



Ecological status of Lake Nasser Khors, Egypt, before operating the Grand Ethiopian Renaissance Dam

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Abstract

Lake Nasser is an artificial reservoir that represents the national freshwater reserve of Egypt and has a number of khors (side extensions) along its eastern and western banks. These khors covered approximately 79% of the lake's total surface area and have an important effect on water quality and fish production in the lake. This study aimed to monitor and assess the water quality, distribution, and structure of the biotic community, including phytoplankton, zooplankton, macrophytes, epiphytes, and macrobenthos in two main khors (Tushka West and Dahmeit) during postflood and preflood periods. There was urgency associated with the study, as it was the last opportunity before the storing of the water behind the Grand Ethiopian Renaissance Dam (GERD), which had begun to fill in July 2020. Although the study confirmed that the water quality of Lake Nasser was good, it is classified as a eutrophic lake (depending on the levels of Chlorophyll-*a* and nutrients). This study found that pH, NO₂, SiO₄, NH₄, PO₄, and temperature were the factors with the greatest effect on the biota community, especially in Dahmeit Khor. In contrast to the phytoplankton and macrobenthos, the highest total density of zooplankton and epiphytic microalgae were detected during the postflood period. This study could be useful in monitoring possible changes in the Lake Nasser environment after the complete filling of the GERD reservoir.

Keywords Aquatic organisms · Macrophytes · Water variables · GERD · Flood · Lake Nasser · Khors

1 Introduction

Lake Nasser is a relatively closed ecosystem with very irregular shoreline characterized by the presence of 85 inundated valleys called khors (The habitats for fish breeding and feeding). There are approximately 48 khor on the eastern side and 37 on the western side of the lake. Khors which have perimeters of more than 100 km at a water level of 180 m MSL include: Kalabsha, Wadi El-Allaqi, Kurkur, Korosko, Khor El-Birba (El-Ramla), Rahma, Dahmeit, Shaturma, Wadi Abyad, Mariya Masmas, Tushka, and Or (Latif 1984). According to Goher and Ali (2009), the total length of the khor systems when the lake is full, i.e., at water level 180 m MSL, is nearly 3,000 km. The total surface area of the khors is 4,900 km² (79% of total lake surface). In volume, they contain 86.4 km³ of water (55% of the total lake volume). The khors are the main source of fish caught in the lake (about 90%) (Goher et al. 2021b). Some khors represent auxiliary, semiisolated lakes. Allaqi, Kalabsha, and Tushka Khors

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are the largest, while others like Korosko and El-Sadake are relatively narrow. Lake Nasser and its Khors are vital participants in the water resources and economy in Egypt, therefore, the regular studies of the environmental status, aquatic communities is of great importance for the full assessment of the complete environmental situation of the Lake Nasser and its khors (e.g. Samaan and Gaber 1976; Latif 1984; Abd El-Monem 1995; Taha and Mageed 2002; El-Shabrawy and Dumont 2003; Ali and Soltan 2006; Goher and Ali 2009; El-Serafy et al. 2009; El-Enany 2009;; Abd El-Karim 2014; Hussian et al. 2015; Khalifa et al. 2015; Abdel Gawad and Abdel-Aal 2018; Rizk et al. 2020; Shalloof et al. 2020; Goher et al. 2021b; Haroon and Abd Allah 2021; Nassif 2021; Zaher and Aly 2021).

The water resources of Egypt are very limited, therefore any future activities and perturbations on the lake due to the construction of the Grand Ethiopian Renaissance Dam (GERD), which began filling in July 2020, should be carefully considered before implementation. In context, the current study aims to evaluate the water quality, structure and distribution of biotic communities in Tushka West and Dahmeit Khors of Lake Nasser during postflood (November 25–30, 2019) and preflood (June 22–27, 2020) as the last opportunity before the storing of water behind the GERD. By recording the ecological status of Nasser Lake before water storage by the GERD reservoir commences, this study should be useful in monitoring its overall ecological status. Additionally, this study enables the monitoring of possible changes in the lake's environment and ecology which may result from effects of the GERD.

