Phytoplankton heterogeneity in subtropical-semiarid reservoir with special reference to spring cyanobacterial bloom

Doaa A. Kassem[1], Mohamad S. Abd El-Karim[1], Ahmed A. El-Awamri[2] and *Amal I. Saleh[2]

[1] National Institute of Oceanography and Fisheries, 101 El-Kasr El-Eny St., Cairo, Egypt
[2] Botany Department, Faculty of Science, Ain Shams University, Cairo, 11566, Egypt

Abstract

Lake Nasser plays a fundamental role in both local and national economy. Phytoplankton represents one of the most interesting groups in water habitats and aquatic food chains. The present work aimed to estimate the spatiotemporal variation in phytoplankton structure, biovolume and carbon content in Khor Ramla and Khor Abu-Simbel of Lake Nasser; during the highest water level in early autumn and the lowest water level in late spring. Nine stations along each khor have been studied in 2014. A total of 180 phytoplankton taxa related to four algal divisions were identified. These divisions are: Chlorophyta (94 taxa), Cyanophyta (52 taxa), Bacillariophyta (32 taxa) and Dinophyta (2 taxa). *Microcystis comperei*, *M. aeruginosa* and *Lyngbya limnetica* were the dominant cyanophytes. *Cosmarium* spp., *Coelastrum reticulatum*, *Oocystis borgei*, *Eutetramorus fottii*, *Ankistrodesmus spiralis*, *Pediastrum simplex*, *Euastrum* sp. and *Dictyosphaerium pulchellum* represented the most abundant species of chlorophytes. Diatoms were dominated mainly by *Aulacoseira granulata*, *A. ambigua*, *A. muzzanensis, Cyclotella ocellata*, *C. glomerata* and *Cymbella affinis*. In spring, the average total biovolume of Khor Abu-Simbel (81.63 mm^3/l) was higher than that of Khor Ramla (1.94 mm^3/l). In autumn, the average total biovolumes in Khor Ramla (3.65 mm^3/l) and Khor Abu-Simbel (3.09 mm^3/l) were slightly different. Cyanophyta was dominant in both studied khors along the study period with obvious blooming at all stations of Khor Abu-Simbel during spring. In Khor Abu-Simbel, the carbon content of all groups during spring was higher than that of autumn, except for diatoms. In Khor Ramla, the carbon content of cyanobacteria and diatoms increased in autumn, while in Dinophyta and Chlorophyta the values increased in spring. A detailed discussion of the factors lead to the dominance and blooming of cyanobacteria in Lake Nasser was given. Canonical Correspondence Analysis (CCA) clarified that a combination of physical, chemical and biological factors rather than a single factor acted in harmony to control the composition and dynamics of phytoplankton community in Khor Abu- Simbel and Khor Ramla in Lake Nasser.

Keywords: Lake Nasser, Phytoplankton biovolume, Carbon content, Physico-chemical variables, *Microystis*, Cyanobacteria.

[*] Corresponding author: email: amalsaleh77@hotmail.com, amalsaleh@sci.asu.edu.eg (ISSN: 1110-8649)

Introduction

Lake Nasser represents one of the most significant artificial reservoirs in the world. It is a long and narrow water channel with side extensions called khors. These khors considered as vital natural surroundings for fish to feed and breed, due to their relative shallowness and abundance of phytoplankton.

Phytoplanktonic algae have a key position in any aquatic food web as they are the main source of nutrition for zooplankton, small and omnivorous fish as well as upper level consumers. They are rich in many valuable nutrients and biologically active ingredients such as fatty acids, amino acids, minerals and antioxidants **(Shields and Lupatsch, 2012; Kovač et al., 2013)**. These important compounds transfer to the upper trophic levels of consumers through the classical food web and finally to human when fish consumed. Phytoplankton also plays a fundamental role in the global carbon cycle **(Basu and Mackey, 2018)**.

Microalgae vary considerably in their shapes and size, from submicron species to some diatom species measuring more than 1 mm in diameter **(Reynolds, 1984)**. In studies concerned with the algal productivity of any water habitat, counting of algal cells doesn't give a real picture on the relative contribution of different algal species to the productivity of this water resource. This is mainly because that in mixed-species samples, although small-sized species may dominate in high numbers, they actually have minor contribution to the total biomass. In contrary, larger-sized species that are few in number may significantly contribute to the overall biomass **(Wetzel and Likens, 1991).** Estimation of biomass is important to compare the relative contribution of different microalgae in mixed taxa samples (**Hillebrand and Sommer, 1997)** and to convert phytoplankton biovolume into carbon **(Rocha and Duncan, 1985)**. Calculation of cell biovolume is the most commonly used method to estimate the microalgal biomass and it could be calculated from the linear dimensions of algal cells measured by the microscope **(Sommer, 1994; Hillebrand and Sommer, 1997)**. **Hillebrand et al. (1999)** provided a series of mathematical equations to calculate geometric shapes and biovolumes of more than 850 marine and freshwater microalgal genera in pelagic and benthic form.

The high productivity of Lake Nasser and its economic importance attract the attention of many authors to study its phytoplankton communities and physico-chemical parameters. But all the previous studies concerned with the quantitative estimation of phytoplanton, except that of **Gharib and Abdel-Halim (2006)**, were based only on counting of algal cells. The present work aimed to estimate the spatiotemporal variations in phytoplankton structure, biovolume and carbon content in Khor Ramla and Khor Abu-Simbel of Lake Nasser, during the highest water level in early autumn and the lowest water level in late spring. It also intended to determine the major physical and chemical parameters that control the composition of phytoplankton community and to investigate the response of phytoplankton to the changes in these parameters.

Materials and Methods

1- Study area

Lake Nasser extends between latitudes 22° 00' - 23° 58' N and longitudes 31° 19' - 33°19' E **(El-Shabrawy, 2009)**. It occupies about 5248 km^2 and has many side expansions (khors). Two khors were selected for this study, Abu-Simbel in the most southern-eastern side, and Ramla in the most north-western side of the lake (Figure 1). The surface area of Khor Ramla is 101.2 km^2 and its length is 17 km **(Latif, 1974)**. It has a mean depth of 14.2 m and 19.5 m in the spring and autumn, respectively, with a maximum depth of 36 m. The maximum length of khor Abu-Simbel is about 11.8 km. The deepest point is about 28m and the mean depth is about 13.72 m in autumn. Nine stations at each khor have been selected to be investigated (Figures 2 and 3).

2- Sampling, identification and counting of phytoplankton

Two cruises were performed in 2014, during highest water level (early autumn, the end of the flood) and lowest water level (late spring, the end of the drought season).

