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Microalgal Distribution in Relation to Water Quality at North Damietta, Egypt

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Abstract

This study aimed to display the microalgal distribution, diversity, and their relationship to water quality at ten selected stations (S1 to S10), North Damietta, Egypt. The water physicochemical parameters as well as the qualitative and quantitative investigations of microalgae were performed seasonally from Autumn 2021 to Summer 2022. Salinity values varied between 0.4 gL-1 at River Nile Dam (S6) to 400 gL-1 at Al-Diba pond (S10). The highest concentrations of ammonia and nitrite (3.7 mgL-1 and 0.5 mgL-1, respectively) were recorded at S1 while the highest concentration of nitrate (5.37 mgL-1) was estimated at S9. Although the orthophosphate concentrations were low, total phosphorus values were acceptable. A total of 137 microalgal taxa, belonging to 7 algal groups, were microscopically identified. Diversity index values indicated that the water status varied between mildly polluted at River Nile (S6) and heavily polluted water at stations 3, 5, 8, 9, and 10. The findings concluded that the species diversity decreases by increasing the pollution as well as increasing salinity. Furthermore, the results confirmed that high species diversity coincides with low dominancy and vice versa.

Keywords: Water physicochemical parameters, Biological assessment; Diversity and Dominance indices.

Introduction

Water is essential for all the forms of life, and thus the continuous monitoring of water quality is a very serious issue to ensure the balance in the aquatic ecosystem. Several indicators, models and indices have been developed to evaluate water quality in fresh, brackish and marine environments **(Escobedo-Uŕas, 2010)**. They depend obsessively on analysis of the physical and chemical parameters of water (trophic level). In addition, they can indicate the water status at the time when these parameters are measured and do not generally detect the resilience, the evolution of pollutant load and buffering capacity of aquatic ecosystems **(Vadeboncoeur et al., 2002)**. Relying on them alone is not enough to assess the water quality, so bioindicators such as microalgae are used as a complement tool to evaluate the water quality.

Microalgae have short life cycle and are sensitive to many environmental factors and nutrient content and thus give them the chance to monitor environmental variations at sampling stations **(Han et al., 2023)**. Moreover, microalgae can evaluate environmental conditions over a wider time range **(Campbell, 2002)**. In addition, there are two more traits encourage their usage in ecosystem surveillance: (1) its sampling is easy and (2) most species are cosmopolitan with well-known autecology **(Porter, 2008)**.

Microalgae respond to the environmental changes through modifications in their distribution, community composition and proportion of sensitive species **(Gharib et al., 2011)**. Thus, the microalgal community structure serves as an indicator of water quality **(Shen and Shi, 2002)**. The usage of Shannon diversity index and the Simpson dominance index can give more information about community structure than the abundance which can do alone as proved by **Asadi et al. (2018).** Diversity and dominance are important features for the description of algal communities **(Thukral et al., 2019)**. Diversity index gives an indication to status of microalgal communities and water pollution **(Meng et al., 2020)**.

The seasonal variations of the microalgal species abundance and diversity are affected by the interaction between the physical and chemical factors that are dependent on the environmental change, physical factors like light intensity and temperature as well as chemical factors like salinity, electrical conductivity, pH, dissolved oxygen, hardness, and nutrient level **(Miranda and Krishnakumar, 2015)**.

Threats of the water quality are diverse with different sources: agriculture (fertilizers, herbicides, and pesticides), domestic domain (sewage, pharmaceuticals, human activities and personal care products), industry (energy production, water abstraction, pollution) and climate change **(Seelen et al., 2019)**. So that, this study aimed to screen the diversity of microalgal species in response to different types of pollutants and water quality seasonally at north Damietta, Egypt by evaluating physicochemical properties of water, assessing biological properties of microalgae and estimating the water quality by biological indices.

Materials and Methods

Study area

The study area included ten stations at North Damietta, Egypt. These stations were selected to exhibit the algal diversity in habitats with different pollution sources **(Table 1) (Fig.1)**. The water and algal samples were seasonally collected from Autumn 2021 to Summer 2022. These stations were described as follow:

Station1 (S1): Gamasa drainage, brackish draining canal receiving agricultural and domestic discharges.

Station 2 (S2): Al-Rikabiya canal, an irrigation canal receiving agricultural discharges.

Station 3 (S3): Western New Damietta drainage, a brackish water receiving agricultural and fish farm discharge.

Station 4 (S4): Water pond, receiving agricultural discharge.

Station 5 (S5): Damietta port pond, brackish water pond receiving agricultural discharge.

Station 6 (S6): River Nile Dam at Damietta, freshwater exposing to agricultural discharge.

Station 7 (S7): River Nile Eustuary, brackish water in contact with the Mediterranean Sea and receives agricultural and domestic discharge.

Station 8 (S8): Shata - (El-Manzala Lake), a fish farm area receiving domestic discharge.

Station 9 (S9): Al Diba - (El-Manzala Lake), a fish farm area.

Station 10 (S10): Al-Diba pond, isolated hypersaline water pond.

Table1. Latitudes and Longitudes of the studied stations

Station No.	Latitude	Longitude
S1	31˚43´13″	31˚55´15″
S2	31˚43´40″	31˚ 56´57″
S3	31˚43´87″	31˚57´92″
S4	31˚43´82″	31˚58´42″
S5	31˚44´09″	31˚76´06″
S6	31˚40´83″	31˚78´71″
S7	31˚40´87″	31˚78´73″
S8	31˚36´30″	32˚02´35″
S9	31˚33´39″	32˚04´13″
S10	31˚34´13″	32˚06´90″

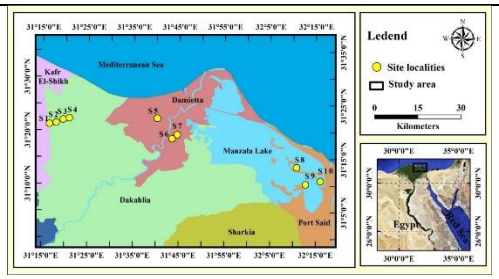

Fig.1 A map of the study area showing the sampling stations

Water Analysis

The surface water samples were collected seasonally (at seven to nine in the morning) from each station for physico-chemical analysis and algal investigations of water. Each station was represented by five points to collect the water samples. Two liters from each point were collected and mixed well to obtain finally one liter for water analysis and one liter for algal investigations. After collecting the samples, they were stored in an icebox and taken to the laboratory for analysis as soon as possible.

