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Phytoplankton abundance and structure as indicator of water quality in the drainage system of the Burullus Lagoon, southern Mediterranean coast, Egypt

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Abstract This study represents the first detailed account of phytoplankton community structure and seasonal succession in eight drain sites and the Brimbal Canal influx into the Burullus Lagoon. The phytoplankton characteristics were studied based on the data collected seasonally over 4 years, from summer 2012 to spring 2016. Various indices such as Palmer's and Shannon's biotic indices were used for the assessment of the water quality of the different drains. There were a total of 194 species belonging to 65 genera and 6 groups: Bacillariophyceae (76 species), Chlorophyceae (59 species), *Cyanophyceae* (30 species), Euglenophyceae (25 species), Dinophyceae (3 species), and Xanthophyceae (1 species). The phytoplankton community was dominated with diatoms, green algae, and euglenoids such as *Cyclotella*, *Scenedesmus*, *Navicula*, *Nitzschia*, *Ankistrodesmus, Chlorella*, and *Euglena*. Maximum and minimum phytoplankton abundance was recorded at the Brimbal Canal and Hooks Drain. Maximum and minimum species diversities (H') were found at the Hooks Drain (2.564) and Burullus Drain (2.055). Species evenness fluctuated between 0.595 (Burullus Drain) and 0.750 (West Burullus Drain). The total score of algal genus pollution index and the algal species pollution index at the different drains showed that Drain 7 and the West Burullus Drain had moderate pollution, and the total score of the other drains were greater than 20 indicating the confirmed high organic pollution. Thus, the present investigation can be considered an attempt to use the phytoplankton community as a bioindicator of organic pollution.

Introduction

Algae are valuable indicators of ecosystem conditions because they respond quickly, both in species composition and densities, to changes in water conditions. Chemical analyses of water provide a good indication of the quality of the aquatic systems but do not necessarily reflect the ecological state of the system (Karr et al., 2000). Phytoplanktons have a short life-span and respond quickly to environmental changes (Zębek, 2004), and therefore, it may be a useful indicator to determine the quality of water and to provide early warning signs of deteriorating conditions (Bhatt et al., 1999; Saha et al., 2000; Dwivedi and Pandey, 2002; Ingole et al., 2010). The density and the diversity of phytoplankton were undertaken by several scientists as biological indicators for evaluating water quality and the degree of eutrophication, e.g., Adoni et al. (1985); Chaturvedi et al. (1999); Ponmanickam et al. (2007); Shekhar et al. (2008).

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The Burullus Lagoon is the second largest of the Nile Delta coastal lagoons, occupying a central position along the Mediterranean Nile Delta coast of Egypt, at the eastern side of Rosetta Nile Branch. The lagoon lies between longitude 30° 30′ and 31° 10′ E and latitude 31° 21′ and 31° 35′ N (Fig. 1). Now, the lagoon is under continuous stress due to the increasing urban and industrial activities that influence the water quality of the drain discharges into it. There are several studies on the physicochemical and biological characterization of the Burullus Lagoon by different authors, but studies on the water quality of the drains, which feed this lagoon, are missing dramatically. Indeed, understanding the phytoplankton status, abundance, community structure, diversity indices, and Palmer's algae pollution indices can help to know the water quality of these drained waters.

Accordingly, the goal of this study was to achieve following targets: (i) assess seasonal variation, community structure, species richness, species diversity, and species evenness of phytoplankton in eight drains and a canal discharging into the Burullus Lagoon; (ii) assess the Palmer index to determine the level of organic pollution in the different drains and in the Brimbal Canal; and (iii) examine the potential use of phytoplankton as bioindicator of pollution in the sampling stations.

Materials and methods

Description of study area

The Burullus Lagoon consists of three basins: eastern, central, and western. The western basin receives fresh Nile water from the Brimbal Canal, West Burullus Drain, and Hooks Drain. The central basin receives the drainage water from two agricultural drains, Drain 8 and Drain 9. Lastly, the eastern basin receives drainage water from four drains named the Burullus Drain, Kitchinar Drain, Teera Drain, and Drain 7. The Teera Drain, Drain 7, Drain 8, Drain 9, and Hooks Drain are located in the southern margin of the Lagoon; the Burullus Drain is at the northeastern side; the Kitchinar Drain is at the southeastern side; the West Burullus Drain is at the northwestern side; and the Brimbal Canal, derived from the Rosetta Nile branch, is situated at the western side of the Lagoon (Fig. 1). These drains discharge wastewater of approximately 3904 million cubic meters per year, including agricultural, industrial, and

domestic wastewater (Abayazid and Al-Shinnawy, 2012).

Methods

During the period from summer 2012 to spring 2016, samples were collected seasonally from surface water for quantitative and qualitative phytoplankton analysis (16 cruises with nine sites) using Ruttiner bottle. Water samples were preserved by Lugol's solution. Phytoplankton samples were counted and identified using 2-ml settling chambers with a Nikon TS 100 inverted microscope at ×400 magnification using the Utermöhl method (Utermöhl, 1958), and the population density was expressed as cells/milliliter. Qualitative and quantitative plankton analyses were done up to the genus, and planktonic organisms were numerically counted, identified, and confirmed by the following handbooks and publications (El-Nayal, 1935, 1936; Khunnah, 1967; Huber Pestalozzi, 1938; Starmach, 1983; and Heurck, 1896).

Statistical analysis

For the analysis of water quality, different qualitative (Palmer 1969) and quantitative (species richness (d), species diversity (H'), and evenness or equitability (J)) indices were calculated using the diversity submodule of the PRIMER package (Xu et al., 2008). Spearman's rank correlation coefficients (r) were calculated using a Minitab program.