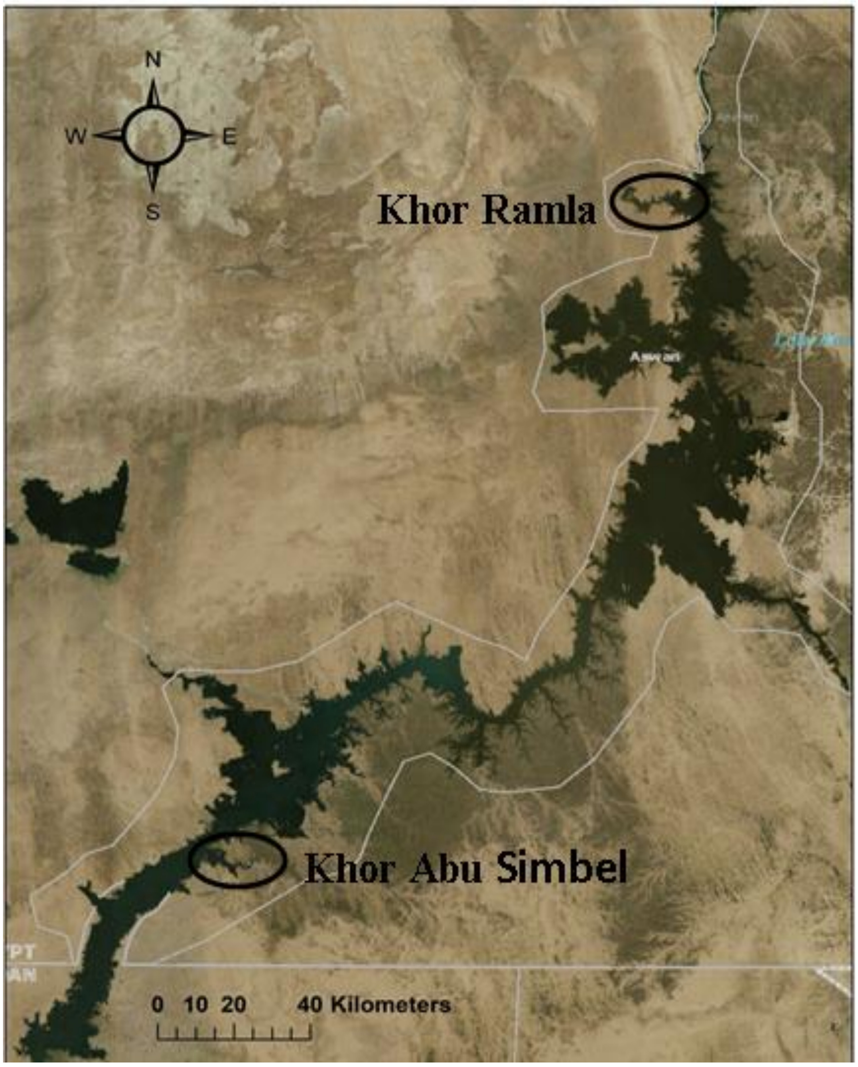

Figure 1. Map of Lake Nasser showing position of Khor Ramla and Khor Abu-Simbel

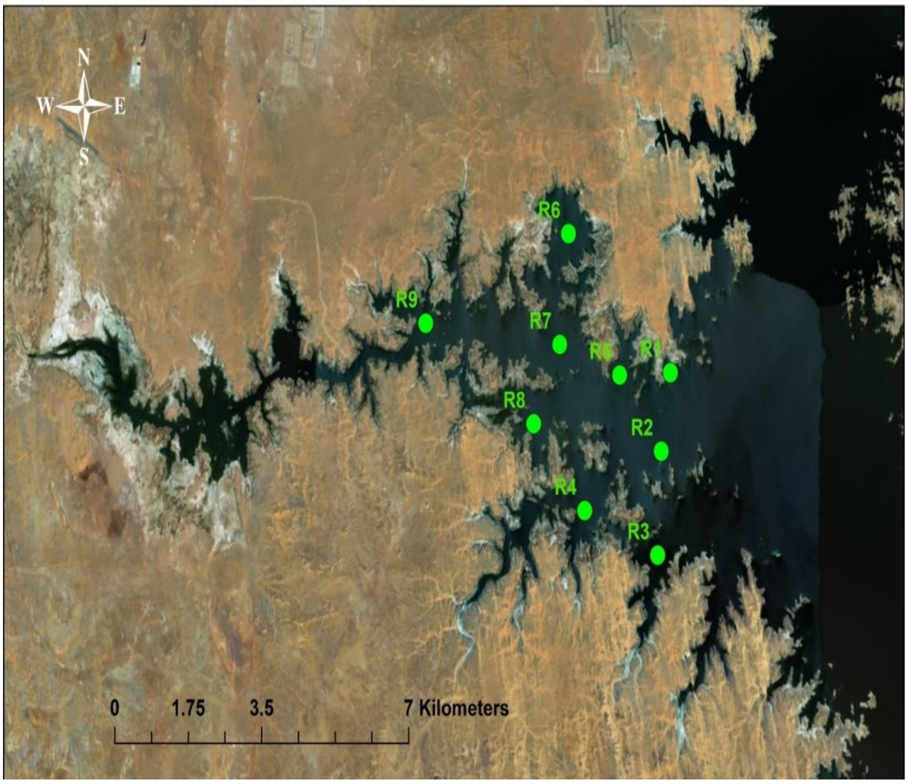

Figure 2. Map showing sampling stations in Khor Ramla

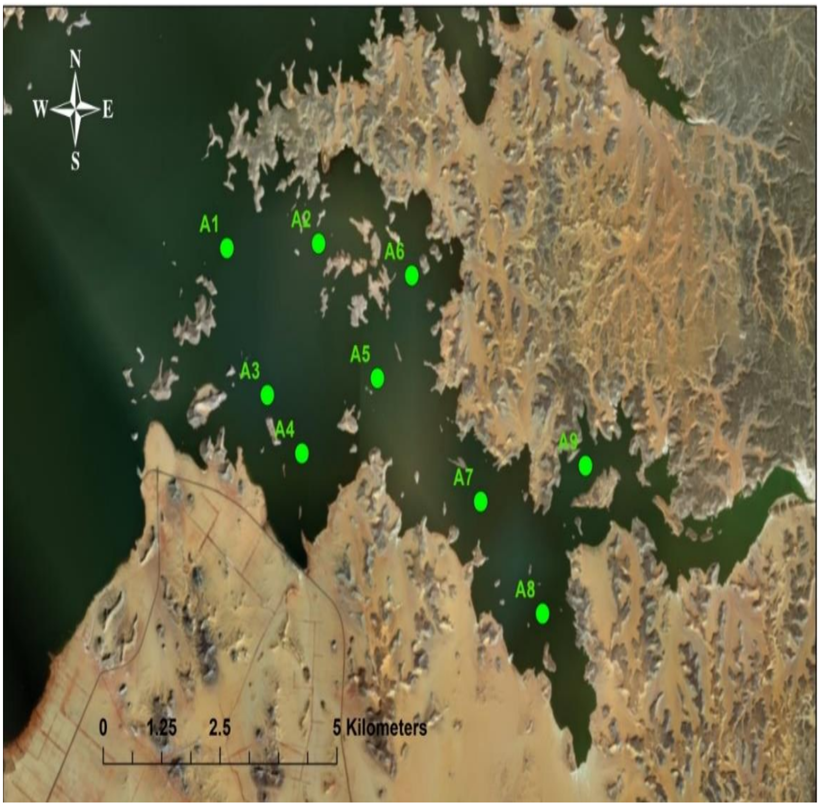

Figure 3. Map showing sampling stations in Khor Abu-simbel

Phytoplankton samples were collected 50 cm subsurface water in 100 ml plastic bottles and preserved with 4% formalin. Species identification and counting were performed according to **Utermöhl (1958)** using an inverted light microscope (Zeiss, Axiovert 25C). For phytoplankton identification, the following references were used; **Dillard (1991)** and **Wehr and Sheath (2003)** for Chlorophyta, **Starmach (1968)** and **Wehr and Sheath (2003)** for Cyanophyta, **Krammer and Lange-Bertalot (1986, 1988 and 1991)** and **Taylor et al. (2007)** for Bacillariophyta.

3- Physical and chemical analyses

Water temperature, pH and electrical conductivity were measured in situ using pH meter **(Crison, MM40)**. Secchi disk of 25cm diameter was adopted for measuring water transparency. Dissolved oxygen (DO, mgl^{-1}) was measured using the modified Winkler method, while biochemical oxygen demand (BOD, mgl^{-1}) was determined using the 5 days method **(APHA, 2005)**. Concentrations of nitrite, nitrate, ammonium, orthophosphate (μgl^{-1}), and reactive silicate (mgl^{-1}) were determined using colorimetric techniques **(APHA, 2005)**. Total phosphorus (TP, μgl^{-1}) was measured as reactive phosphate after persulfate digestion.

4- Estimation of Chlorophyll a concentration

Chlorophyll a was extracted using acetone (90%) and measured according to **APHA (2005)** using Perkin Elmer (LS45) fluorescence spectrometer at an excitation wavelength of 430 nm and emission wavelength of 663 nm and compared with standard curve and reported as μgl^{-1}.

5- Calculation of phytoplankton biovolume and their carbon content

Phytoplankton biovolume was estimated using formula for geometric shapes according to **Hillebrand et al. (1999)** and **Sun and Liu (2003)**. Carbon content was calculated from the biovolume of phytoplankton according to **Sournia (1978)**, using the following equations:

For phytoplankton groups, except diatoms

$$\log_{10} C = 0.94 (\log 10\ V) - 0.60$$

Since diatoms have lower carbon content per unit cell volume, they are usually treated separately from other groups of phytoplankton.

$$\log_{10}C = 0.76\ (\log_{10}V) - 0.352$$

V representing total cell volume (µm3) and C the amount of carbon as picograms per cell.