Physical parameters of water

Water temperature was directly measured in the field using a Celsius Thermometer. pH was directly determined using a Horizon Ecology Co pH meter 5995. EC, TDS and salinity were directly estimated using conductivity/ TDS meter.

Chemical parameters of water

Water dissolved oxygen was fixed directly in the sampling stations and titrated in the laboratory according to **APHA (2017)**. The collected water samples were filtered using Whatman filter paper to remove the debris. Estimation of ammonia was carried out using phenate method, nitrite by colorimetric method, nitrate by Ultraviolet spectrophotometric screening method, ortho-phosphate by Ascorbic acid method and total phosphorus by Per sulfate digestion method that were according to **APHA (2017)**.

Biological analysis of microalgae

One liter of the water samples was treated with formalin (4%) and lugol's solution (1%) to fix and preserve the present microalgae **(Utermöhl, 1936).** The fresh as well as preserved samples were examined microscopically for qualitative investigation of microalgae. The morphological features of microalgal species were recorded and algal species were identified according to pertinent guides to the species identifications **(Guiry and Guiry, 2022 and Bellinger and Sigee, 2015).** Marine microalgae were identified basing on World Register of Marine species (https://www.marinespecies.org/lifewatch.php).

Quantitative investigation of microalgae was carried out by sedimentation of a known volume of water sample (e.g. one liter) in a measuring cylinder for 2 days using formalin (4%) and lugol's solution (1%) **(Utermöhl, 1936)**. Most of the supernatant was carefully siphoned using a siphon droplite system (0.1 mm in diameter) with a tight piece of phytoplankton net (mesh < 10 mm) on its end, which emerged in the sample. The sedimented microalgae was then swirled to make a homogenous suspension, its volume was measured and kept in a dark bottle. Counting the microalgal cells was carried out in the large central square of Haemocytometer chamber and number of cells was expressed as (Number of cells $x10^5$ cell/L). Each count was repeated three times.

Biological assessment of water quality

Diversity index (H):

The diversity of microalgal community was calculated according to **Shannon and Weaver (1949)** using the following equation**:**

$$H= -\sum \frac{ni}{n} log e(\frac{ni}{n})$$

ni= number of individuals of ith species
n= total number of collected individuals of all species

value grade:

> 4: clean water,
3 - 4: mildly polluted water,
2 - 3: moderately polluted water and
< 2: heavily polluted water

Dominance index (C) was calculated based on Simpson (1949):

$C= \sum(ni/N)^2$
ni= number of individuals of ith species
N= total number of collected individuals of all species

value grade:

$0<C\leq0.5$ = low dominance
$0.5\leq C\leq0.75$ = moderate dominance
$0.75\leq C\leq1.0$ = high dominance

Statistical analysis

For each parameter, three replicates were used. The data were expressed as mean values ± SE. Pearson correlation coefficients were achieved out by the statistical software SPSS (Version 22.0 for Windows).

Results

Physico-chemical parameters of water

The temperature values ranged from 14± 0.3°C during winter to 34± 0.01°C during summer (Table 2). The difference in water temperatures between the ten stations was very narrow. Temperature was negatively correlated with nitrate (r= -0.246**) as shown in table (3).

Water was almost neutral or slightly alkaline during the study period, with pH values ranged from 6.6± 0.03 at (S10) during autumn to 8.81± 0.01 at (S3) during summer (Table 2). pH showed positive correlation with nitrate (r= 0.464**). On the other hand, pH values were negatively correlated with EC (r= -0.601**), TDS (r= -0.606**), salinity (r= -0.608**), ammonia (r= -0.278**) and nitrite (r= -0.249**).

The minimum value of electrical conductivity (0.39± 0.002 mS/cm) was recorded at (S6) during summer, while the maximum value (488± 0.11mS/cm) was recorded at (S10) during summer. There was an increase in EC values during spring and summer compared to autumn and winter (Table 2). EC showed positive correlation between TDS (r-= 1.000**) and salinity (r=1.000**). While it was negatively correlated with DO (r= -0.465**), ammonia (r= -0.189*), nitrate (r= -0.428**) and O- phosphate (r= -0.292**) (Table 3).

The lowest values of TDS and salinity were 0.23± 0.002 gL^{-1} and 0.4± 0.01 gL^{-1}, respectively at station (6) during summer, while the highest values were 390± 0.33 gL^{-1} and 400± 0.88 gL^{-1}, respectively at station (10) during summer (Table 2). From table 3, TDS was significantly correlated with salinity (r= 1.000**).

The lowest value of DO (3.8± 0.01mg/L) was recorded at (S10) during summer whereas the highest value (6.9± 0.03 mg/L) was recorded at (S1) during winter. DO concentrations fluctuated with seasons, the highest values of DO were recorded during winter while the lowest values were recorded during summer in most of the stations (Table 2). DO was negatively correlated with nitrate (r= -0.275**) and T- phosphorus (r= -0.218*) (Table 3).

The highest concentration of ammonia-N (3.7± 0.06 mg/L) was recorded at (S1) during winter, while the lowest concentration (0.02± 0.002mg/L) was recorded at (S5) as shown in table 2. It was interesting that ammonia was undetectable at stations (6 and 7) during autumn and summer, respectively. Ammonia had positive correlation with nitrite (r=0.761**), O- phosphate (r= 0.296**) and T- phosphorus (r= 0.291**), but it was negatively correlated with pH (r= -0.278**) as recorded in table (3).

The lowest mean value (0.01± 0.002mg/L) of nitrite-N was recorded at (S2) during summer while the highest value (0.54± 0.01mg/L) was recorded at (S1) during autumn. Nitrite-N concentrations were low at the studied stations during the study period (Table 2). Nitrite-N was positively correlated with ammonia (r= .761**), while it was negatively correlated with the pH (r= -0.249**) (Table 3).