2 Materials and methods

2.1 Study area

Water samples were collected from five sites each in Tushka West and Dahmeit Khors during the postflood 2019 (November) and preflood 2020 (June) periods (Table 1; Fig. 1). Those two khors were chosen to represent the different khor types of the lake. Tushka West Khor is one of the largest Lake Nasser khors, contains 17 islets, some of which are usually fully exposed and some others which are covered by water during high flood periods. It is located in the south-west of the lake between 22°31'41.3" and 22°43'27.5" N latitude, and 31°32'19.7" and 31°47'08.7" E longitude, and is separated from the main channel of the lake with a wide natural water channel of 11.25 km width with no outlet. It extends for 34.5 km in an east–west direction, with a maximum width of 12.7 km, total surface area of 184.8 km², regular bottom topography, and medium water depth (from a few centimeters to ≤ 30 m). The shallower water depths are primarily found close to the

Table 1 Geographical coordinates of sampling stations in Nasser Lake khors

Sampling Khors	Stations code	Latitude N	Longitude E
Tushka Khor	T1	22°32'1.51"	31°47'3.32"
	T2	22°34'25.82"	31°44'44.18"
	T3	22°37'50.12"	31°41'35.19"
	T4	22°36'0.97"	31°40'42.09"
	T5	22°33'14.10"	31°43'17.78"
Dahmeit Khor	D1	23°44'55.98"	32°57'31.73"
	D2	23°45'29.31"	32°59'2.32"
	D3	23°44'51.30"	32°59'52.12"
	D4	23°45'4.39"	33° 1'6.49"
	D5	23°43'51.66"	33° 2'0.44"

shoreline and along the western bank of the khor; however the deeper depths exist near the inlet of the khor (Abd ullah and El-Geziry 2016). Meanwhile, Dahmeit Khor is smaller compared to Tushka West Khor, and is located in the north-eastern corner of the lake and includes 10 islets. This khor occupies the area between 23°43'21.4" and 23°48'01.4" N latitude, 32°57'22" and 33°03'17.6" E longitude, and is connected to the main channel of Lake Nasser by a natural narrow mouth (0.45 km width) with no outlet. This khor spreads in the east–west direction, with a total length of 12.4 km, a maximum width of 0.9 km, and a surface area of 12.0 km². This khor is classified as a deep water khor with no regular bottom topography, and has depths which vary between a few centimeters and 55 m. The greatest water depths are found near the entrance of the khor, however the shallowest depths occur near the shoreline and along the eastern side of the Khor.

2.2 Sampling program

2.2.1 Abiotic characteristics

Subsurface and bottom water samples were collected using polyvinyl chloride water samplers (2L). Glass stoppered oxygen bottles were used for measurements of dissolved oxygen (DO) and biochemical oxygen demand (BOD), and were carefully filled with water samples. Water temperature (°C), pH, and conductivity (EC, $\mu\text{S cm}^{-1}$) were measured in-situ using a Hydrolab multiparameter (Orion Research Ion Analyzer 399A, Orion Research, Cambridge, MA, USA). Water transparency was measured using a white/black Secchi disk (25 cm in diameter). Total solids (TS), Total dissolved solids (TDS), Total suspended solids (TSS), Water Alkalinity, Chlorides (Cl^-), DO, BOD, Chemical Oxygen Demand (COD), Nitrogen–Ammonium (N-NH_4), Nitrogen–Nitrite (N-NO_2), Nitrogen–Nitrate