6- Statistical analysis

Changes in physico-chemical parameters and phytoplankton biovolume between different stations in the two khors as well as between seasons were tested with Two-way ANOVA using **MINITAB 14.1** package. Canonical Correspondence Analysis (CCA) was used to relate phytoplankton species directly to measured environmental variables. CCA was carried out with Canoco for Windows version 4.5 **(Leps and Smilauer, 2003)** for the most frequented taxa (58 taxa in Khor Abu-Simbel and 60 taxa in Khor Ramla). CCA biplots were drawn with Cano Draw for Windows. The environmental variables were submitted to a stepwise forward selection procedure in which the statistical significance of each variable was tested by the Monte Carlo permutation test (499 permutations) at a cut-off point of $P = 0.05$.

Note. Some of the collected samples from Khor Ramla (stations R4, R8 and R9) and Khor Abu-Simbel (station A9) during autumn were lost in the field.

Results

(i) Physical and chemical properties of water in Khor Ramla and Khor Abu-Simbel

The physico-chemical characteristics of water in Khor Abu-Simbel and Khor Ramla were given in Tables (1&2). The results showed that average concentrations of EC, DO, BOD and NO_3 in the two studied khors were greater during autumn. Whereas the average values of orthophosphate and silicate in the two khors were higher during spring.

During autumn, it was noticed that Khor Abu-Simbel showed the highest average values for the studied parameters: pH, NO_2, TP and NH_4 as compared with the average values recorded in spring. In contrast, Khor Ramla showed the highest average values for the same parameters in spring. It was observed that the average value of water transparency in khor Abu-Simbel was higher during spring than autumn, the opposite is true for Khor Ramla.

ANOVA revealed that the temporal and spatial variations in transparency, orthophosphate and total phosphorus were non-significant (P > 0.05). On the other hand, there were highly temporal and spatial significant variations in EC, BOD and NO_3 (P =0.0001, P =0.000 and P =0.000, respectively); significant temporal variations in NH_4, DO and silicate (P =0.006, P =0.000, P =0.000, respectively); and significant spatial variations in pH and NO_2 (P<0.05).

(ii) Chlorophyll a

Results showed that average concentrations of chlorophyll a in Khor Abu-Simbel were higher than Khor Ramla during both autumn and spring (Table 3). ANOVA indicated a highly significant spatial (P= 0.000) and temporal (P=0.027) variations in chlorophyll a content between the two khors.

(iii) Phytoplankton composition

A total of 180 phytoplankton taxa were identified related to four algal divisions; Chlorophyta (94 taxa), Cyanophyta (52 taxa), Bacillariophyta (32 taxa) and Dinophyta (2 taxa).

Concerning Cyanophyta, *Microcystis comperei*, *M. aeruginosa* and *Lyngbya limnetica* were the most dominant species. Chlorophyta members were dominated by *Cosmarium* spp., *Coelastrum reticulatum*, *Oocystis borgei*, *Eutetramorus fottii*, *Lagerheimia subsalsa*, *Oocystis solitaria*, *Ankistrodesmus spiralis*, *Monactinus simplex*, *Euastrum* sp., *Dictyosphaerium pulchellum* and *Pediastrum simplex* in the two studied khors.

Table 1. Physical and chemical characteristics of water in khor Abu- Simbel during spring and autumn 2014. Sp.: spring, Au.: autumn and n.d.: no data.

Stations		A1	A2	A3	A4	A5	A6	A7	A8	A9	Average
Transp. (cm)	Sp.	200.00	250.00	230.00	300.00	300.00	200.00	200.00	250.00	200.00	242.86
	Au.	155.00	170.00	170.00	200.00	165.00	155.00	110.00	160.00	n.d.	160.63
Temp. (°c)	Sp.	27.40	28.30	28.60	29.90	29.00	27.20	28.80	29.50	28.2	28.54
	Au.	20.30	18.90	20.40	20.20	21.20	21.50	22.20	21.4	n.d.	20.76
pH	Sp.	8.18	8.24	8.16	8.52	8.64	8.52	8.56	8.52	8.20	8.39
	Au.	8.73	8.69	8.75	8.71	8.79	8.89	8.88	8.91	n.d.	8.79
EC (µS/cm)	Sp.	188.30	191.50	190.40	193.10	188.10	180.50	179.60	178.10	175.90	185.06
	Au.	236.10	238.60	230.40	234.70	233.90	229.70	222.50	230.60	n.d.	232.06
DO (mg/l)	Sp.	1.40	1.50	1.00	1.10	1.80	1.40	1.20	1.30	1.30	1.33
	Au.	9.66	9.48	9.24	9.44	9.32	9.43	9.45	9.25	n.d.	9.41
BOD (mg/l)	Sp.	1.36	1.23	1.32	1.46	0.67	1.64	0.83	1.16	1.30	1.22
	Au.	2.30	2.20	1.50	2.65	1.98	1.78	1.95	2.24	n.d.	2.08
NO_2 (µg/l)	Sp.	2.86	2.38	1.43	2.38	2.38	0.00	3.81	3.33	5.71	2.70
	Au.	10.45	15.00	25.45	9.09	10.45	35.91	17.73	16.36	n.d.	17.56
NO_3 (µg/l)	Sp.	21.82	29.09	65.45	40.00	27.27	16.36	23.64	9.09	16.36	27.68
	Au.	325.00	453.67	737.55	553.16	380.71	363.47	380.71	305.10	n.d.	437.42
NH_4 (µg/l)	Sp.	38.05	42.48	24.78	35.40	25.66	15.93	92.92	23.01	18.58	35.20
	Au.	25.60	27.20	54.40	23.20	36.80	50.40	40.80	24.80	n.d.	35.40
PO_4 (µg/l)	Sp.	58.70	81.52	70.11	61.96	81.52	73.37	79.89	89.67	61.96	73.19
	Au.	7.50	7.50	7.50	9.38	11.25	9.38	20.63	5.63	n.d.	9.84
TP (µg/l)	Sp.	692.93	345.65	445.11	608.15	753.26	508.70	745.11	595.11	681.52	597.28
	Au.	575.63	646.88	645.00	703.13	598.13	759.38	615.00	585.00	n.d.	641.02
Silicate (mg/l)	Sp.	2.22	2.33	2.20	2.33	2.17	2.18	2.25	2.55	2.27	2.28
	Au.	1.90	2.20	1.95	1.98	1.96	1.86	1.71	1.90	n.d.	1.93

Table 2. Physical and chemical characteristics of water in khor Ramla during spring and autumn 2014. Sp.: spring, Au.: autumn and n.d.: no data.

Stations		R1	R2	R3	R4	R5	R6	R7	R8	R9	Average
Transp (cm)	Sp.	250.00	200.00	200.00	200.00	220.00	240.00	200.00	190.00	180.00	208.89
	Au.	410.00	360.00	380.00	n.d.	300.00	310.00	340.00	n.d.	n.d.	350.00
Temp. (°c)	Sp.	27.70	27.10	29.30	29.20	27.30	26.70	27.30	29.10	27.20	27.88
	Au.	22.60	21.00	20.90	n.d.	21.10	21.90	20.30	n.d.	n.d.	21.30
pH	Sp.	8.12	8.34	8.65	8.57	8.19	8.40	8.39	8.60	8.58	8.43
	Au.	7.89	8.08	8.22	n.d.	8.09	8.56	8.27	n.d.	n.d.	8.19
EC (µS/cm	Sp.	200.00	207.00	208.00	192.30	197.70	197.00	198.00	198.60	185.00	198.17
	Au.	261.00	262.60	262.30	n.d.	263.40	261.25	263.30	n.d.	n.d.	262.31
DO (mg/l)	Sp.	1.80	2.00	2.20	2.30	1.80	2.30	1.90	2.20	2.00	2.06
	Au.	7.85	7.68	8.19	n.d.	8.40	8.66	8.61	n.d.	n.d.	8.23
BOD (mg/l)	Sp.	1.50	1.70	1.79	1.67	1.52	1.45	1.63	1.40	1.25	1.55
	Au.	4.04	5.92	5.76	n.d.	6.20	6.96	6.24	n.d.	n.d.	5.85
NO_2 (µg/l)	Sp.	5.24	6.19	5.71	5.24	8.10	7.14	6.19	8.10	7.14	6.56
	Au.	0.00	0.00	0.45	n.d.	0.45	0.00	0.45	n.d.	n.d.	0.23
NO_3 (µg/l)	Sp.	25.45	29.09	14.55	12.73	10.91	20.00	25.45	21.82	20.00	20.00
	Au.	242.76	277.25	201.63	n.d.	70.31	131.33	116.73	n.d.	n.d.	173.33
NH_4 (µg/l)	Sp.	60.18	56.64	57.52	68.14	47.79	42.48	41.59	49.56	71.68	55.06
	Au.	12.80	8.80	12.00	n.d.	30.40	19.20	23.20	n.d.	n.d.	17.73
PO_4 (µg/l)	Sp.	831.52	73.37	68.48	71.74	65.22	61.96	70.11	63.59	76.63	153.62
	Au.	39.38	31.88	30.00	n.d.	35.63	28.13	16.88	n.d.	n.d.	30.31
TP (µg/l)	Sp.	510.33	1079.35	971.74	282.07	577.17	748.37	484.24	735.33	1332.0	746.74
	Au.	622.50	594.38	631.88	n.d.	622.50	586.88	583.13	n.d.	n.d.	606.88
Silicate (mg/l)	Sp.	2.42	2.47	2.30	2.36	2.41	2.30	2.20	2.22	2.23	2.32
	Au.	1.32	2.40	1.70	n.d.	1.70	1.55	1.55	n.d.	n.d.	1.70

Table 3. Concentrations of Chlorophyll a in Khor Abu-Simbel and Khor Ramla during autumn and spring. n.d.: no data.