Palmer (1969) proposed a pollution index based on algal genus and species used in the rating water sample for high or low organic pollution. He collected information on pollution-tolerant algae compiled from reports from 165 authors, the genera and species most often referred to as significant fall into a relatively stable series. The pollution-tolerant genera and species of algae were recorded from selected sampling stations. When phytoplankton analysis shows that the alga genera are present at a density of 50 or more cells in a 1-ml sample, their index value is recorded. The algae are assigned a pollution index value of 1–6. Following analysis, the values are totaled. A list of most pollution-tolerant genera and species according to the Palmer's index was calculated for all sampling stations. A pollution index factor was assigned to each genus and species by determining the relative number of total points scored by each alga.
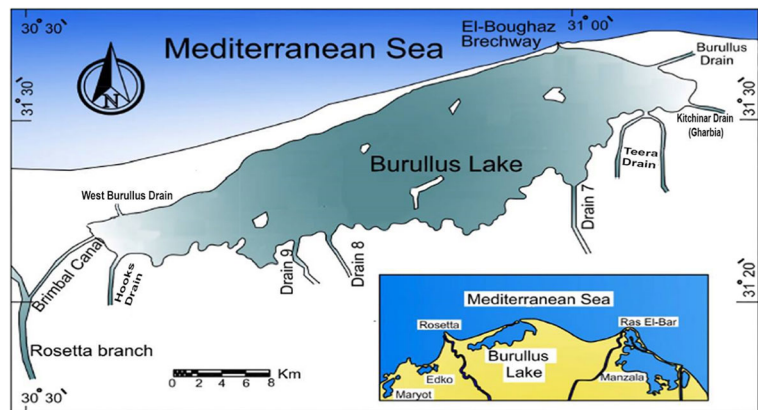
Following numerical values for pollution classification of Palmer (1969),

0–10 indicated lack of organic pollution.

11–15 indicated moderate pollution.

16–20 indicated probable high organic pollution.

21 or more confirms high organic pollution.

Results

Phytoplankton community structure and composition

Over the 4-year study period, a total of 194 phytoplankton species were quantified through the analysis of the 141 samples collected from nine drains in 16 seasons, during the period from summer 2012 to spring 2016. Bacillariophyceae presented the highest number (24 genera, 76 species) followed by Chlorophyceae (21 genera, 59 species). There were a remarkably low numbers of Cyanophyceae (13 genera, 30 species) and Euglenophyceae (3 genera, 25 species). Dinophyceae and Xanthophyceae were represented by 3 and 1 species, respectively. Furthermore, the genera rather rich in species number were *Navicula* (17 species), *Nitzschia* (16 species), *Euglena* (16 species), *Scenedesmus* (10 species), and *Oscillatoria* (8 species). Among the most abundant group, qualitatively (39.18 %) and quantitatively (48.15 %) was Bacillariophyceae. Chlorophyceae came second in importance as it constituted 35.75 % of the total phytoplankton densities and 30.41 % of the total phytoplankton diversity.

High diversities (130 and 129 species) were recorded at the Hooks Drain and Burullus Drain. While the West Burullus Drain had 126 species, 123 species were recorded at Drain 9 and the Brimbal Canal.

Approximately similar numbers of species (115–116 species) were recorded at the Teera Drain and Kitchinar Drain, while a conspicuously smaller number (110 and 111 species) were found at Drain 8 and Drain 7. The numbers of phytoplankton species recorded during 2012–2013, 2013–2014, 2014–2015, and 2015–2016 were 137, 126, 128, and 119, respectively, and the maximum number of species number in a single sample was 47, at Drain 9 during spring 2013. The numbers of taxa found in the different sites over 4 years within individual phytoplankton classes were dissimilar (Table 1).

Cyclotella and *Nitzschia* genera from Bacillariophyceae were particularly vastly represented as well as *Scenedesmus* and *Crucigenia* genera from Chlorophyceae. Cyanophyceae was dominated by *Oscillatoria* spp. and Euglenophyceae by *Euglena*. Many species of the community were rare, having a negligible frequency of occurrence, but they were very important because they controlled the levels of species diversity.

Over the 4-year period of the study, mean phytoplankton density was higher in the Brimbal Canal (1805 ± 2074 cells/ml) and Drain 8 (1009 ± 1174 cells/ml), while lower values were recorded in the Hooks Drain (428 ± 267 cells/ml) and West Burullus Drain (479 ± 494 cells/ml). The spatial differences between the different drains were most pronounced during the study period. Bacillariophytes were of a quite high importance in the Burullus Drain (82.83 %) and to less extent in the West Burullus Drain (52.78 %), Drain 9 (49.76 %), Teera Drain (47.26 %), and Brimbal Canal (44.19 %). Chlorophyceae dominated the community in the Kitchinar Drain (50.06 %), Drain 7 (47.97 %), and Drain 8 (44.42 %).

Table 1 Number of species and genera observed in each algal division in the different drains from summer 2012 to spring 2016

Drain group	Drain 7		Drain 8		Drain 9		Burullus Drain		Kitchinar Drain		Teera Drain		Hooks Drain		West Burullus Drain		Brimbal Canal	
	Species	Genus	Species	Genus	Species	Genus	Species	Genus	Species	Genus	Species	Genus	Species	Genus	Species	Genus	Species	Genus
Chlorophyceae	41	17	37	17	46	18	35	15	38	16	40	18	44	19	38	15	44	18
Bacillariophyceae	33	11	35	12	34	13	58	18	39	13	33	13	38	15	49	18	36	16
Cyanophyceae	21	9	20	7	22	10	19	7	19	7	24	10	27	11	21	8	23	10
Euglenophyceae	15	3	17	3	19	3	15	3	19	3	17	3	19	3	17	3	18	3
Dinophyceae	1	1	1	1	1	1	2	2	1	1	1	1	2	2	1	1	1	1
Xanthophyta	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1
Total	111	41	110	40	123	46	129	45	116	40	115	45	130	50	126	45	123	49

Cyanophyceae appeared in obvious numbers in the Brimbal Canal (16.14 %) and Hooks Drain (13.04 %) and with less frequency in the other drains (1.46–5.30 %). Euglenophyceae was more abundant in Drain 8 and Drain 9 (10.79 and 12.08 %, respectively) and ranged only between 0.84 and 7.49 % in the other drains (Fig. 2). Dinophyceae and Xanthophyceae were minor groups. The top of ten dominant phytoplankton species, sampled from summer 2012 to spring 2016, and their percentage to the average phytoplankton in the different drains are illustrated in Table 2.

The species diversity indices of phytoplankton are shown in Table 3. The lowest and highest species diversities (H') were 0.906 (Burullus Drain, summer 2014) and 3.175 (Hooks Drain, winter 2015). The species evenness (J) varied between 0.257 (Burullus Drain) in summer 2014 and 0.946 (Kitchinar Drain) in winter 2016. The species richness (d) fluctuated between 0.890 (Drain 7) in summer 2012 and 3.428 (Hooks Drain) in winter 2013.

Testing the diversity-equitability, diversity-species number, and diversity-richness relationship showed that diversity was considerably influenced by species evenness ($r = 0.926$, $p < 0.001$), species number ($r = 0.468$, $p < 0.001$), and species richness ($r = 0.577$, $p < 0.001$) and exhibited negative significant relation with phytoplankton abundance ($r = -0.326$, $p < 0.001$). Equitability had a negative relationship with species numbers ($r = -0.424$, $p < 0.001$).