Nitrate-N values oscillated between the lowest value (0.3± 0.02 mg/L) at (S6) during summer and the highest value (5.4± 0.25 mg/L) at (S9) during spring (Table 2). Our results showed high concentrations of nitrate in the all studied stations compared to those of nitrite and ammonia. There was a remarkable increase in nitrate-N content at (S9) during spring. Nitrate-N concentrations fluctuated during seasons and decreased during spring and summer. This trend was recorded for most stations. Nitrate-N values at (S10) weren't determined. From table (3), nitrate was positively correlated with T-phosphorus (r= 0.191*), O- phosphate (r= 0.290**) and pH (r= 0.464**).

Table 2. Seasonal variations of physico-chemical parameters of water at different stations

Stations	Season	Temp. (C°)	pH	EC (mS/cm)	TDS (g/l)	Salinity (g/l)	DO (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)	Ortho-p (mg/L)	Total p (mg/L)
S1	Aut.	19.3± 0.3	8.2± 0.01	3±0.001	1.2± 0.01	1.2±0.01	6.2±0.12	3.4±0.06	0.5±0.01	2.6±0.1	0.1±0.001	0.8±0.01
	Win.	14.3± 0.3	7.3±0.009	3.5±0.04	1.5±0.17	1.6±0.03	6.9±0.03	3.7±0.06	0.3±0.003	2.9±0.15	0.1±0.002	0.6± 0.018
	Spr.	24.3± 0.3	8.2± 0.01	5.7± 0.01	2.6± 0.01	2.8± 0.01	5.5± 0.15	3.3± 0.04	0.2± 0.001	1.9± 0.03	0.2± 0.001	1.5± 0.11
	Sum.	33.3± 0.3	8.3± 0.04	7.6± 0.02	3.1± 0.03	3.9± 0.01	5.8± 0.01	2± 0.08	0.2± 0.01	1.5± 0.03	0.08± 0.001	0.4± 0.01
S2	Aut.	19.3± 0.3	8.05± 0.01	2.7± 0.004	1.01± 0.001	0.9± 0.01	5.3± 0.15	0.9± 0.02	0.1± 0.01	1.4± 0.15	0.03± 0.001	0.2± 0.01
	Win.	14.3± 0.3	7.9± 0.01	3.1± 0.003	1.1± 0.09	1.2± 0.01	5.6± 0.01	2.3± 0.08	0.08± 0.01	1.7± 0.01	0.1± 0.001	0.8± 0.02
	Spr.	25± 0.01	8.4± 0.007	4.8± 0.03	3.0± 0.02	1.9± 0.01	5.2± 0.13	2.2± 0.02	0.03± 0.01	1± 0.009	0.2± 0.007	1.5± 0.009
	Sum.	32± 0.58	8.3± 0.02	6.3± 0.03	3.0± 0.02	2.5± 0.01	5.2± 0.01	1.5± 0.005	0.01± 0.002	0.9± 0.03	0.13± 0.001	0.6± 0.02
S3	Aut.	19.3± 0.3	8.8± 0.003	16.8± 0.03	10.1± 0.02	8± 0.01	5.3± 0.01	0.01± 0.002	0.05± 0.001	4.5± 0.26	0.05± 0.002	0.7± 0.01
	Win.	14.6± 0.3	8.4± 0.01	13.9± 0.02	8.3± 0.02	6.4± 0.03	5.2± 0.14	0.02± 0.001	0.01± 0.001	4.7± 0.003	0.07± 0.01	0.4± 0.03
	Spr.	24.3± 0.3	8.7± 0.006	17.6± 0.01	10.5± 0.01	8.4± 0.01	4.8± 0.01	0.05± 0.003	0.03± 0.001	3.4± 0.05	0.2± 0.002	1.5± 0.01
	Sum.	33.3± 0.3	8.8± 0.01	15.4± 0.14	9.3± 0.08	7.2± 0.07	4.4± 0.01	0.08± 0.007	0.04± 0.01	3± 0.03	0.04± 0.0003	0.7± 0.003
S4	Aut.	19.3 ± 0.3	8.8 ± 0.01	6.2 ± 0.02	3.7 ± 0.01	2.6 ± 0.03	5 ± 0.01	0.3± 0.003	0.01± 0.002	1.2 ± 0.03	0.06 ± 0.003	0.7 ± 0.009
	Win.	14.3 ± 0.3	7.7 ± 0.06	6.03± 0.015	3.1 ± 0.09	3.2 ± 0.03	6.1 ± 0.006	0.05 ± 0.004	0.1 ± 0.007	2.7 ± 0.02	0.1 ± 0.003	0.8 ± 0.003
	Spr.	24.7 ± 0.3	8.4 ± 0.01	9.9 ± 0.009	5.9± 0.03	4.3± 0.03	5.03 ± 0.01	0.3 ± 0.004	0.01 ± 0.01	1.5± 0.003	0.3± 0.03	1.5± 0.03
	Sum.	31.7± 0.3	8.3± 0.01	11.6± 0.15	6.6± 0.01	4.9± 0.03	5.03± 0.01	0.3± 0.002	0.02± 0.003	1.3± 0.03	0.2± 0.001	1.2± 0.03