Stations	Chl.a (µg/l)			
	Abu-Simbel		Ramla	
	Autumn	Spring	Autumn	Spring
1	5.57	12.22	3.05	4.37
2	10.08	11.67	2.65	4.63
3	11.05	13.43	2.77	2.97
4	7.61	8.80	n.d.	3.02
5	11.54	11.93	3.51	4.50
6	12.95	22.01	4.44	9.74
7	19.55	16.46	3.57	5.70
8	13.51	7.90	n.d.	3.36
9	n.d.	11.31	n.d.	9.74
Average	11.48	12.86	3.33	5.34

Dinophyta was represented by only two species namely, *Ceratium hirundinella* and *Peridinium willei*. Diatoms were represented mainly by *Aulacoseira granulata* followed by *Cymbella affinis*, *A. ambigua*, *Cyclotella ocellata, C. glomerata, A. muzzanensis and Mastogloia danseyi.*

The relative biovolumes of phytoplankton groups in Khor Ramla and Abu-Simbel were shown in Figure (4). In Khor Abu-Simbel, Cyanophyta dominated during spring at all stations that represented 91.74% of the total phytoplankton biovolume, whereas, Dinophyta, Bacillariophyta and Chlorophyta showed average percentage of 3.04%, 2.88% and 2.34% of total biovolume, respectively. In autumn, Cyanophyta occupied the first rank with lower contribution (67.44%) than spring which gave chance to the other groups to appear in higher proportions than spring. Bacillariophyta was the second dominant group that comprised mean proportion of 25.70% of the total biovolume. Chlorophyta and Dinophyta represented 4.66% and 2.20% of the total phytoplankton biovolume, respectively.

In Khor Ramla, Cyanophyta was the most prevalent group (40.34% of the overall phytoplankton biovolume) during spring. Chlorophyta shared dominance (32.03% of the total phytoplankton biovolume). Dinophyta contributed by 25.41% of the total phytoplankton biovolume, followed by Bacillariophyta (2.22%). During autumn, Cyanophyta was the most dominant group (81.69% of total biovolume), followed by Dinophyta (11.27%). Chlorophyta and Bacillariophyta occupied the last ranks of 3.84% and 3.20%, respectively.

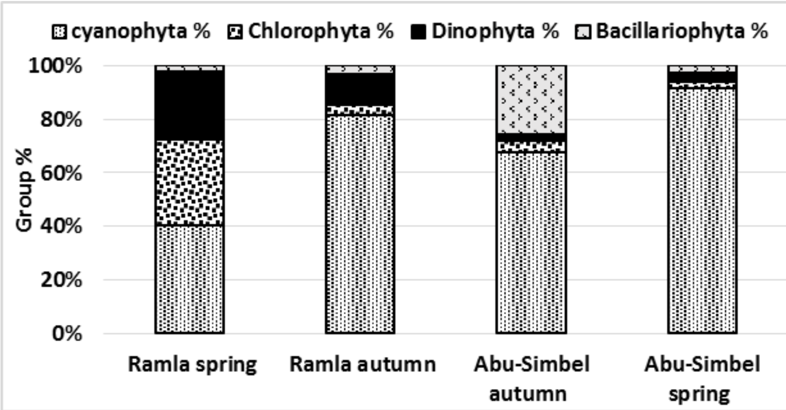

Figure 4. Relative biovolume of phytoplankton groups of Khor Ramla and Abu-Simbel

(iv) Spatiotemporal variations in the total phytoplankton biovolume

As comparing the total biovolume in the two studied khors, it was noted that the average total biovolume of Khor Abu-Simbel in spring (81.63 mm^3/l) was obviously higher than that of Khor Ramla (1.94 mm^3/l). Whereas, the average total biovolumes in Khor Ramla (3.65 mm^3/l) and khor Abu-Simbel (3.09 mm^3/l) in autumn were slightly different. ANOVA reflects a slight spatial and temporal significant differences in the total biovolume between Khor Ramla and Khor Abu-Simbel, (P =0.058) and (P =0.066), respectively.

In Khor Ramla, results revealed lower phytoplankton biovolumes near the main channel (stations; 1, 2 and 3) than other stations during both seasons. In autumn, phytoplankton biovolume had a sharp increase (13.18 mm^3/l) at the middle of the Khor (station 6), whereas other stations were slightly different from each other with minimum value of 1.14 mm^3/l at station 1 (Figure 5). In spring, there was a gradual increase from station 3 (1.01 mm^3/l), till station 7 which attained the greatest biovolume (3.71 mm^3/l). ANOVA revealed no spatial (P=0.298) or temporal (P =0.287) significant variation among stations of Khor Ramla.

In Khor Abu-Simbel, there was a marked increase in the total biovolume of phytoplankton at the middle of the Khor in both seasons, followed by an obvious decrease in the two opposite directions till the two ends and re-increased at stations 1 and 9 in spring only (Figure 6). Maximum (234.57 mm^3/l) and minimum (1.09 mm^3/l) biovolumes of phytoplankton were recorded during spring at stations 6 and 2, respectively. ANOVA showed non-significant variation in total biovolume among stations of Khor Abu-Simbel (P=0.482), while revealed a significant variation in it as regarding the two studied seasons (P =0.028).

(v) Carbon content of phytoplankton

Carbon levels are commonly used to measure population metabolism and transitions of energy and have become the main currency used in aquatic ecosystem studies. In the present study, it was noticed that minimum carbon contents in Khor Abu-Simbel during spring were recorded near the main channel and increased inwards. The highest values during autumn were recorded near the main channel but then deceased inwards and re-increased again at the end of the khor (Figure7). The total average of carbon contents of Khor Abu-Simbel during spring and autumn were 18.455 µg/ml and 17.326 µg/ml, respectively.