Seasonal variations of phytoplankton

Over the 4-year study period, the phytoplankton communities consisted mainly of Bacillariophyceae and Chlorophyceae, even if their contribution to the composition of the community in terms of abundances was different at the different drains, formed, respectively, 48.15 and 35.75 % of the total abundance. Phytoplankton abundance decreased in the drains discharged into the eastern basin (Burullus-Kitchinar-Teera) during the sequence years to reached the lowest counts during 2015–2016. The same observation was recorded among drains discharged into the middle basin, but with abrupt drop in the density during the third year (2014–2015) followed by an obvious increase during 2015–2016. As for the drains and canal that connected the western lagoon basin, phytoplankton density in the Hooks Drain decreased gradually during the sequence years to reach the lowest count during the fourth year, but in the West

Burullus Drain and Brimbal Canal, phytoplankton densities showed the lowest counts during 2014–2015.

The annual variation of phytoplankton abundance and the dominating phytoplankton groups differ over the nine drainage basins (Fig. 3a, b).

In year 2012–2013, a total of 137 species of phytoplankton were recorded, of which 47 species belonged to Bacillariophyceae and Chlorophyceae, 25 species to Cyanophyceae, 17 to Euglenophyceae, and only 1 species belonged to Dinophyceae. Phytoplankton abundance average was 910 ± 1589 cells/ml: Bacillariophyceae (43.81 %) was the dominant group, followed by Chlorophyceae (35.51 %) and Cyanobacteria (16.26 %). The lowest count of 238 cells/ml was recorded in Drain 7, while the highest of 2935 cells/ml was in the Brimbal Canal. Bacillariophyceae dominated the community in all sites (38.9–69.1 %) except of Drains 7, 8, and Teera, where Chlorophyceae was dominant (47.7–60.9 %). Two centric diatoms: *Cyclotella meneghiniana* Kützing, 1844, and *Cyclotella glomerata* H. Bachmann, 1911, and three pennate diatoms: *Ceratoneis closterium* Ehrenberg, 1839, *Placoneis placentula* (Ehrenberg) Mereschkowsky, 1903, and *Nitzschia palea* (Kützing) W. Smith, 1856, were the dominant diatom species, besides colonial genera: *Scenedesmus* and *Pediastrum* from Chlorophyceae. The previous species, co-dominant with *Crucigenia* spp., *Placoneis placentula*, and *Oscillatoria* spp. constituted the main components at the Brimbal Drain. *Actinastrum hantzschii* Lagerheim, 1882, and *Crucigenia* spp. were the dominant at Drain 8 during summer. *Cyclotella meneghiniana*, *Aulacoseira granulata* (Ehrenberg) Simonsen, 1979, and *Scenedesmus* spp. were high in the Kitchinar and Hooks Drains during spring.

In year 2013–2014, a total of 126 species of phytoplankton were recorded, of which 42 species belonged to Bacillariophyceae, 43 to Chlorophyceae, 21 to Cyanophyceae, and 18 to Euglenophyceae. Dinophyceae and Xanthophyceae were represented by one species each. Phytoplankton abundance average was 975 ± 922 cells/ml: Bacillariophyceae (59.05 %) was the dominant group, followed by Chlorophyceae (30.32 %) and Cyanobacteria (4.47 %). The lowest counts of 535 cells/ml were recorded in the Hooks Drain, while the highest of 1665 cells/ml were recorded in Drain 9. Bacillariophyceae dominated the community in all sites (49.21–79.81 %) except in the Kitchinar Drain, in which Chlorophyceae was the dominant (53.59 %). *Cyclotella meneghiniana*, *Cyclotella glomerata*, and *Nitzschia palea* were the dominant diatom species. The most abundant chlorophytes were *Scenedesmus quadricauda* Chodat, 1926, *Acutodesmus obliquus* (Turpin) Hegewald & Hanagata, 2000, *Chlorella vulgaris* Beyerinck [Beijerinck], 1890, and *Willea rectangularis* (A. Braun) D. M. John, M. J. Wynne & P. M. Tsarenko, 2014. The previous species, co-dominant with *Coelastrum microporum* Nägeli, 1855, constituted the main components during autumn at Drain 7 *Monoraphidium mirabile* (West & G.S. West) Pankow, 1976, *W. rectangularis*, and *Acutodesmus acuminatus* (Lagerheim) Tsarenko, 2001, during spring at Drain 9, filamentous Cyanobacteria *Oscillatoria irrigua* Kützing ex Gomont, 1892, during spring at the Hooks Drain, *Staurogenia tetrapedia* Kirchner, 1880, *Oocystis borgei* J.W. Snow, 1903, and *Acutodesmus acuminatus* during spring at the West Burullus Drain.

In year 2014–2015, a total of 128 species of phytoplankton were recorded, of which 42 species belonged to Bacillariophyceae, 44 to Chlorophyceae, 22 to
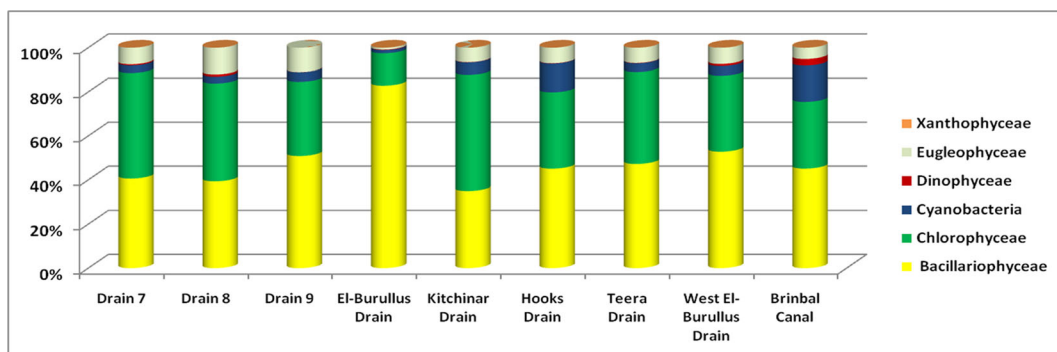

Fig. 2 Percentage contribution of phytoplankton and main algal groups in the different drains over 4-year period

Table 2 Top ten dominant phytoplankton species sampled from summer 2012 to spring 2016 and their percentage to the average phytoplankton in the different drains