S5	Aut.	18.7± 0.33	8.7± 0.006	12.1± 0.003	9.2± 0.01	5.3± 0.03	4.3± 0.15	0.05± 0.003	0.04± 0.002	4.2± 0.03	0.3± 0.01	1.6± 0.09
	Win.	14.3± 0.33	8.6± 0.006	18.6± 0.04	11.1± 0.03	9.0± 0.03	4.9± 0.03	0.02± 0.002	0.02± 0.01	4.8± 0.003	0.2± 0.004	1.1± 0.04
	Spr.	23.3± 0.33	8.3± 0.01	29.3± 0.07	23.6± 0.03	24.6± 0.1	4.7± 0.23	0.08± 0.003	0.03± 0	4.6± 0.32	0.2± 0.003	1.1± 0.003
	Sum.	33± 0.01	8.5± 0.01	40.1± 0.15	32.5± 0.06	34.1± 0.09	4.7± 0	0.1± 0.003	0.06± 0	4.03± 0.03	0.09± 0.007	1.06± 0.02
S6	Aut.	20± 0.01	8.03± 0.01	0.4± 0.003	0.3± 0.002	0.5± 0.01	6.4± 0.13	0	0.04± 0	0.9± 0.01	0.02± 0.01	0.11± 0.007
	Win.	15± 0.01	8.7± 0.006	0.6± 0.004	0.4± 0.003	0.5± 0.01	6.8± 0.49	0.05± 0.004	0.02± 0	0.9± 0.006	0.02± 0.01	0.10± 0.009
	Spr.	22.3± 0.33	8.6± 0.04	0.4± 0.02	0.2± 0.009	0.4± 0.03	6.5± 0.01	0.07± 0.005	0.02± 0.003	0.4± 0.006	0.05± 0.001	0.11± 0.003
	Sum.	33± 0.01	8.6± 0.14	0.39± 0.002	0.2± 0.002	0.4± 0.01	6.1± 0.003	0.06± 0.004	0.02± 0.01	0.3± 0.02	0.05± 0.001	0.10± 0.006
S7	Aut.	20± 0.01	7.9± 0.003	25.2± 0.09	15.2± 0.05	13.3± 0.09	6.4± 0.13	0.09± 0.004	0.07± 0.001	1.4± 0.003	0.08± 0.002	0.3± 0.02
	Win.	15± 0.01	8.4± 0.006	26.2± 0.07	15.9± 0.18	14.1± 0.09	6.5± 0.33	0.1± 0.004	0.04± 0.001	1.5± 0.009	0.01± 0.007	0.1± 0.003
	Spr.	22.7± 0.33	8.3± 0.02	29.8± 0.06	17.9± 0.04	15.1± 0.12	6.5± 0.14	0.1± 0.004	0.02± 0.001	1.7± 0.007	0.02± 0.001	0.1± 0.007
	Sum.	33.3± 0.33	8.1± 0.04	34.2± 0.03	23.5± 0.03	19.0± 0.03	6.2± 0.03	0	0.02± 0.01	1.04± 0.01	0.02± 0.001	0.13± 0.01
S8	Aut.	19± 0.01	8.6± 0.02	26.8± 0.03	16.1± 0.02	14.4± 0.13	4.1± 0	0.036± 0.005	0.04± 0.001	3.2± 0.18	0.05± 0.002	0.4± 0.02
	Win.	14.3± 0.33	8.7± 0.003	29.1± 0.06	17.8± 0.06	16.2± 0.2	4.5± 0.12	0.039± 0.001	0.04± 0.01	3.7± 0.01	0.05± 0.003	0.1± 0.01
	Spr.	21.7± 0.33	8.4± 0.02	35.1± 0.06	24± 0.07	21.0± 0.03	4.5± 0.01	0.042± 0.002	0.01± 0.002	3.8± 0.12	0.02± 0.001	0.1± 0.001
	Sum.	34± 0.01	8.5± 0.02	48.7± 0.07	36.2± 0.06	35.2± 0.13	4.1± 0.007	0.1± 0.005	0.01± 0.002	2.6± 0.02	0.02± 0.001	0.2± 0.003
S9	Aut.	18± 0.01	8.6± 0.009	42.1± 0.03	25.2± 0	27.1± 0.03	4.1± 0.03	0.02± 0.002	0.03± 0.002	4± 0.01	0.04± 0.001	0.4± 0.01
	Win.	14.3± 0.33	8.8± 0.003	38.8± 0.19	23.4± 0.13	24.3± 0.25	4.5± 0.12	0.09± 0.002	0.07± 0.01	4.4± 0.01	0.07± 0.009	0.36± 0.003
	Spr.	22± 0.6	8.6± 0.009	42.1± 0.09	25.9± 0.07	26.03± 0.03	4.3± 0.03	0.09± 0.003	0.03± 0.002	5.4± 0.25	0.05± 0.002	0.32± 0.09
	Sum.	33.7± 0.33	8.3± 0.02	50.03± 0.15	32.4± 0.09	33.03± 0.2	4.2± 0.03	0.04± 0.003	0.02± 0.01	2.6± 0.02	0.02± 0.002	0.27± 0.03
S10	Aut.	18.7± 0.33	6.6± 0.03	385.9± 0.06	308.7± 0.2	310.3± 1.45	4.1± 0.01	0.01± 0.003	0.03± 0.003	-	0.021± 0.009	0.4± 0.006
	Win.	14.3± 0.33	8.1± 0.003	369.3± 0.12	295.5± 0.1	295.4± 0.15	3.8± 0.09	0.09± 0.002	0.04± 0.001	-	0.024± 0.002	0.5± 0.02
	Spr.	24.3± 0.33	7.6± 0.02	435± 0.01	348± 0.14	353.2± 0.17	4.4± 0.01	0.3± 0.003	0.03± 0.001	-	0.01± 0.003	0.4± 0.003
	Sum.	33.7± 0.33	7.3± 0.02	487.5± 0.12	390.3± 0.33	400.3± 0.9	3.8± 0.01	0.1± 0.009	0.04± 0.001	-	0.021± 0.003	0.9± 0.009