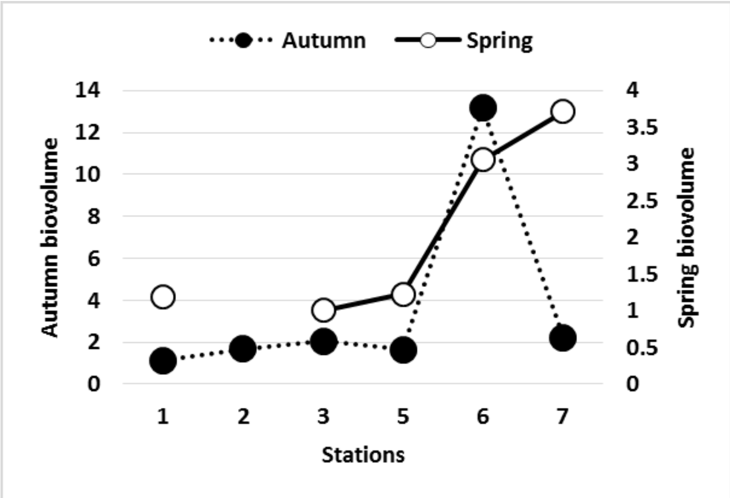

Figure 5. Total biovolume (mm^3/l) of phytoplankton at Khor Ramla

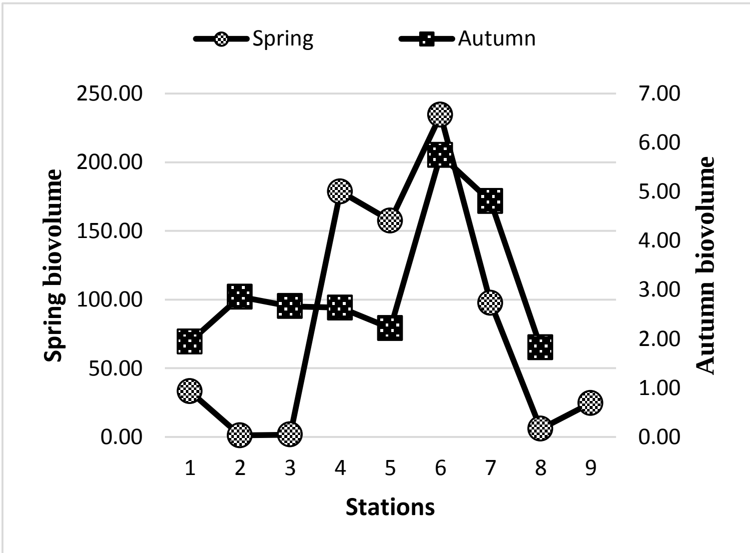

Figure 6. Total biovolume (mm^3/l) of phytoplankton in Khor Abu-Simbel

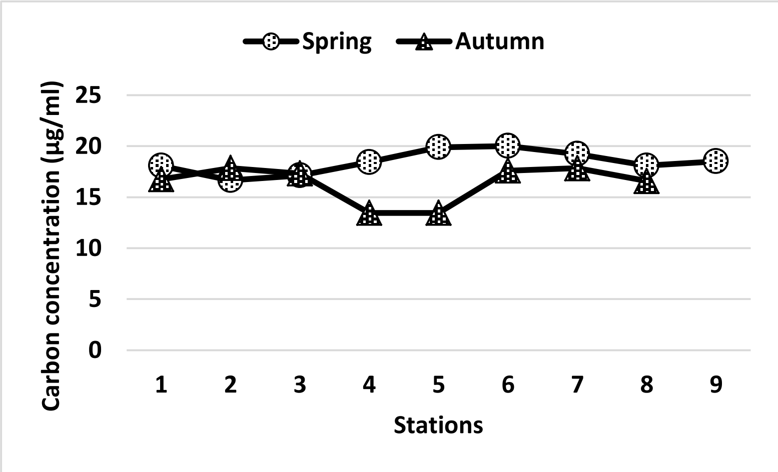

Figure 7. Total carbon content (µg/ml) in Khor Abu-Simbel during spring and autumn.

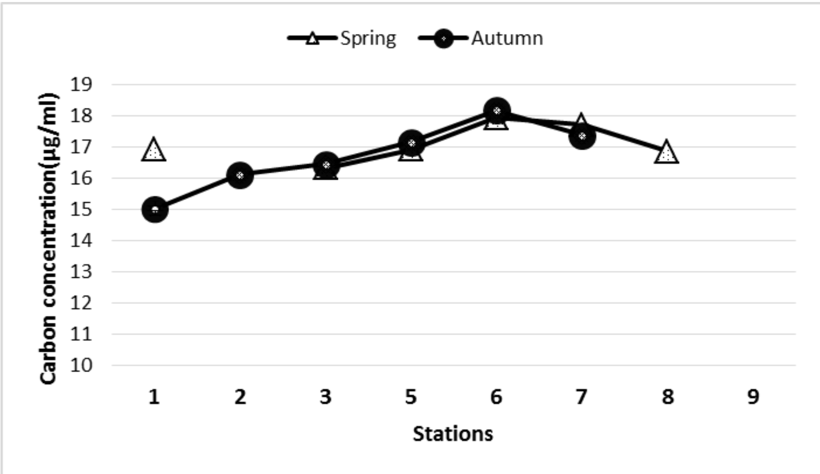

Figure 8. Total carbon content (µg/ml) in Khor Ramla during spring and autumn.

In Khor Ramla, carbon contents were minimal near the main channel and increased inwards till the middle of the khor during both seasons then re-decreased at the end of the khor (Figure 8). The total average of carbon contents during autumn and spring were 17.12 and 16.71 µg/ml, respectively.

(vi) Canonical Correspondence Analysis (CCA) of dominant phytoplankton taxa and environmental variables in khor Ramla and khor Abu-Simbel

A) Khor Abu-Simbel

CCA results showed that EC (r=0.97), DO (r=0.95), NO_3 (r=0.93), BOD (r=0.85), NO_2 (r=0.73) and pH (r=0.68) were positively correlated with phytoplankton biovolume in Khor Abu-Simbel, while temperature (r= -0.95), PO4 (r=-0.95), silicate (r=-0.67) were negatively influencing the phytoplankton biovolume. Total phosphorus and ammonium had the lowest effect on species composition in this khor.

Dominant cyanobacteria species reacted differently to environmental variables. *Microcystis aeruginosa* and *Radiocystis* sp. were strongly positively associated with NO_2, BOD, EC, NO_3 and pH, while *Tetrarcus ilsteri* and *Chroococcus minutus* var. *thermalis* were the most positively affected species by temperature, silicate and orthophosphate (Fig. 9 and Table 4).

About Chlorophyta species, it was noted from CCA that Desmidiales (especially, *Cosmarium* sp., *Staurastrum* sp., *Closterium acutum*) and Klebsormidiales (*Elakatothrix genevensis*) were positively correlated with temperature, orthophosphate and silicate. Meanwhile, Chlorellales spp. exhibit a strong positive association with NO_2, BOD, EC, NO_3, and pH.

CCA indicated that diatoms have high affinity towards pH and oxygenated nitrogen forms and low affinity towards silicate and temperature, while dinoflagellates showed typical opposite trends to diatoms (Fig. 9 and Table 4).

B) Khor Ramla

Temperature (r=0.91), NO_2 (r=0.90) and NH_4 (r=0.88) were the major factors positively affect the growth of abundant species, followed by silicate (r=0.56) and pH (r=0.52). While EC (r= -0.91), DO (r=-0.89), BOD (r=-0.86), secchi depth (r=-0.87) and nitrate (r=-0.85) negatively affect the phytoplankton composition.

For blue-green algae *Lyngbya limnetica* and *Microcystis wesenbergii* had a high affinity towards temperature, less oxygenated nitrogen forms (NO_2 and NH_4) and PO_4. Different environmental variables had cumulative effects towards *Merismopedia glauca*, *M. punctata* and *Microcystis aeruginosa* (Fig. 10 and Table 5).

At higher temperatures and high concentrations of NH_4, some green algae as *Elakatothrix gelatinosa*, *E. genevensis*, *Oocystis submarina* and *Lagerheimia quadriseta* had higher growth performance but *Lagerheimia subsalsa*, *Planctonema lauterbornii*, *Dictyosphaerium subsolitarium* and *Coelastrum reticulatum* had a lower growth performance. *Micractinium pusillum*, *Dictyosphaerium pulchellum* and *Nephrocytium obesum* had a higher tendency towards higher NO_3, low phosphorus and low temperature but *Ankistrodesmus spiralis*, *Lagerheimia citriformis* and *Kirchneriella lunaris* had a lower tendency toward these factors (Fig. 10 and Table 5).

Ceratium hirundinella and *Peridinium willei* were moderately positively associated with temperature, NH_4, silicate and TP. Bacillariophyta, except *Cymbella affinis*, had a low affinity towards NH_4, silicate and TP. However, they had a higher affinity towards NO_3 (Fig. 10 and Table 5).

Table 4. Codes of the most frequent phytoplankton taxa recorded in Khor Abu-Simbel used in CCA.