Drain 7	Percentage	Drain 8	Percentage	Drain 9	Percentage
Cyclotella meneghiniana	27.79	*Cyclotella meneghiniana*	26.35	*Cyclotella meneghiniana*	42.10
Acutodesmus obliquus	14.36	*Scenedesmus quadricauda*	6.78	*Scenedesmus quadricauda*	8.12
Scenedesmus quadricauda	6.37	*Cyclotella glomerata*	6.73	*Euglenaria caudata*	3.23
Cyclotella glomerata	5.83	*Crucigenia quadrata*	6.36	*Cyclotella glomerata*	3.31
Schroederia setigera	4.09	*Euglena viridis*	3.92	*Willea rectangularis*	2.64
Coelastrum microporum	3.55	*Actinastrum hantzschii*	3.91	*Staurogenia tetrapedia*	2.35
Ankistrodesmus falcatus	3.41	*Willea rectangularis*	3.79	*Acutodesmus obliquus*	1.88
Euglenaria caudata	2.49	*Acutodesmus obliquus*	3.42	*Pectinodesmus javanensis*	1.63
Staurogenia tetrapedia	2.34	*Euglenaria caudata*	2.98	*Nitzschia palea*	1.63
Acutodesmus acuminatus	1.91	*Acutodesmus obliquus*	2.98	*Padiastrum duplex*	1.53
Hooks Drain	**Percentage**	**Teera Drain**	**Percentage**	**West Burullus Drain**	**Percentage**
Cyclotella meneghiniana	23.67	*Cyclotella meneghiniana*	27.74	*Cyclotella meneghiniana*	34.75
Aulacoseira granulata	6.40	*Cyclotella glomerata*	12.44	*Scenedesmus quadricauda*	7.36
Scenedesmus quadricauda	5.53	*Scenedesmus quadricauda*	7.63	*Chlorella vulgaris*	5.07
Nitzschia palea	4.78	*Coelastrum microporum*	4.62	*Willea rectangularis*	4.66
Pediastrum duplex	4.45	*Nitzschia palea*	3.35	*Crucigenia quadrata*	3.92
Oscillatoria irrigua	3.47	*Staurogenia tetrapedia*	3.01	*Nitzschia palea*	3.67
Schroederia setigera	3.32	*Willea rectangularis*	2.98	*Cyclotella glomerata*	2.82
Oscillatoria simplicissima	3.21	*Euglenaria caudata*	2.84	*Bacillaria paxillifera*	2.53
Cyclotella glomerata	3.18	*Acutodesmus obliquus*	2.38	*Staurogenia tetrapedia*	2.08
Pediastrum simplex	2.90	*Actinastrum hantzschii*	2.33	*Euglenaria caudata*	1.73
Burullus Drain	**Percentage**	**Kitchinar Drain**	**Percentage**	**Brimbal Canal**	**Percentage**
Cyclotella glomerata	39.53	*Cyclotella meneghiniana*	27.32	*Cyclotella meneghiniana*	24.33
Cyclotella meneghiniana	25.72	*Scenedesmus quadricauda*	10.19	*Phormidium breve*	14.04
Nitzschia palea	4.68	*Cyclotella glomerata*	6.98	*Ceratoneis closterium*	12.44
Bacillaria paxillifera	3.75	*Willea rectangularis*	6.00	*Cyclotella glomerata*	7.45
Scenedesmus quadricauda	2.79	*Acutodesmus obliquus*	5.75	*Scenedesmus quadricauda*	6.20
Acutodesmus obliquus	2.76	*Staurogenia tetrapedia*	3.84	*Gymnodinium* sp.	2.87
Ceratoneis closterium	2.33	*Ankistradesmus falcatus*	3.06	*Willea rectangularis*	2.25
Diploneis elliptica	1.48	*Acutodesmus obliquus*	2.97	*Actinastrum hantzschii*	1.93
Schroederia setigera	1.37	*Acutodesmus acuminatus*	2.90	*Chlorococcum* sp.	1.93
Scenedesmus arcuatus	0.88	*Pectinodesmus javanensis*	2.52	*Ankistrodesmus falcatus*	1.79

Cyanophyceae, and 17 to Euglenophyceae. Dinophyceae was represented by 3 species. Phytoplankton abundance average was 871 ± 1100 cells/ml, of which Bacillariophyceae was the dominant group (49.94 %), followed by Chlorophyceae (37.87 %) and Euglenophyceae (8.09 %). Cyanobacteria (3.30 %) and Dinophyceae (0.80 %) were frequently recorded. The lowest counts of 376 cells/ml were recorded in the Hooks Drain, while the highest of 1518 cells/ml were recorded in the Burullus Drain. Bacillariophyceae dominated the community in Drain 8, the Burullus Drain, West Burullus Drain, and Brimbal Canal (38.08–92.03 %), while the community was dominated by Chlorophyceae in Drains 7, 9, Kitchinar, Hooks, and Teera (48.90–56.29 %). Cyanobacteria fluctuated between 0.42 and 4.96 % of the total density, except for Drain 8 and the Hooks Drain, which showed increasing numbers of Cyanobacteria (7.59–9.10 %). *Cyclotella meneghiniana* and *Cyclotella glomerata* were the dominant diatom species. Other coccal chlorophytes were present such as *Scenedesmus quadricauda*, *Acutodesmus obliquus*, *W. rectangularis*, *Staurogenia*