Results are means of three replicates ± SE. Aut: Autumn; Win: Winter; Spr: Spring; Sum: Summer; EC: Electrical conductivity; TDS: Total dissolved solids; DO: Dissolved oxygen.

The maximum value of Ortho phosphate (0.3 ± 0.01 mg/L) was recorded at (S5) during autumn while the minimum value (0.05± 0.001 mg/L) was recorded at (S6) during spring and summer (Table 2). O- phosphate was positively correlated with nitrate (r= 0.290**), ammonia (r= 0.296**) and T- phosphorus (r= 0.876**). On the other hand, it was negatively correlated with EC (r= -0.292**) and salinity (r=-0.286**) as shown in table 3.

As recorded in Table 2, The lowest value (0.1± 0.01 mg/L) of total phosphorus was recorded at (S6) whereas the highest value (1.6 ± 0.09 mg/L) was recorded at (S5) during autumn. T- phosphorus had positive correlation with O- phosphate (r= 0.876**), ammonia (r= 0.291**) and nitrate (r= 0.191*). While, it was negatively correlated with DO (r= -0.218*) according to table (3).

Biological analysis of microalgae at the studied stations

A total of 137 microalgal taxa that belong to 7 algal groups were identified during the different four seasons at the study area. The microalgal community was diverse with Bacillariophyta (50 taxa, 27 genera), Chlorophyta (42 taxa, 25 genera), Cyanophyta (23 taxa, 14 genera), Euglenophyta (11 taxa, 6 genera), Dinophyta (9 taxa, 8 genera), Cryptophyta (1 taxon, 1 genus) and Haptophyta (1 taxon, 1 genus) (figure 2).

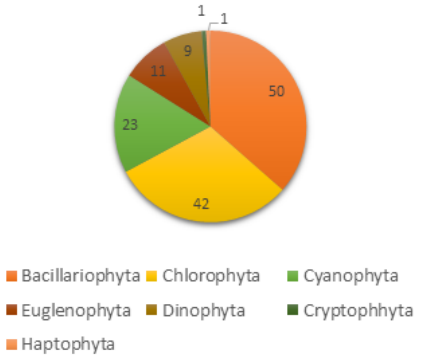

Fig. 2 Number of microalgal taxa belonging to each algal group at the studied stations

Table 3. Pearson Correlation coefficient between the different physico-chemical parameters of water at 10 stations north Damietta.

	Temp.	pH	EC	TDS	Salinity	DO	NH_3-N	NO_2-N	NO_3-N	Total- p	Ortho- p
Temp.	1										
pH	.040	1									
EC	.071	-.601**	1								
TDS	.073	-.606**	1.000**	1							
Salinity	.075	-.608**	1.000**	1.000**	1						
DO	-.168	-.073	-.465**	-.457**	-.456**	1					
Amm.-N	-.045	-.278**	-.189*	-.182*	-.178	.342**	1				
Nitrite-N	-.155	-.249**	-.135	-.130	-.126	.338**	.761**	1			
Nitrate-N	-.246**	.464**	-.428**	-.437**	-.438**	-.275**	-.122	.035	1		
Total- p	.081	.053	-.059	-.051	-.050	-.218*	.291**	.139	.191*	1	
Ortho- p	-.056	.120	-.292**	-.285**	-.286**	-.061	.296**	.144	.290**	.876**	1

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

The lowest cell number of Cyanophyta species (32×10^5 cell/L) was recorded at (S9) during autumn and winter while the highest cell number (1471×10^5 cell/L) was recorded at (S3) during autumn (Table 4). *Merismopedia tenuissima* was the dominant species and represented 83.8% of total cyanophyta species at (S3) during autumn (Table 5). The minimum number (38×10^5 cell/L) of the cell number of Chlorophyta species was recorded at (S7) during autumn whereas the maximum number (6465×10^5 cell/L) was recorded at (S9) during winter (Table 4).

Chlorella salina was the dominant species at (S9) during the four seasons and recorded 99.8%. 99.9%, 99.8%, and 99.6% during autumn. winter, spring, and summer, respectively (Table 5). *Dunaliella salina* was only recorded at (S10) and its maximum growth (228×10^5 cell/L) was reported during autumn (Table 5).

Station (4) contained the highest cell number of Bacillariophyta species (541×10^5 cell/L) during autumn (Table 4). It was mainly dominated by *Stephanocyclus meneghinianus* which represented 39% of total Bacillariophyta species (Table 5). However, station (10) recorded the lowest cell number (1×10^5 cell/L) during autumn and winter. The highest cell number of Euglenophyta species (140×10^5

cell/L) was recorded at (S3) during winter, while the lowest cell number (2×10^5 cell/L) was recorded at (S7) during spring and summer (Table 4). *Euglena gracilis* recorded high growth (109×10^5 cell/L) during winter at (S3) as shown in table 5.

The maximum cell number (181×10^5 cell/L) of Dinophyta was estimated at (S5) during summer, while the lowest cell number (2×10^5 cell/L) was at (S1) during autumn and winter (Table 4). *Heterocpsa* sp. was only recorded at (S5) during summer and exhibited high growth (181×10^5 cell/L) as reported in table 5. Haptophyta (represented by *Prymnesium parvum*) was only recorded at (S5). The highest cell number (358×10^5 cell/L) of *P. parvum* was recorded during winter, whereas the lowest cell number (40×10^5 cell/L) was recorded during summer. Cryptophyta (mainly represented by *Cryptomonas phaseolus*) was recorded at the stations that characterized by fresh or slightly brackish water. Low abundance of *C phaseolus* was exhibited during autumn and winter but its abundance increased during spring and summer (Table 4).

The highest value of diversity index (3.5) was recorded at (S6) indicating high species diversity and mildly polluted water, whereas the lowest value (0.1) was recorded at (S9) indicating very low species diversity and heavily polluted water (Figure 3).

Dominance index values ranged from 0.067 to 0.984 with the highest average value during the four seasons at (S9) of 0.955, which showed high dominance and the lowest at (S4) of 0.093, which showed low dominance. Dominance was low at stations (1,2,3,4,5,6 and 7), moderate at stations (8,10) and high at station (9) as shown in figure (4).

Table4. Seasonal variations of microalgal groups abundance (no x 10^5 cell/L) during the study period at the different stations.