No.	Taxa	No.	Taxa
1	*Aphanocapsa incerta* (Lemmerm.) G.Cronberg & Komárek	**20**	*Ankistrodesmus fusiformis* Corda
2	*Chroococcus dispersus* (Keissler) Lemmerm.	**21**	*Ankistrodesmus spiralis* (W.B.Turner) Lemmerm.
3	*Chroococcus minutus* var. *thermalis* J.J.Copeland	**22**	*Chlorella* Beyerinck [Beijerinck]
4	*Chroococcus sonorensis* Drouet & Daily	**23**	*Choricystis chodatii* (Jaag) Fott
5	*Coelomoron microcystoides* Komárek	**24**	*Closterium acutum* Bréb.
6	*Coelomoron tropicale* P.A.C.Senna, A.C.Peres & Komárek	**25**	*Coelastrum reticulatum* (P.A.Dangeard) Senn
7	*Geitlerinema lemmermannii* (Woloszynska) Anagnostidis	**26**	*Cosmarium* sp.1
8	*Gomphosphaeria aponina* Kütz.	**27**	*Crucigenia apiculata* (Lemmerm.) Schmidle
9	*Lyngbya limnetica* Lemmerm.	**28**	*Dictyosphaerium pulchellum* H.C.Wood
10	*Merismopedia glauca* (Ehr.) Kütz.	**29**	*Elakatothrix genevensis* (Reverdin) Hindák
11	*Merismopedia punctata* Meyen	**30**	*Eutetramorus fottii* (Hindák) Komárek
12	*Microcystis aeruginosa* (Kütz.) Kütz.	**31**	*Gloeocystis vesiculosa* Nägeli
13	*Microcystis comperei* Komárek	**32**	*Golenkinia radiata* Chodat
14	*Microcystis wesenbergii* (Komárek) Komárek ex Komárek	**33**	*Keratococcus braunii* (Nägeli) Hindá
15	*Radiocystis geminata* Skuja	**34**	*Kirchneria contorta* (Schmidle) Hindák
16	*Tetrarcus ilsteri* H.Skuja	**35**	*Koliella spiculiformis* (Vischer) Hindák
17	Unidentified blue-green granulated filament	**36**	*Lagerheimia citriformis* (J.W.Snow) Collins
18	*Woronichinia klingiae* Komárek & Komárková-Legnerová	**37**	*Lagerheimia subsalsa* Lemmerm.
19	*Ankistrodesmus falcatus* (Corda) Ralfs	**38**	*Lagerheimia quadriseta* (Lemmerm.) G.M.Smith

Table 4. Continued.

No.	Taxa	No.	Taxa
39	*Monoraphidium dybowskii* (Woloszynska) Hindák & Komárkova Legnerová	**49**	*Scenedesmus quadricauda* (Turpin) Bréb.
40	*Monoraphidium griffithii* (Berkeley) Komárková-Legnerová	**50**	*Selenastrum gracile* Reinsch
41	*Nephrocytium obesum* West & G.S.West	**51**	*Sphaerocystis schroeteri* Chodat
42	*Oocystis borgei* J.W.Snow	**52**	*Staurastrum* sp.
43	*Oocystis solitaria* Wittrock	**53**	*Ceratium hirundinella* (O.Müll.) Dujardin
44	*Pediastrum simplex* Meyen	**54**	*Peridinium willei* Huitfeldt-Kaas
45	*Planctococcus* sp.	**55**	*Aulacoseira ambigua* (Grunow) Simonsen
46	*Planctonema lauterbornii* Schmidle	**56**	*Aulacoseira granulata* (Ehr.) Simonsen
47	*Planktosphaeria gelatinosa* G.M.Smith	**57**	*Aulacoseira granulata* var. *angustissima* (O.Müll.) Simonsen
48	*Scenedesmus ecornis* (Ehr.) Chodat	**58**	*Cyclotella ocellata* Pant.

Table 5. Codes of the most frequent phytoplankton taxa recorded in Khor Ramla used in CCA.

No.	Taxa	No.	Taxa
1	*Aphanothece smithii* Komárková-Legnerová & G.Cronberg	**20**	*Ankistrodesmus spiralis* (W.B.Turner) Lemmerm.
2	*Chroococcus dispersus* (Keissler) Lemmerm.	**21**	*Chlorella* Beyerinck [Beijerinck]
3	*Chroococcus minutus* var. *thermalis* J.J.Copeland	**22**	*Choricystis chodatii* (Jaag) Fott
4	*Coelomoron microcystoides* Komárek	**23**	*Closterium acutum* Bréb.
5	*Geitlerinema lemmermannii* (Woloszynska) Anagnostidis	**24**	*Coelastrum reticulatum* (P.A.Dangeard) Senn
6	*Gomphosphaeria aponina* Kütz.	**25**	*Cosmarium pygmaeum* W.Archer
7	*Gomphosphaeria* sp.	**26**	*Crucigenia apiculata* (Lemmerm.) Schmidle
8	*Lyngbya limnetica* Lemmerm.	**27**	*Dictyosphaerium pulchellum* H.C.Wood
9	*Merismopedia elegans* A.Braun ex Kütz.	**28**	*Dictyosphaerium subsolitarium* Van Goor
10	*Merismopedia glauca* (Ehr.) Kütz.	**29**	*Elakatothrix gelatinosa* Wille
11	*Merismopedia punctata* Meyen	**30**	*Elakatothrix genevensis* (Reverdin) Hindák
12	*Microcystis aeruginosa* (Kütz.) Kütz.	**31**	*Eutetramorus fottii* (Hindák) Komárek
13	*Microcystis comperei* Komárek	**32**	*Gloeocystis vesiculosa* Nägeli
14	*Microcystis wesenbergii* (Komárek) Komárek ex Komárek	**33**	*Golenkinia radiata* Chodat
15	*Oscillatoria gracilis* M.T.P.Azevedo & C.L.Sant'Anna, nom. illeg.	**34**	*Keratococcus braunii* (Nägeli) Hindá
16	*Tetrarcus ilsteri* H.Skuja	**35**	*Keratococcus glareosus* Hindák
17	*Woronichinia klingiae* Komárek & Komárková-Legnerová	**36**	*Kirchneria contorta* (Schmidle) Hindák
18	*Ankistrodesmus falcatus* (Corda) Ralfs	**37**	*Kirchneriella lunaris* (Kirchner) Möbius
19	*Ankistrodesmus fusiformis* Corda	**38**	*Koliella spiculiformis* (Vischer) Hindák

Table 5. Continued.

No.	Taxa	No.	Taxa
39	*Lagerheimia citriformis* (J.W.Snow) Collins	**50**	*Radiococcus nimbatus* (De Wildeman) Schmidle
40	*Lagerheimia subsalsa* Lemmerm.	**51**	*Sphaerocystis schroeteri* Chodat
41	*Lagerheimia quadriseta* (Lemmerm.) G.M.Smith	**52**	*Staurastrum* sp.
42	*Micractinium pusillum* Fresenius	**53**	*Tetraëdron minimum* (A.Braun) Hansgirg
43	*Monoraphidium griffithii* (Berkeley) Komárková-Legnerová	**54**	*Ceratium hirundinella* (O.Müll.) Dujardin
44	*Nephrocytium obesum* West & G.S.West	**55**	*Peridinium willei* Huitfeldt-Kaas
45	*Oocystis solitaria* Wittrock	**56**	*Aulacoseira granulata* (Ehr.) Simonsen
46	*Oocystis submarina* Lagerheim	**57**	*Cyclotella ocellata* Pant.
47	*Oocystis submarina* Lagerheim	**58**	*Cymbella affinis* Kütz.
48	*Planctonema lauterbornii* Schmidle	**59**	*Fragilaria brevistriata* Grun.
49	*Planktosphaeria gelatinosa* G.M.Smith	**60**	*Gomphonema clavatum* Ehr.

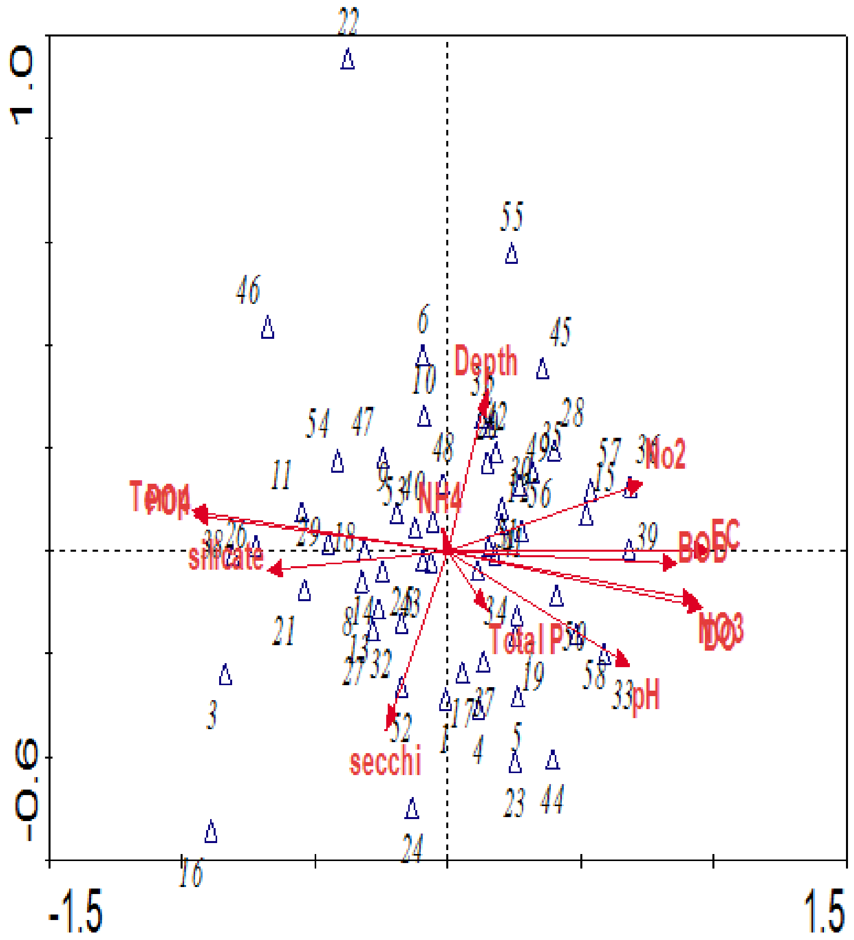

Figure 9. CCA biplot of dominant phytoplankton taxa and environmental variables in Khor Abu-Simbel.