Table 3 Diversity indices of phytoplankton in the different drains

Diversity index	Years	Drain 7	Drain 8	Drain 9	Burullus Drain	Kitchinar Drain	Hooks Drain	Teera Drain	West Burullus Drain	Brimbal Drain
Shannon–Weiner index		H'	H'	H'	H'	H'	H'	H'	H'	H'
	2012–2013	2.014	2.146	2.409	2.147	2.282	2.588	2.523	2.364	2.077
	2013–2014	1.732	1.999	1.946	1.998	2.240	2.331	2.127	2.439	1.897
	2014–2015	2.597	2.568	2.696	1.832	2.730	2.605	1.572	2.796	2.057
	2015–2016	2.522	2.578	2.624	2.230	2.562	2.730	2.279	2.609	2.549
Species evenness		J	J	J	J	J	J	J	J	J
	2012–2013	0.623	0.665	0.669	0.656	0.649	0.722	0.706	0.700	0.577
	2013–2014	0.531	0.639	0.570	0.552	0.675	0.657	0.614	0.761	0.556
	2014–2015	0.737	0.776	0.765	0.514	0.772	0.742	0.738	0.818	0.646
	2015–2016	0.762	0.773	0.750	0.649	0.837	0.782	0.682	0.720	0.721
Species richness		D	D	D	D	D	D	D	D	D
	2012–2013	2.053	1.909	2.717	2.134	2.439	2.718	2.603	2.231	2.371
	2013–2014	1.889	1.683	2.18	2.647	2.025	2.581	2.223	1.98	2.102
	2014–2015	2.467	2.082	2.516	2.489	2.591	2.512	2.335	2.385	1.836
	2015–2016	2.003	1.988	2.417	2.320	1.830	2.592	2.037	2.867	2.344
Number of species		N	N	N	N	N	N	N	N	N
	2012–2013	26.0	27.5	37.7	27.5	33.8	36.5	36.0	29.5	35.0
	2013–2014	26.5	23.3	30.5	38.0	28.5	34.5	31.5	26.0	30.8
	2014–2015	34.0	28.0	34.5	34.8	34.8	33.0	33.5	31.3	25.0
	2015–2016	27.5	28.0	33.5	31.3	23.5	33.25	28.5	37.5	34.3
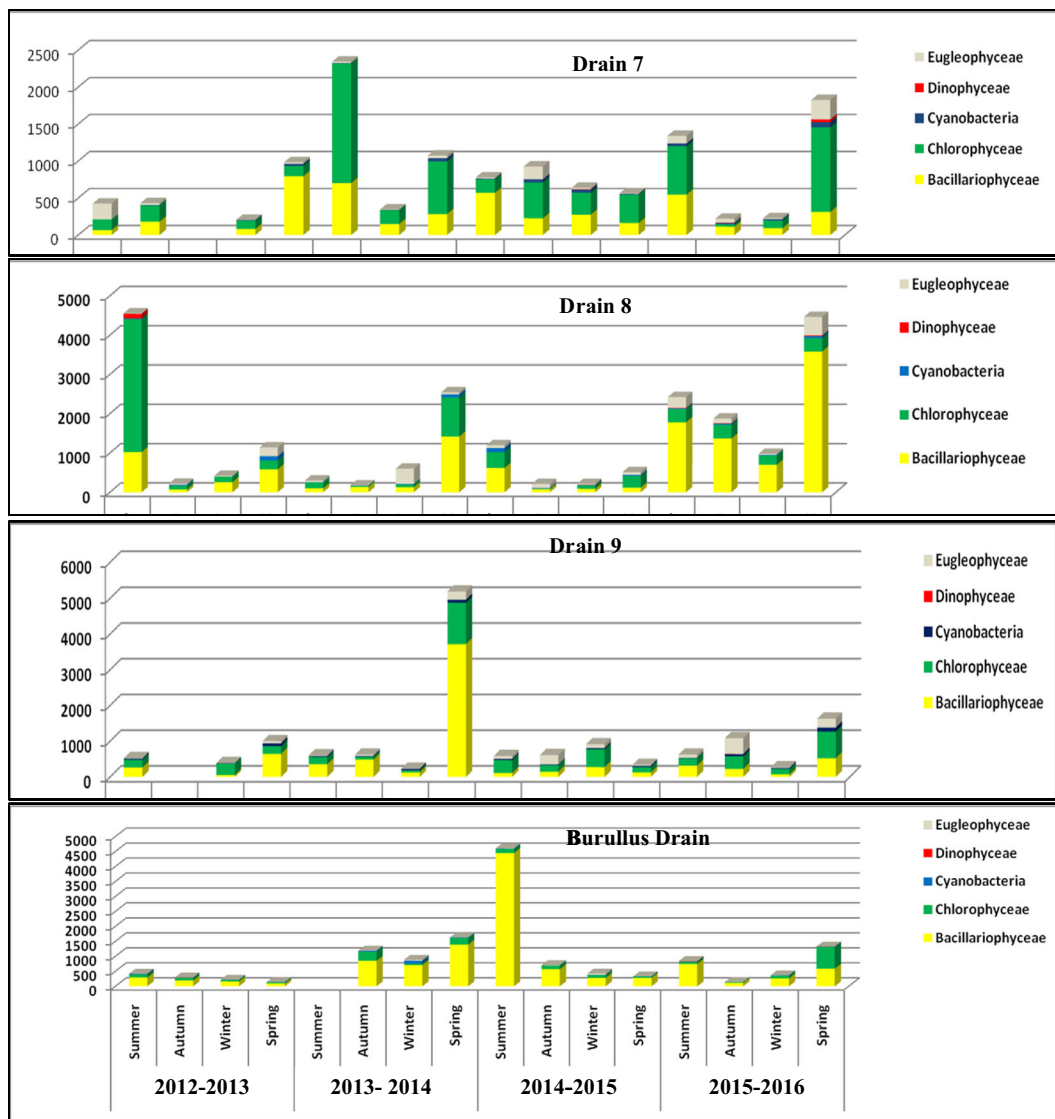
Fig. 3 **a** Seasonal variations of phytoplankton abundance (cells/ml) subdivided by algal groups of the different drains from summer 2012 to spring 2016. **b** Seasonal variations of phytoplankton abundance (cells/ml) subdivided by algal groups of the different drains from summer 2012 to spring 2016

tetrapedia, and *Actinastrum hantzschii* Lagerheim, 1882. The previous species, co-dominant with *Nitzschia palea* and constituted the main components during summer at the Burullus Drain, are *Ankistrodesmus* spp., *Crucigenia* spp., *Scenedesmus* spp., and *Merismopedia punctata* Meyen, 1839, during summer at the Kitchinar Drain, *Actinastrum hantzschii*, *Coelastrum microporum* Nägeli, 1855, and *Monactinus simplex* (Meyen) Corda, 1839, during summer at the Teera Drain; *Nitzschia* spp., *Synedra ulna* (Nitzsch) Ehrenberg, 1832, *Chlorella vulgaris*, *Microcystis aeruginosa* (Kützing) Kützing,

1846, *Gymnodinium* sp., and *Euglena* spp. during autumn at the West Burullus Drain; and *Gomphonema longiceps* var. *subclavatum* Grunow, 1878, *Navicula gracilis* Ehrenberg, 1832, *Ankistrodesmus* spp., *Microcystis aeruginosa*, *Gymnodinium* sp., and *Euglenaria caudata* (Hüber) A. Karnowska-Ishikawa, E. Linton & J. Kwiatowski, 2010, during winter at the Brimbal Canal.