Microalgal group		Stations									
	Seasons	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
		Cell no x 10^5 L^{-1}									
Cyanophyta	Aut.	330	326	1471	1361	103.5	515	377	36	32	38
	Win.	430	345	513	968	87.5	515	377	40	32	38
	Spr.	360	501	593	814	202	1030	602	48	48	76
	Sum.	403	483	446	828	148	876	667	840	53	88
Chlorophyta	Aut.	129	89.3	1195	246	1692	122	38	1729	4169	230
	Win.	138	90	381	136	556	122	38	1206	6465	120
	Spr.	341	264	3315	158	1073	244	75	1047	3073	59
	Sum.	413	271	4265	169.5	4955	244	92	461	1416	64
Bacillariophyta	Aut.	147	70	83	541	10	50	66	114.5	15	1
	Win.	176	54	79	164	10	48	59	90	11	1
	Spr.	146	60	95	106	11	44	255	56	11	2
	Sum.	128	51	70.5	92	11	42	43	37	10	2.3
Euglenophyta	Aut.	11	24	50	47	-	-	2.5	-	-	-
	Win.	12	24	140	30	-	-	2.2	-	-	-
	Spr.	17	37	48	30	-	-	2	-	-	-
	Sum.	16	25	31	29	-	-	2	-	-	-
Dinophyta	Aut.	2	6	20	10	-	-	-	72	3	-
	Win.	2	8	50	8	-	-	-	61	3	-
	Spr.	3	10	99	7	-	-	-	40	3.3	-
	Sum.	3	6	70	7	181	-	-	23	3.3	-
Cryptophyta	Aut.	1	1	1	1	-	1	-	-	-	-
	Win.	1	1	1	1	-	1	-	-	-	-
	Spr.	3.3	6	5	3.3	-	2	-	-	-	-
	Sum.	3.3	10	5	6	-	2	-	-	-	-
Haptophyta	Aut.	-	-	-	-	50	-	-	-	-	-
	Win.	-	-	-	-	358	-	-	-	-	-
	Spr.	-	-	-	-	150	-	-	-	-	-
	Sum.	-	-	-	-	40	-	-	-	-	-

Table 5. Abundance of the common microalgal species recorded at the different stations.

Microalgal group and species	**Stations**									
	Seasons	S1	S2	S3	S4	S5	S5	S7	S8	S9	S10
Cyanophyta	**Cell no x 10^5 L^{-1}**										
Merismopedia tenuissima Lemmermann	Aut.	32	80	1232	160	32	-	-	36	32	-
	Win.	32	64	320	80	16	-	-	40	32	-
	Spr.	64	53.3	144	53	13	-	-	48	48	-
	Sum.	107	53.3	80	53	13.6	-	-	40	53.3	-
Chlorophyta											
Chlorella vulgaris	Aut.	2.5	6	847	160	-	1	-	-	-	-
	Win.	3	20	23.75	70	-	1	-	-	-	-
	Spr.	3.3	46.7	3060	26.7	-	2	-	-	-	-
	Sum.	73.3	55	4040	30	-	2	-	-	-	-
Chlorella salina Kufferath	Aut.	-	-	-	-	920	-	1	1724	4160	-
	Win.	-	-	-	-	49.5	-	1	1200	6460	-
	Spr.	-	-	-	-	358.3	-	2	1038	3067	-
	Sum.	-	-	-	-	4550	-	18.7	452	1410	-
Dunaliella salina (Dunal) Teodoresco	Aut.	-	-	-	-	-	-	-	-	-	228
	Win.	-	-	-	-	-	-	-	-	-	118
	Spr.	-	-	-	-	-	-	-	-	-	55
	Sum.	-	-	-	-	-	-	-	-	-	48
Bacillariophyta											
Stephanocyclus meneghinianus (Kützing) Kulikovskiy, Genkal & Kociolek	Aut.	2.5	21	7	210	-	2.8	3	13.5	5	-
	Win.	2.5	12	4.75	3.3	-	2.5	4	10	4	-
	Spr.	10	6.67	3	3.3	-	2	6	6	4	-
	Sum.	10	3.3	2	3	-	2	8	4	3.3	-
Euglena gracilis G.A.Klebs	Aut.	2.5	3	21	2	-	-	2.5	-	-	-
	Win.	2.5	5	109	3.3	-	-	2.2	-	-	-
	Spr.	3.3	20	9	3.3	-	-	2	-	-	-
	Sum.	3.3	10	5	3.3	-	-	2	-	-	-
Haptophyta											
Prymnesium parvum N.Carter	Aut.	-	-	-	-	50	-	-	-	-	-
	Win.	-	-	-	-	358	-	-	-	-	-
	Spr.	-	-	-	-	150	-	-	-	-	-
	Sum.	-	-	-	-	40	-	-	-	-	-
Dinophyta											
Heterocpsa sp	Aut.	-	-	-	-	-	-	-	-	-	-
	Win.	-	-	-	-	-	-	-	-	-	-
	Spr.	-	-	-	-	-	-	-	-	-	-
	Sum.	-	-	-	-	181	-	-	-	-	-

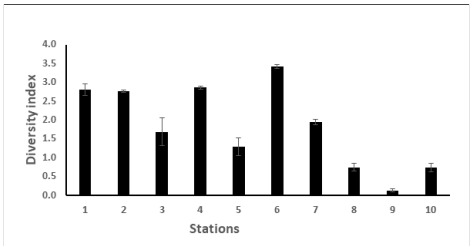

Fig. 3 Diversity index of microalgal species at the studied stations

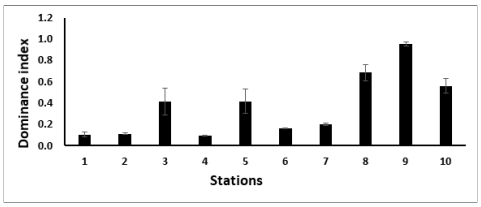

Fig. 4 Dominance index of microalgal species at the studied stations

Discussion

Surface water temperature showed remarkable seasonal variations. These variations explain the climatic conditions prevailing in Egypt (cold in winter and hot in summer). Temperature has a strong effect on the cellular composition, rate of uptake of nutrients, fixation of carbon dioxide, and growth rate for each algal species **(Li et al., 2019)**. Moreover, temperature has an effect on the microbial community structure **(Ashok et al., 2019)**.

Generally, water pH values in the studied stations, except S10, tend to be alkaline. An increase in pH values could be the effect of photosynthetic activity of microalgae and thus the consumption of carbon dioxide from water

(Gerardi, 2015). In addition, the high pH value of the water indicates the high algal productivity of the water body **(Deyab et al., 2020)**. pH was low and near to neutral side at(S10), this may be attributed to this station is a hypersaline water. This agreed with the findings of **Krumgalz (1980)** that pH value decrease in concentrated seawater.