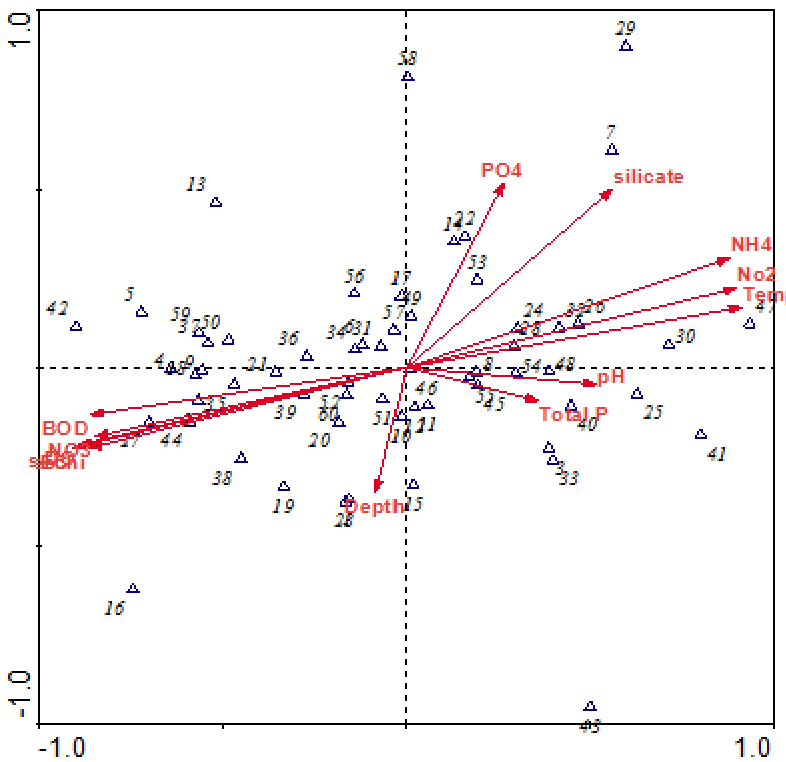

Figure 10. CCA biplot of dominant phytoplankton taxa and environmental variables in Khor Ramla.

Discussion

Lake Nasser is the subject of a lot of studies for a long time, because of its great importance as the major water resource in Egypt and as a vital source of fish and hydropower. Phytoplanktonic species are the main producers in any aquatic ecosystem, especially deepest ones, and they form the foundation of food webs in Lake Nasser.

Results of the present study revealed that average concentrations of transparency, EC, BOD, ammonium, orthophosphate and total phosphorus were higher in Khor Ramla than Abu-Simbel. Our results agree with **Abd El-Monem (2008), Toufeek and Korium (2015)** as well as **Abdel Gawad and Abdel-Aal (2018)** who mentioned that the trend of phosphate, water visibility, EC and ammonium in the lake were increased northward. On the other side, pH, dissolved oxygen, NO_2, NO_3 and silicate were greater in Khor Abu-Simbel than Ramla which concordant with **Gharib and Abdel-halim (2006); Toufeek and Korium (2015).**

Average concentrations of EC, DO, BOD and NO_3 in the two khors were greater during autumn, while mean values of orthophosphate and silicate in the two khors were higher during spring. The decrease in NO_3 during spring could be principally due to utilization by phytoplankton or to the reduction by denitrifying bacteria (**Toufeek and Korium, 2015**). Lake Nasser is fed by River Nile water heavily loaded with inorganic clay, silt, sand and organic detritus and therefore conductivity increase while transparency decrease (**Hussian et al., 2016**). High dissolved oxygen levels during the cold season reflected the elevated solubility of oxygen at low temperatures, as well as lower levels of respiration by the plankton community than during the warm season (**Srifa et al., 2016).** The increased pH in Khor Abu-Simbel may be related to the increase of total phytoplankton biovolume than Khor Ramla and hence increase photosynthesis. Our results are in agreement with **Gharib and Abdel-halim, 2006 and Toufeek and Korium, 2015.**

Average concentrations of chlorophyll a in Khor Abu-Simbel in both seasons were greater than that of Khor Ramla. Our results are in accordance with **Fead (1980)** who recorded that the southern region of Lake Nasser has higher average annual values of chlorophyll a than the northern region and reported that the highest values of chlorophyll a at Abu-Simbel directly preceding the annual flood. Similar findings were recorded in the study of **Abd El-Karim & Mahmoud (2016)** at five sectors in the main channel and in Tushka and Dahmeit khors.

One hundred and eighty phytoplankton taxa related to four algal divisions were identified in the present study. Lower species numbers were recorded in the previous studies in Lake Nasser (27 species by **Samaan (1971)**; 43 species by **Zaghloul (1985)**; 59 species by **El-Otify (1985)**; 135 species by **Abd EL-Monem (1995)**; 71 species by **Gharib and Abdel-Halim (2006)**; 135 species by **Hussian et al. (2016**); 137 species by **Abdel Gawad and Abdel-Aal (2018**). This may be partly attributed to **Utemöhl (1958)** identification and counting method used in this study and it mostly seems that, the older the lake, the more it becomes diversified with phytoplankton species.

Blooms of Cyanobacteria in rivers and lakes are of worldwide concern due to their effect on the water quality and human health (**Paerl et al., 2001; Taranu et al., 2012)**. Cyanobacteria are well adapted to perform under environmental stress conditions including high temperatures, low light, high ultraviolet intensities and either scarce or abundant nutrients **(Reynolds, 2006).** Bloom of *Microcystis* presents a serious problem for drinking water supply system because, when *Microcystis* stressed, it releases hepatotoxins (microcystin) into water **(Wetzel, 2001; Paerl and Otten, 2013 and Khairy and El-Sheekh, 2019).**

During this investigation, cyanobacteria were recorded as a dominant group, sometimes constituted more than 90% of total biovolume with obvious blooming of *Microcystis* spp. These results coincide with early and recent findings reported in Lake Nasser (**Latif, 1984; Abd el-Monem, 1995; Hamed,**

2000; Gharib and Abd El-Halim, 2006; Abd El-Monem, 2008; Hussian et al., 2015 and 2016). Dominance of cyanobacteria is a phenomenon reported in many freshwater ecosystems. Studies in Argentina, Uruguay, and southern Brazil show that *Microcystis* predominates South American freshwater aquatic environments (**Almanza et al., 2019).**

The growth of cyanobacterial blooms is not limited to high temperatures, at least in any intensively studied temperate lakes in North America and Europe, where blooms are found at the beginning of the spring growing season (Reynolds, 2006). Over the past decades, there has been a worldwide increase in the occurrence and distribution of cyanobacterial blooms (Paerl and Paul, 2012; Paerl, 2014; Li et al., 2016 and Haakonsson et al., 2017).