In year 2015–2016, a total of 119 species of phytoplankton were recorded, of which 42 species belonged to Bacillariophyceae, 37 species to Chlorophyceae, 23
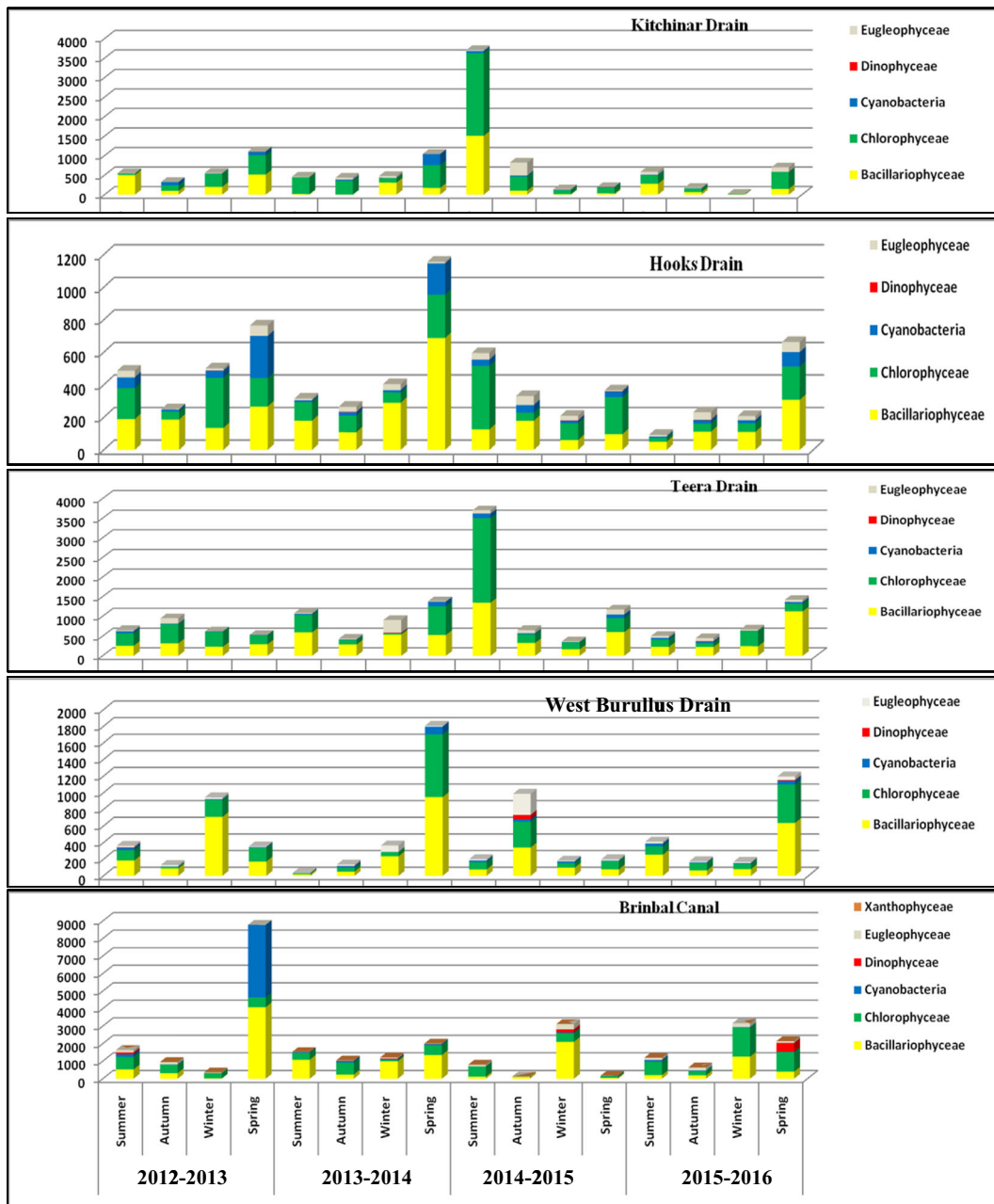
Fig. 3 continued.

species to Cyanophyceae, and 16 to Euglenophyceae. Dinophyceae was represented by 1 species. Phytoplankton abundance average was 801 ± 707 cells/ml, in which Chlorophyceae was the dominant group (41.78 %), followed by Bacillariophyceae (40.48 %) and Euglenophyceae (11.90 %). Cyanobacteria (3.63 %) and Dinophyceae (2.17 %) were frequently recorded.

The lowest counts of 299 cells/ml were recorded in the Hooks Drain, while the highest counts of 1786 cells/ml were recorded in the Brimbal Canal. Bacillariophyceae dominated the community in Drain 8, the Burullus Drain, Hooks Drain, Teera Drain, and West Burullus Drain (42.92–63.86 %), while the community was dominated by Chlorophyceae in Drains 7, 9, Kitchinar, and

the Brimbal Canal (40.15–53.43 %). Euglenoids were third in importance forming between 0.57 and 22.27 % of the total density. Cyanobacteria and Dinophyceae were frequently represented, with increasing numbers of Cyanobacteria in the Hooks Drain (11.47 %). *Cyclotella meneghiniana* and *Cyclotella glomerata* were the dominant diatom species, and *Scenedesmus quadricauda*, *Acutodesmus obliquus*, *Schroederia setigera* (Schröder) Lemmermann, 1898, *Chlorococcum* sp., and *Chlorella vulgaris* from Chlorophyceae. The previous species, co-dominant with *Navicula gracilis*, *Synedra ulna* (Nitzsch) Ehrenberg, 1832, *Ankistrodesmus* spp., and *Coelastrum microporum* Nägeli, 1855, were most abundant in summer and spring at Drain 7; *Tryblionella apiculata* Gregory, 1857, *Synedra ulna*, *Ankistrodesmus* spp., *W. rectangularis*, and *Scenedesmus* spp. during summer and spring at Drain 8; *Nitzschia* spp., *Crucigenia quadrata* Morren, 1830, *Chlamydocapsa planctonica* (West & G.S. West) Fott, 1972, *Pediastrum simplex* Meyen, 1829, *Planktosphaeria gelatinosa* G.M. Smith, 1918, *Chroococcus dispersus* (Keissler) Lemmermann, 1904, *Oscillatoria irrigua*, and *Euglena* spp. during spring at the Hooks Drain; *Bacillaria paxillifera* (O.F. Müller) T. Marsson, 1901, *Nitzschia* spp., *Ankistrodesmus* spp., *Anabaena tanganyikae* G.S. West, 1907, *Monoraphidium irregulare* (G.M. Smith) Komárková-Legnerová, 1969, *O. irrigua*, and *Euglena* spp. were most abundant in spring at the West Burullus Drain.