EC is the measurement of the dissolved substances in an aqueous solution **(Perlman, 2014)**. Consequently, conductivity is correlated to total dissolved solids **(Pal et al., 2015)**. In the obtained results, TDS and EC are dependent on temperature, by increasing temperature, TDS as well as EC increases. This is attributed to the high temperature which lead to water evaporation without external continuous supply of freshwater lead to increase TDS content as stated by **Madkour (2000)**. In addition, increasing temperature increases the movement of ions and thus increases the conductivity **(Poisson, 1980)**.

The lower EC value at (S6) is attributed to the water is fresh and contains low dissolved salts whereas, the higher EC value at (S10) is attributed to the water is stagnant and contains high salts. The variation in EC values in the rest of the stations could be due to different types of pollutants that are thrown in these stations. Agricultural drainage or sewage leakage may be the main reason of the rise in water electrical conductivity due to the high inclusive concentrations of chloride, nitrate and phosphate ions **(Pal et al., 2015)**.

Salinity can affect the growth and biochemical structure of microalgae **(Maurya et al., 2014)**. The variation in water salinity of the studied stations could be attributed to soil type, as the soil of North Damietta is saline or may be saltmarshes. On the other hand, the studied stations are exposed to different types of pollutants which, in turn, can increase salinity level in water. This is an agreement with **Aziz et al., (1996)** who revealed that he industrial and urban discharges increase the water salinity. According to **Madkour (2000)**, the high value of water salinity is related to the soil nature that is affected by seawater, the high rate of evaporation due to elevated water temperature, and the absence of a continuous supply of fresh water.

Oxygen is one of the most important chemical parameters in aquatic ecosystems, due to its importance for the respiration of aerobic biota, its role in oxidation reactions, and indicates the quality of the aquatic ecosystem **(Al-Zubaidi et al., 2021)**. The minimum concentration of dissolved oxygen which encourages the growth of aquatic biota, is from 4 to 5 mg/l **(Patel and Vashi, 2015)**. The low values of dissolved oxygen in the different stations could be due to various pollutants thrown in water which encourage the growth of certain microorganisms such as blue green algae. In this regard, **Hammoumi et al. (2024)** stated that the low level of dissolved oxygen in water is attributed to the input of organic wastes.

The higher DO concentration during winter and its lower during hot seasons could be attributed to the high temperature leading to a decrease in DO concentration and vice versa. This finding agreed with the results obtained by **Koue et al. (2020)** and **Mavropoulou et al. (2020)** who reported that high temperature led to a decrease in DO concentration. In addition, **Al-Zubaidi et al. (2021)** mentioned that a decrease in DO concentration during summer was a result of increasing in TDS which was due to high temperature. As well as, during summer, the rate of biological oxidation is highly increased and can, in turn, decrease the DO content **(Patel and Vashi 2015)**. The lower oxygen concentration at (S10) could be attributed to that its water is a stagnant and hypersaline with low level of water mixing. This was in agreement with the suggestion of **Rudneva et al. (2023)** that a decrease in pH value and dissolved oxygen content was associated in high salinity in hypersaline lakes such as Saki Lake. This suggestion was explained by the negatively significant correlation between DO and salinity.

Nitrogen is an important nutrient for microalgal growth, and the growth is significantly affected by the availability, type and amount of nitrogen source. Ammonia is naturally occurring in water as a result of the biological degradation of organic matter in the process known as ammonification **(Bernhard, 2010)**. In the obtained results, the higher concentrations of ammonia at (S1) could be due to that S1 receives different types of agricultural and domestic pollutants. According to **Christensen et al., (2001)** high ammonia concentrations are often associated with anthropogenic sources such as manure leaking, sewage effluent, and leachates from landfills. In addition, the high level of ammonia might be due to the leaching of fertilizer residues used in

agriculture that are rich in nitrogenous compounds into the drains **(Abdel-Satar, 2008)**. The absence of ammonia during autumn and summer at stations 6 and 7, respectively, may be due to the utilization of ammonia by phytoplankton species. In this context, ammonium ion (NH_4^+) is preferred by microalgae and they utilize it until completely consumed **(Wang et al., 2018)**. The decrease of ammonia concentration in some stations during summer could be attributed to ammonia gas formation and thus volatilization of ammonia by increasing temperature and pH (**Huang and Shang 2006)**.

The lower nitrite concentrations in water are mainly due to it being relatively unstable and can be rapidly oxidized to nitrate as well as its consumption by plankton **(Awadallah and Moalla, 1996)**. The difference in nitrite concentration between the stations is related to the degree of water pollution as stated by **Weikert (1987)**. In this context, **Madkour (2000)** reported a positive correlation between nitrite concentration and pollution level in seawater.

The higher nitrate concentrations in all studied stations could be attributed to that nitrate is the more stable form of oxidized nitrogen **(WHO, 2016)** and the presence of different types of pollutants. In this context, **Allison et al. (2017)** stated that nitrate can be considered as an indicator of man-made pollution of surface water and groundwater. Moreover, the nitrate content is related to the nitrification process which involves the oxidation of ammonia to nitrite by ammonia-oxidizing bacteria and nitrite is further oxidized to nitrate by nitrite-oxidizing bacteria **(IARC, 2010)**.

The lower values of nitrate at (S6) may be due to low addition of pollutants as well as high nitrate uptake by phytoplankton species **(Madkour, 2000)**. The higher nitrate content at (S9) may be due to fish farm drainage that is rich in nitrogenous compounds (**Boyd, 2007)**. The decrease of nitrate content during summer could be attributed to microbial denitrification **(Qu et al., 2022)**.

Orthophosphate is the only form of phosphate that autotrophs can uptake **(Correll, 1999).** The higher O-phosphate concentration at the stations (S1, S4 and S5) this may be attributed to that these stations receive agricultural and domestic drainage. In this respect, **Boyd (2015)** reported that agricultural and municipal pollution is a main source of phosphorus to many water bodies.

The high total phosphate concentrations at the stations S1, S4 and S5 could be attributed to that these stations receive agricultural runoff and domestic input with high input of organic pollutants that increase the concentration of total phosphate **(Boyd, 2015)**.

There was a positive correlation between total phosphorus, ammonia, nitrite, and nitrate. This may be attributed to that nitrogen and phosphorus are key nutrients for growth and reproduction of living organisms **(Davis and Cornwell, 1991**).