Many investigators tried to pinpoint the deterministic factors for the anarchical dominance of cyanobacteria in different water resources. Light, Temperature, N, P, C, grazing and microbial interactions have been reported by **Pearl et al. (2001)** as the major factors that may be involved in the dominance of cyanobacteria. The ratio between total nitrogen (TN) and total phosphorus (TP) is one of the strongest and disputed explanations for the cyanobacterial blooming. **Smith (1983)** studied the algal flora of 17 lakes located worldwide and concluded that bloom-forming cyanobacteria tended to dominate in lakes where the TN:TP ratio was less than 29. This conclusion has led to the so-called ‘‘TN:TP rule’’. Some authors support this rule **(Aleya et al., 1994; Jacoby et al., 2000)**, but others hold the reverse view **(Pearl et al., 2001). Xie et al. (2003)** found that *Microcystis* blooms developed in sediments rich in phosphorus which leads to a remarkable decrease of TN:TP ratios to about 10. This result may indicate that the TN:TP ratio is not a deterministic factor for *Microcystis* blooms at least in the eutrophic Lake Donghu. **Pearl et al. (2001)** also suggested that the ‘‘N:P rule’’ is less applicable to eutrophic systems when both N and P loadings are very high. They stated that the absence of *Microcystis* blooms was most probably due to low availability of phosphorus, <10μgL^{-1}, regardless it was N- limited or not. **Sas (1989)** suggested that if reactive phosphate was <10 μgL^{-1} and nitrogen<100μgL^{-1}, cyanobacterial growth was assumed to be P and N-limited during the growing season. Findings of **Sas (1989) and Xie et al. (2003)** may, in part, explain the cyanobacterial dominance in Lake Nasser. The results of the present investigation revealed that cyanobacteria dominated in Lake Nasser at very low TN:TP, sometimes <1, a great excess of TP (≥ 600 μg/L) and considerable concentration of TN, specifically NO_3 form that sharply decreases during the bloom in Khor Abu-Simble. Another important mechanism is that *Microcystis* is superior competitors under conditions of low ammonium nitrogen concentrations and low NH_4/NO_3 ratio which was always less than 1 in both Ramla and Abu-Simbel. These results concordant with the findings of **Jacoby et al. (2000)** in Meiliang Bay and **Liu et al. (2011)** in Lake Taihu that *Microcystis* species tended to dominate at low NH_4-N: NOX-N (<1) during higher temperatures.

Temperature is one of the environmental parameters that considered as a key driver of cyanobacterial blooming. Generally, cyanobacteria have high temperature optima for growth and frequently dominate at higher temperatures (more than 20 ℃) **(McQueen and Lean, 1987)**. Harmful cyanobacteria such as *Microcystis* populations have been shown to dominate at, or above 25 °C **(Robarts and Zohary, 1987; Nalewajko and Murphy, 2001 and Chen et al., 2003)**. Average temperature values in this study ranged between 20 and 29°C, this range was suitable for the outburst of *Microcystis* as reported by **Tian et al. (2012)**. Moreover, the stability of thermal stratification helps *Microcystis* to benefit from buoyancy and to persist in the water column for a longer period of time **(Carey et al., 2012)**. In Lake Nasser, *Microcystis aeruginosa* scums formed during spring, when the temperature exceeded 25 °C and the water column was stratified and stable. This indicates that high nutrient concentrations (mainly TP), low NH_4-N: NOX-N (<1) and increased temperature act synergistically to initiate and intensify the blooming of *Microcystis* as reported by **Harke et al. (2016).**

In addition to the profound effects of the abiotic factors on cyanobacterial blooming in Lake Nasser, grazing by zooplankton and filter-feeding fish can also play an important role in cyanobacterial proliferation. Although some authors showed substantial ingestion of cyanobacteria by zooplankton **(Wang et al., 2010; Leitão et al., 2018)**, the majority found that other groups of phytoplankton are preferred for zooplankton grazers. Size, morphology, nutritional quality and toxins secretion are the main factors controlling zooplankton selectivity towards natural feeding **(Rollwagen-Bollens et al., 2013)**. Several mesozooplanktons, like cladocerans and copepods that comprise about 85% of the total zooplankton in Lake Nasser in spring **(Hegab, 2015)** are poor grazers of cyanobacteria **(Tillmanns et al., 2008)** but preferentially graze other phytoplankton groups. This would decrease competition for nutrients allowing cyanobacteria to grow faster and facilitate bloom propagation **(Davis et al., 2012)**. Moreover**,** *Microcystis* spp. in Lake Nasser characterized by large size, >50µ in diameter, which considered as a strategy of survival to resist zooplankton grazing that forbids zooplankton ingestion **(Lehman, 1988)**. Filter-feeding fish in Lake Nasser, mainly tilapias, constitute an annual average of 73% of the total fish yield in Lake Nasser. Filter-feeding fish can enhance cyanobacterial blooming by selective feeding on diatoms which reduce competition with cyanobacteria **(Wang et al., 2004; Zhang et al., 2006 and Wang et al., 2016)**.

In conclusion, there are seasonal and spatial variations in phytoplankton succession and distribution in Khor Abu-Simbel and Khor Ramla. Flood cycle clearly affects physico-chemical parameters, thereby affects abundance, biovolume and carbon content of phytoplankton in Lake Nasser. A combination of physical, chemical and biological factors rather than a single factor act in harmony to control the composition of phytoplankton community in Lake Nasser. Regular monitoring of Lake Nasser is recommended to follow up the changes in its phytoplankton composition and water characteristics to ensure its quality and as an important step to enhance fish production in Lake Nasser.

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تنوع العوالق النباتية في مستودع ماء شبه استوائي وشبه جاف، مع إشارة خاصة لازدهار السيانوبكتيريا في فصل الربيع

دعاء عبد الله السيد قاسم[١]، محمد سعد عبد الكريم[١]، أحمد عبد الرحمن العوامرى[٢]، أمل إبراهيم صالح[٢]

١ – المعهد القومي لعلوم البحار والمصايد.

٢ – قسم النبات–كلية العلوم–جامعة عين شمس.

تلعب بحيرة ناصر دورا أساسيا فى الاقتصاد القومى المصرى، وتعد العوالق النباتية من أكثر المجموعات الطحلبية أهمية في سلاسل الغذاء والبيئات المائية. تهدف هذه الدراسة إلى تقدير الاختلافات المكانية والزمانية فى الحجم الحيوي والمحتوى الكربوني والتركيب النوعي للعوالق النباتية فى خور الرملة وخور أبو سمبل في بحيرة ناصر، خلال أعلى مستوى للمياه في أول الخريف وأقل مستوى للمياه في آخر الربيع. تم اختيار تسع محطات فى كل من الخورين للدراسة خلال عام 2014. أسفرت هذه الدراسة عن تسجيل 180 نوعا من العوالق النباتية تضم 94 نوعا من الطحالب الخضراء، و52 نوعا من السيانوبكتيريا، و32 نوعا من الدياتومات، ونوعين من الدينوفلاجيلات. كانت الأنواع *Microcystis comperei, M. aeruginosa* and *Lyngbya limnetica* هى السائدة من الطحالب الخضراء المزرقة، بينما سادت *Cosmarium* spp., *Coelastrum reticulatum, Oocystis borgei, Eutetramorus fottii, Ankistrodesmus spiralis, Pediastrum simplex, Euastrum* sp. and *Dictyosphaerium pulchellum* الطحالب الخضراء فى هذه الدراسة. كانت الأنواع *Aulacoseira granulata, A. ambigua, A. muzzanensis, Cyclotella ocellata,C. glomerata* and *Cymbella affinis* هى السائدة من الدياتومات، وسادت السيانوبكتيريا في الخورين خلال فترة الدراسة، مع ازدهارها بشكل واضح في جميع محطات خور أبو سمبل خلال فصل الربيع. كان متوسط الحجم الحيوى الكلى فى خور أبو سمبل فى فصل الربيع (81.63 ملم^3/ لتر) أعلى منه فى خور الرملة (1.94 ملم^3/لتر). بينما في فصل الخريف، كان متوسط الحجم الحيوي الكلي في خور الرملة (3.65 مم^3/ لتر) وأبو سمبل (3.09مم^3/لتر) مختلفين اختلافا بسيطا. وقد سجل أعلى محتوى كربونى لجميع المجموعات الطحلبية ما عدا الدياتومات فى خور أبو سمبل خلال فصل الربيع، في حين سجل أعلى محتوى كربوني في السيانوبكتيريا والدياتومات في خور الرملة فى الخريف بينما سجل أعلى محتوى كربوني في الطحالب الخضراء والدينوفلاجيلات في هذا الخور فى فصل الربيع. اشتملت الدراسة على مناقشة تفصيلية للأسباب التى أدت إلى سيادة السيانوبكتيريا وازدهارها في بحيرة ناصر. أظهرت نتائج تحليل CCA أن مزيجا من العوامل الفيزيائية والكيمائية والبيولوجية تعمل معا فى توافق لتتحكم فى ديناميكية مجتمع العوالق النباتية وتكوينها في خور الرملة وخور أبو سمبل.