Palmer's index of pollution was calculated at the different basin sites in order to rate water samples as high or low in organic pollution. While Drain 7, the Burullus Drain, and West Burullus Drain rated between moderate and probable high organic pollution, the other sites rated a pollution score list of more than 20, indicating a high rate of organic pollution therein. The total score at the Brimbal Canal (29) was greater than that at the Kitchinar Drain (26) and Drain 8 (25) (Fig. 4). Of the reported algal indicator genera, *Ankistrodesmus*, *Cyclotella*, *Euglena*, and *Secnedesmus* were dominantly observed at all study sites.

Discussion

Algae are one of the mainly rapid detectors of water pollution, because they have a short life-span and are extremely responsive to change in the environment (Ingole et al., 2010; Zębek, 2004). Diversity, distribution, abundance, and variation of phytoplankton provide information on the aquatic systems (Shinde et al., 2011). Hence, for any scientific use of water resources, phytoplankton study is of primary interest and should be a good indicator of the conditions prevailing in the aquatic environment and can be used as bioindicators to monitor eutrophication, pollution, and water quality (Round, 1984).

The Burullus Lagoon is subjected to great modifications because it is closely associated with drainage water driven through eight drains beside the Brimbal Canal. These drainage waters are subjected to multiple sources of contamination like metals, toxic industrial waste products, and agricultural water containing huge amount of fertilizers, which eradicated some sensitive fish stocks and tainted the water, even some of the fishermen suffer from skin diseases (Khalil, 2013). There are several studies on the Burullus Lagoon, the most recent of which was conducted by Nassar and
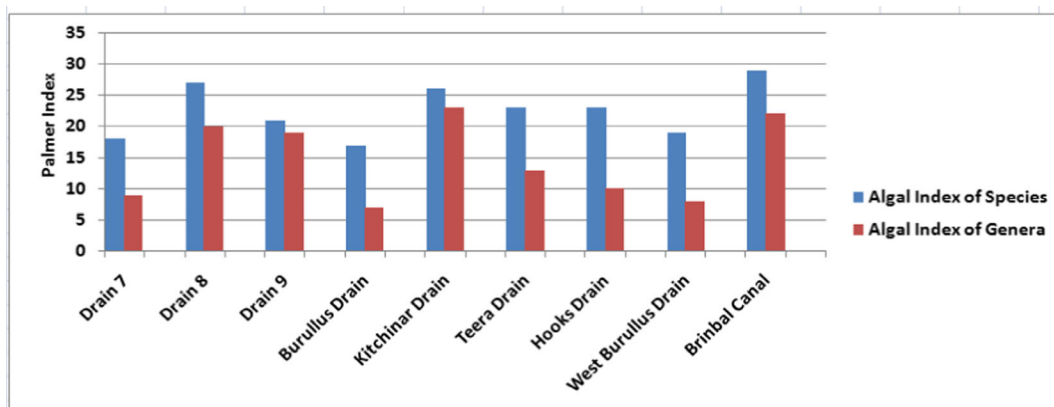
Fig. 4 Pollution index score of algal genera and species at the different sites for the period of summer 2012 to spring 2016

Gharib (2014) who found no sign of eutrophication in the Lagoon. No previous studies have been recorded in the algal flora about drain influx into the Lagoon. This study represents the first detailed account of phytoplankton communities and is based on the data collected over a period of 4 years from the nine drains surrounding the Burullus Lagoon basin, and the phytoplankton have been also used as biomonitors of organic pollution.

Phytoplankton assemblages in the present study differed among drains as a function of drainage basin characteristics but exhibited common seasonal changes related to the surrounding environmental factors over time (Shen et al., 2010), but species are mainly of fresh or in brackish water forms.

A total of 194 species of phytoplankton were recorded during the study period, showing a well-diversified taxonomy. *Cyclotella*, *Nitzschia*, and *Scenedesmus* were the dominant genera throughout the study period, whereas *Ankistrodesmus* and Euglenoids were subdominant genera; the previous genera were present at all sites on all dates.

The effect of pollutant supply on phytoplankton population structure is even more unpredictable. The relationship between nutrient enrichment and phytoplankton abundance has often been shown to be proportional (Fanuko, 1984; Pan & Subba Rao, 1997; Mozetič et al., 2008; Skejić et al., 2011). Nevertheless, the studied drains are subjected to additional multiple sources of contamination like metals and toxic industrial waste products besides the nutrient supply; these may be responsible for the reduction of both phytoplankton abundance and species diversity in the different drains over the years to reach the lowest counts during 2015–2016. The same observation was recorded in the Burullus Lagoon (Nassar and Gharib, 2014) in which about 25–50 % reduction was recorded in the phytoplankton densities between 2009 and 2013. Nassar and Gharib (2014) also studied the phytoplankton community structure in the Lagoon and registered 195, 155, and 148 taxa with phytoplankton densities of 4537, 2343, and 1144 cells/ml during 2012–2013, 2013–2014, and 2014–2015, respectively. Results of the present study revealed, on the other hand, 137, 126, 125, and 119 taxa records in the nine sites of study, with phytoplankton densities of 861, 1013, 879, and 858 cells/ml, during the years 2012–2013, 2013–2014, 2014–2015, and 2015–2016, respectively. The gradual decrease in

phytoplankton diversities and abundances may be due to the increasing pollution that causes stress, elimination of sensitive species, and increased numbers of tolerant species to make their dominance (Patrick, 1949). Other authors noted the negative consequences of increased nutrient input in terms of reduced species diversity and increased occurrences of harmful algal bloom events (Fanuko, 1984; Pan & Subba Rao, 1997; Wang et al., 2006). In general, pulsed nutrient and other pollutant inflows can influence phytoplankton abundance and control phytoplankton diversity (Arhonditsis et al., 2000; Buyukates & Roelke, 2005).

Drain sites revealed a more or less similar phytoplanktonic composition with two dominant classes (Bacillariophyceae and Chlorophyceae) but in different relative abundances. Bacillariophyceae differed between 33.27 and 82.83 %. It is well-known that diatoms are sensitive to a range of any environmental variables, and their community structure may rapidly respond to changing physical, chemical, and biological conditions in the environment (Mooser et al., 1996; Rajasegar et al., 2002). Bacillariophyceae can be used as a unique indicator for the determination and investigation of metal toxicity (Jamali et al., 2012). In the metal-polluted sites, diatom assemblages were dominated by metal-tolerant species, such as *N. palea* (Chen et al., 2013).