Differences in microalgal communities are considered as benefit bioindicators of water quality, trophic status of the aquatic system as well as ecosystem health (**Abdel-Hamid & Galal 2019).** Many freshwater microalgae such as *Scenedesmus quadricauda*, and *Monoraphidium contortum* were recorded at brackish water in stations S1 and S3. This may be attributed to brackish microalgal strains of freshwater origin can adapt to low salinity level. They can maintain congruous cell growth at salinity varying between (0 to nearly 10 ppt) **(Klin et al., 2023).**

Higher growth of Cyanophyta at S3 may be due to high growth of *Merismopedia tenuissima*. The abundance of blue green algae indicates the eutrophic conditions of water bodies **(Khan et al., 2011).** The higher Chlorophyta growth at (S9) may be attributed to the high growth of *Chlorella salina*, which was the predominant species. This station is a fish farm rich by nutrients (nitrogen and phosphorus) that encourage the growth of microalgae as reported by **Enwereuzoh et al. (2021)**. *Dunaliella salina* was the predominant species at S10. This is concerned with ability of *D. salina* to grow in extremely variable salinities, from nearly 50 ‰ to saturation (**Borowitzka and Siva, 2007**).

The higher number of Bacillariophyta species at S4 may be a result of high growth of *Stephanocyclus meneghinianus* which represented 39% of total Bacillariophyta species. The presence of Bacillariophyta species such as *Stephanocyclus meneghinianus* (210×10^5 cell/L) give an evidence that water is organically polluted **(Kshirsagar and Gunale, 2011)**.

The higher growth of Euglenophyta specially *Euglena gracilis* (109×10^5 cell/L) at

S3 may be attributed to the agricultural and fish farm discharge in that station. **Krajčovič et al. (2015)** stated that *Euglena gracilis* is a freshwater flagellate found in many aquatic habitats especially shallow eutrophic ponds. Moreover, **Satpati and Pal (2017)** confirmed that different species of Euglenophyta such as *E. gracilis* can thrive in brackish water habitat. The highest growth of *E. gracilis* was during winter, which was an abnormal condition because it prefers the elevated temperature (27-30°C), but the rise in temperature due to global warming that has been recorded during daytime of winter may be the encouraging reason of such growth.

Prymnesium parvum appeared only at S5 which is a brackish water body. *P. parvum* is a unicellular haptophyte that can thrive and bloom in inshore and brackish waters **(Moestrup, 1994)**. High growth of *P. parvum* may be the reason for the decreased growth of *Chlorella* during winter at S5. It can release allelopathic compounds that can reduce the growth of the other phytoplankton. These compounds also affect some microalgal groups more than others and thus altering the community structure **(Fistarol et al., 2003)**. Presence of high concentrations of N and P due to the agricultural drainage in that station can encourage the high growth of *P. parvum* and production of its allelopathic compounds **(Granéli and Salomon, 2010).**

High diversity of microalgae at S6 indicates that it is mildly polluted. This could be concerned with this station is fresh water and is somewhat exposed to agricultural discharge. Species diversity was moderate at stations (1, 2, 4, and 7) indicates that these stations are moderately polluted. This could be attributed to that these stations are exposed to agricultural and domestic discharge. Low species diversity at (S3) and (S5) indicates that these stations are heavily polluted. This could be attributed to these stations are contaminated by agricultural and fish farm discharge. Whereas, very low species diversity at stations (8, 9and 10) indicates that stations are heavily polluted. This may be resulted from fish farm discharge at stations (8 and 9) while (S10) is a stagnant and unmixed hypersaline water pond.

From the obtained results, we can confirm that the species diversity decreases by increasing the pollution level. From another point of view, the higher of the microalgal diversity index indicates better water quality **(Gharib et al., 2011)**. We also confirmed that high species diversity coincides with low dominancy and vice versa. According to **Zakiyah et al. (2020)** who reported that higher values of dominance are congruous with lower diversity values. In addition, the obtained results suggested that increasing salinity leads to decreased species diversity. This is in agreement with **Jin (2008)** who stated that the salinization of inland waters that is related to anthropogenic activities decreases biodiversity.

Conclusions

The present study confirms the importance of microalgal usage as bioindicators for monitoring the water quality. Microalgal species diversity not only decreases by increasing the pollution degree but also by increasing salinity degree. This study recommends the continuous monitoring of water quality to ensure the balance in the aquatic ecosystem.

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الملخص العربي

عنوان البحث: : توزيع الطحالب الدقيقة وعلاقتها بجودة المياه في شمال دمياط، مصر

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يهدف البحث إلى دراسة توزيع وتنوع الطحالب الدقيقة وعلاقتها بجودة المياه في شمال دمياط، مصر. تمت دراسة التحاليل الفيزيائية والكيميائية للمياه بالإضافة إلى التحليل البيولوجي الكمي والنوعي للطحالب الدقيقة في عشر محطات (S1 إلى S10) من خريف ٢٠٢١ إلى صيف ٢٠٢٢. تراوحت قيم الملوحة من ٤, جم/لتر عند سد نهر النيل (S6) إلى ٤٠٠ جم/لتر عند بركة الديبة (S10.). وتم تسجيل أعلى تركيز للأمونيا والنيتريت (٣,٧ مجم /لتر، ٥, مجم/لتر على التوالي) عند S1، بينما تم تقدير أعلى تركيز للنترات (٥,٣٧ مجم/لتر) عند S9. وعلى الرغم من أن قيم الفسفور المتاح كانت قليلة، إلا أن قيم الفسفور الكلي كانت مقبولة. كما تم تسجيل ١٣٧ نوعا من الطحالب الدقيقة تنتمي إلى سبعة مجموعات من الطحالب. وأوضحت قيم دليل التنوع إلى أن المياه عند نهر النيل (S6) كانت خفيفة التلوث بينما كانت شديدة التلوث في المحطات S3,S5,S8,S9, S10 . وأكدت النتائج أن تنوع الأنواع الطحلبية يقل بزيادة كلا من درجة التلوث والملوحة. كما أكدت النتائج أن التنوع العالي للأنواع يتوافق مع انخفاض سيادة الأنواع.