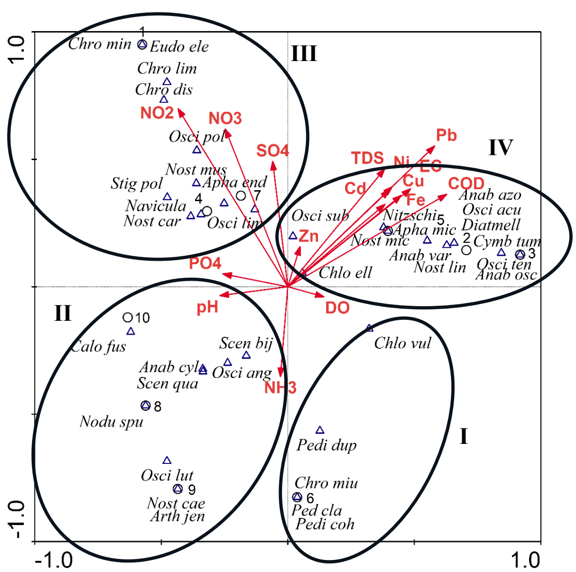

Figure 4. Canonical correspondence analysis biplot with water characteristics (→) and species (Δ) of algae in Lake Burullus (Egypt): The algae species are organized as the following: Group I (*Chroococcus miutus, Chlorella vulgaris, Pediastrum duplex var cohaerens Bohlin, Pediastrum duplex var clathratum, Pediastrum duplex Meyen*); Group II (*Anabaena cylindrical, Arthrospira jenneri, Calothrix fusca, Nostoc caeruleum, Nodularia spumigena, Oscillatoria anguina, Oscillatoria lutea, Scenedesmus bijugatus, Scenedesmus quadricauda*); Group III (*Aphanocapsa endophytica, Chroococcus disperses, Chroococcus minor, Chroococcus limneticus, Nostoc carneum, Nostoc muscorum, Oscillatoria limnetica, Oscillatoria polifica, Stigeoclonium polymorphum, Eudorina elegans, Navicula sp.*); Group IV (*Anabaena oscllarioides, Anabaena azollae, Anabaena variabilis, Aphanocapsa endophytica, Aphanotheca microscopica, Chroococcus limneticus, Nostoc carneum, Nostoc linckia, Nostoc microscopicum, Oscillatoria subbrevis, Oscillatoria acutissima, Oscillatoria tenuis, Chlorella ellipsoidea, Cymbella tumida, Diatomella sp., Navicula sp, Nitzschia sp.*).

Table 7. Inter-set correlations of soil properties with CCA axes. Significant values are bold.

Soil variables	Axis 1	Axis 2
TDS	0.3826	0.4627
EC	0.4852	0.3840
DO	0.1428	-0.0396
COD	0.6281*	0.3626
NO_2	-0.4342	0.6989**
NO_3	-0.2467	0.6189*
NH_3	-0.0294	-0.3529
PO_4	-0.2571	0.0501
SO_4	-0.0600	0.4919
Fe	0.3839	0.3235
Cu	0.4488	0.3579
Ni	0.4124	0.3925
Pb	0.5809*	0.5525*
Zn	0.0484	0.1578
Cd	0.4015	0.3796

-values followed with * and ** indicated significant at $P \leq 0.05$ and highly significant variance at $P \leq 0.01$, respectively.

variabilis, Aphanotheca microscopica, Nostoc linckia, Nostoc microscopicum, Oscillatoria subbrevis, Oscillatoria acutissima, Oscillatoria tenuis (Cyanophyaceae), *Chlorella ellipsoidea, (Chlorophyaceae), Cymbella tumida, Diatomella, Nitzschia* (Bacillarophyaceae).

DISCUSSION

The primary determinants of the abundance of microalgae in lakes, fish farms, pump stations and water canals are thought to be the qualities of the water. The primary determinants of species distribution and abundance are salinity and temperature (Zakaria and El-Naggar 2019). According to Tavsanoglu *et al.,* (2015), salinity variations will have a significant effect on aquatic ecosystems, where they may cause cellular ionic ratio alterations, osmotic stress on cells, and ion uptake or loss. The biotic factors of various sites along the Mediterranean Sea coast were significantly impacted by increased human activity and sewage discharge that contained high amounts of nutritional salts and other harmful substances (Farrag *et al.,* 2019; Shaban *et al.,* 2020). The acquired results verify that the distribution and abundance of the microalgae under investigation are significantly influenced by the water qualities and properties between the sites under study and between brackish water and wastewater, respectively. Most of our findings concurred with those of Heneash *et al.,* (2022), who found a substantial relationship between the patterns of environmental heterogeneity and species variation. The condition of the water at the sample locations varies in salinity, EC, phosphate, ammonia, nitrite, and nitrate as well as pH values. This could be because sewage, industrial, and agricultural drains immediately pump pollutants from the city into the sampling locations, making the saltwater surrounding the sites unfit for marine life due to ongoing contamination (Alprol *et al.,* 2021).

According to obtained results, Badawy *et al.,* (2022) reported that the Kitchner drain is a freshwater canal that is accessed by various nutrients and pollutants. Cyanophyta are highly abundant organisms in both low and high pollution levels, which may account for their potential role in environmental bioremediation (Singh *et al.,* 2016). Due to the regular flow of fresh water and the ongoing, regular irrigation operation, recorded microalgae in investigated locations of the Kitchner drain, fish farms, pump stations, and Lake Burullus get nearly regular freshwater drainage input since the construction of the Egyptian High Dam (Elmousel *et al.*, 2023). By using this technology, the lake's water level is raised to a height of 25 to 60 cm above sea level, preventing seawater from penetrating the lake through the Burullus inlet (Dumont and El-Shabrawy 2007). According to Elmousel *et al.,* (2023), these reports provide compelling evidence for the abundance of various freshwater species, including *Chlorella vulgaris* and *Nostoc muscorum*, in both the Kitchner drain and Lake Burullus. This study introduces the relationship between biotic microalgae and abiotic components on the one hand, and brackish water and freshwater (drain canals, fish farm, and pump station) on the other hand, depending on changes in the phytoplankton community and water quality. Cyanophyta is highly abundant in most locations, due to high concentration of contaminants (such as Zn, and phosphate), which may account for the high abundance and diversity of Cyanophyta and Chlorophyta in agreement with Fernandez-Figueroa *et al.,* (2021). The abundance of Bacillariophyta is about identical in the two habitats under investigation. The high concentration of pollutants and salt in Burullus Lake areas may be the reason for the high diversity of Bacillariophyta. Burullus Lake's measured TDS levels were higher than those of other locations. This short lake-to-sea channel and the lake's higher elevation than the sea make the established habitat perfect for Bacillariophyta growth as reported by Heneash *et al.,* (2015).

CONCLUSIONS

The abundance and frequency of microalgae investigated have a significant correlation with the environmental abiotic components. The species that belong to Cyanophyta are the most abundant colonies (118) followed by Chlorophyta (96) colonies and then Bacillariophyta (49) colonies. *Scenedesmus bijugatus* (Chlorophyta) was the most frequent species (P 80%), followed by *Oscillatoria subbrevis* (Cyanophyta) (P 70%) and *Chlorella vulgaris* (Chlorophyta) (P 60%). The total species no. of Cyanophytes is the highest value. Chlorophytes showed the highest count of species in the case of Burullus Lake, while Cyanophyta showed the highest record in other locations. Abiotic components showed a direct relationship on distributing the microalgae, where ammonia, phosphate, iron, Zinc, cadmium, TDS, and EC exhibited influence on algal abundance.

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