The number of pennate diatoms (65 species) is higher than centric diatoms (11 species). This is justified by the shallowness of the basins and resuspension of sediment and microphytobenthos (Sekadende et al., 2004).

Cyclotella meneghiniana, *Nitzschia palea*, and *Navicula gracilis* were abundant in the different basins. Nather Khan (1990) explained that these species were common and abundant in both organically enriched and non-enriched areas.

Phytoplanktons are also good indicators of healthy or clean water, since many species occur and flourish in the clean water or non-polluted water. Cryptophyceae and Chrysophyceae are reported to be indicators of clean and/or unpolluted water (Lackey, 1941). It is of interest to indicate that the two groups did not register in the present study; however, Cryptophyceae appeared in the phytoplankton samples of the Burullus Lagoon during 2009–2010 (Nassar and Gharib 2014) and totally disappeared in the subsequent years. This may be due to that Cryptophyceae is restricted to clean water and any sign

of pollutant inhibits its growth. The previous observation of Nassar and Gharib (2014) indicated that Chrysophyceae is more sensitive to pollutants than any algal groups.

Biodiversity indices were calculated using Palmer's algal index and Shannon-Wiener diversity index to know the diversity of phytoplankton and pollution status of the different drains. Three diversity indices were used to serve as indicators that the ecosystem is under the influence of pollution stress or eutrophication (Telesh, 2004). Comparing the average values of 4 years about diversity index in the different drains, it has been observed that the values varied over a narrow range (0.509), and the maximum values (> 3) were observed in the Burullus Drain (winter 2015), Brimbal Drain (summer 2012), Kitchinar Drain (winter, autumn, 2015), Hooks Drain (winter and autumn 2013 and winter and autumn 2015), and West Burullus Drain (summer 2014 and autumn 2015). Non-polluted waters are often characterized by high diversity, with large number of species and no single species dominating in numbers over others. The lowest value (1) was recorded once in the Burullus Drain during summer 2014, due to a monotonous structure in phytoplankton community or phytoplankton blooms by two species: *Cyclotella meneghiniana* and *Cyclotella glomerata* (Margalaf, 1978). Rehabilitations resulted in major ecosystem shift in a highly polluted estuary and were followed by consecutive blooms of different species (Tas et al., 2009). The common characteristic of eutrophic ecosystems is known to be the presence of few dominant species with high density (Green 1993).

Most of phytoplankton diversity index fluctuated between 2 and 3, which reflects the low pollution levels. Generally, the diversity indices showed that the drains have a more or less balanced phytoplankton community that enjoyed an even representation of several species indicating the dynamic nature of aquatic ecosystem.

Species evenness index varied from 0.257 and 0.946. These wide ranges of values coupled with their spatial and temporal variations reflecting the heterogeneity of the population that would be regularly examined by phytoplankton are unbalanced. Evenness showed a negative correlation with phytoplankton density ($r = -0.424$, p 0.001) which means that evenness decreased with increasing size of the phytoplankton population and many species are equally abundant.

There is a significant correlation between diversity index and evenness ($r = 0.926$, $p < 0.001$); this relationship is similar to that in the study by Reed (1978), who found that diversity indices were closely related to evenness.

The highest value of richness index (3.428) was recorded in the Hooks Drain and the lowest value (0.895) in Drain 8. The highest value indicated healthy status, and the lowest value indicated unhealthy and polluted status because of the elimination of sensitive species and the flourishing of tolerant species.

A comparison of the average biodiversity indices in the nine basins suggested that the diversity indices were slightly higher in the Hooks and West Burullus Drains and lower in Drain 8 and the Burullus Drain. This may be related to the extreme restrictive environmental conditions associated with the eutrophication process (Sladecek 1983).

Palmer (1969) made the first major attempt to identify and prepare a list of genera and species of algae tolerant to organic pollution and to establish the status of the aquatic body. Two Palmer algae pollution indices (one listed by genera, the other by species) were compiled and ranked the genera/species most often encountered in waters with high rates of organic pollution. According to Palmer, scores of 20 or more are indicators of high organic pollution. Pollution-tolerant genera and species as *Oscillatoria*, *Euglena*, *Scenedesmus*, *Chlamydomonas*, *Navicula*, *Nitzschia*, *Stigeoclonium*, and *Ankistrodesmus* are the species found in organically polluted waters as supported by Jafari and Gunale (2006). Similar observations were recorded in the present investigation, where *Scenedesmus*, *Euglena*, *Lepocinclis*, *Phacus*, *Nitzschia*, *Navicula*, *Oscillatoria*, *Cyclotella*, *Chlorella*, and *Ankistrodesmus* were the more common pollution-tolerant genera encountered in the studied drains. *Cyclotella* which was found to be the most active participant in all stations may be the good indicator of pollution tolerance; similar observation is recorded by Venkatachalapathy and Karthikeyan (2013).

By using Palmer's index of pollution, the rating of water samples to register the degree of organic pollution at the nine drains including a canal was tested. The present study showed 15 pollution-tolerant genera found at all sampling stations, of which Chlorophyceae comprised 5, Cyanophyceae 2, Bacillariophyceae 5, and Euglenophyceae 3 genera. According to Palmer algal rating, Drain 7, the Burullus Drain, and West Burullus

Drain have between moderate pollution and probable high organic pollution, but the other sites have a pollution score list of more than 20, indicating a high rate of organic pollution therein. The Brimbal Canal accounted with maximum (29) pollution score, compared to the Kitchinar Drain (26) and Drain 8 (27).

Summary and conclusion

Based on the different indices used in present study, the water quality of the Burullus Drain, Drain 7, and the West Burullus Drain are the best. Among the other sites, the Brimbal Canal and Drain 8 appear to be highly polluted, followed by the Kitchinar Drain. These sites are tending fast toward "eutrophism." The increase in the anthropogenic activities and agricultural runoff is major cause of eutrophication at these sites. These selected drains require immediate attention in order to conserve their water quality. And therefore, management efforts should be focused accordingly to check the deteriorating water quality of these drains. Based on these observations, other researchers can develop concepts to monitor the water quality of different water bodies. To conclude, phytoplankton has the potential to act as bioindicators of pollution status. These should be preferred over others for early signals due to their low cost, less time consumption, and ease of handling.

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