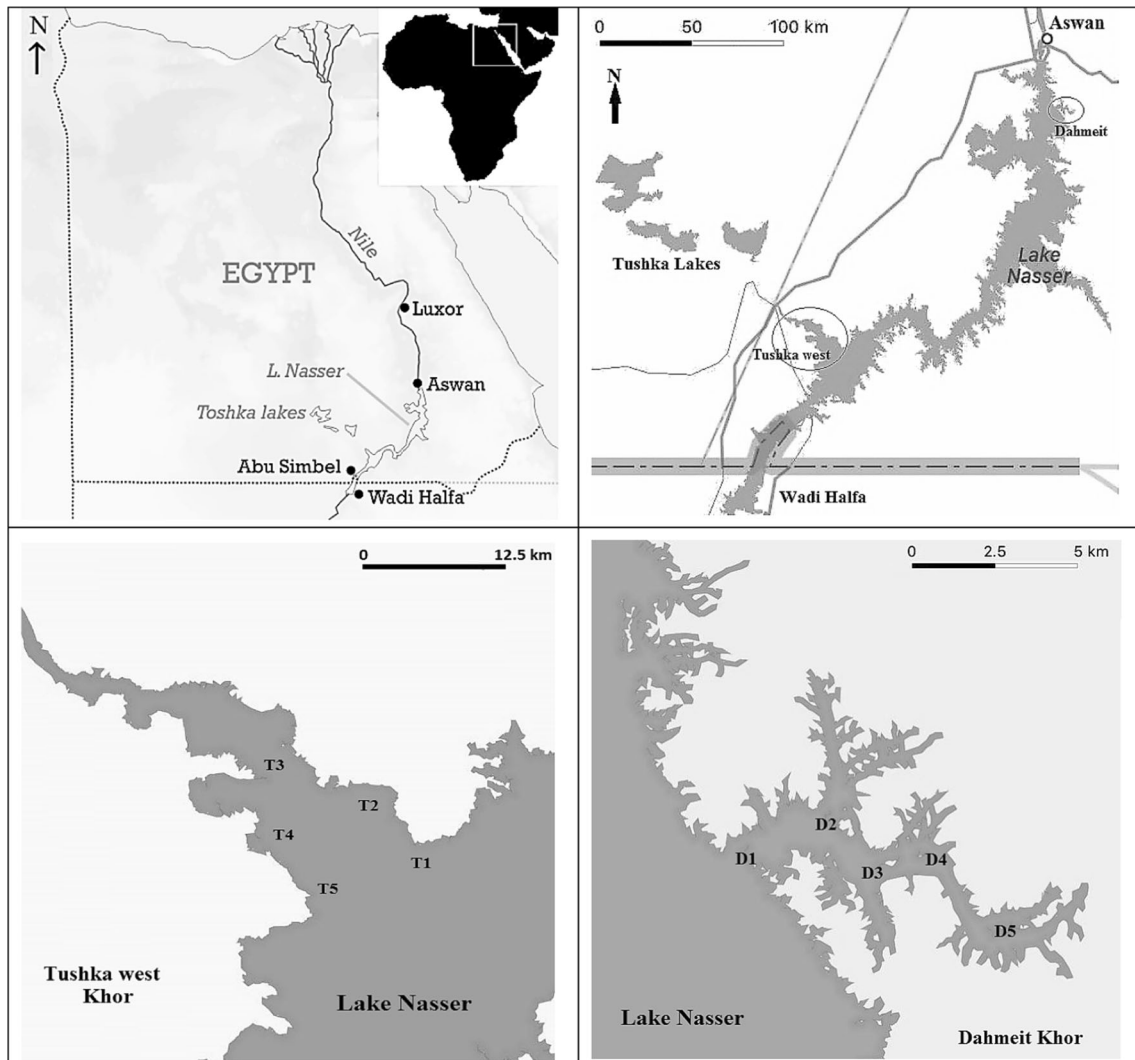


Fig. 1 The map of locations and the sampling sites in Nasser Lake khors (after Abdel Gawad and Abdel-Aal, 2018)

(N-NO_3), Orthophosphates (P-PO_4), Silicates (SiO_4), Calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), and potassium (K^+) levels were determined using the methods discussed by the American Public Health Association (APHA 2005).

2.2.2 Biotic characteristics

Planktons (phytoplankton and zooplankton), macrophytes, and attached epiphytic microalgae were collected, prepared, and preserved according to the methods described by Goher et al. (2021b). The macrophyte samples were identified according to Boulos (2005). The phytoplankton and epiphytic microalgae species were identified according to previous studies (Cleve-Euler 1952; Prescott 1978; Wehr and Sheath 2003; Komárek and Zapomělová 2007; Taylor et al. 2007). The zooplankton species were identified according to previous studies (Edmondson 1959; Pennak

1978; Verheye and Dumont 1984). The macrobenthos samples were collected using an Ekman grab sampler (opening area of 750 cm^2). Three grab samples were taken from each station at the upper layer of the bottom sediments. The samples were immediately washed to remove adhering sediments, sieved through a $500 \mu\text{m}$ mesh diameter net, and preserved with 10% formalin. In the laboratory, the samples were washed and sieved through a $500 \mu\text{m}$ mesh diameter net and preserved with 7% formalin. The benthic animals were identified according to previous studies (Wirth and Stone 1956; Habashi 1993; Brinkhurst and Jamison 1971; Brown 1980; Madden 2010).

2.3 Statistical analyses

The summary statistics of data obtained (minimum, maximum, mean) and correlation (predictive statistics) were carried out using the XLSTAT 2013 add-on for Microsoft

Excel. The correlation coefficients were considered significant at the 95% confidence level ($p \leq 0.05$). The percentage of the coefficient of variability (CV) was calculated using Microsoft excel program 2019. The multivariate analysis method of Canonical Correspondence Analysis (CCA) was performed using the CANOCO v. 4.0 program (Ter Braak and Smilauer 1998). This elucidated the relationships between the water characteristics and the aquatic organisms within different sampling stations in Tushka and Dahmeit Khors during post and pre-flood periods.

3 Results and discussion

3.1 Water characteristics

The physicochemical characteristics of water in Tushka and Dahmeit Khors are shown in Tables 2 and 3. Temperatures fell within the expected range according to the period of sampling, and varied from 20.8 °C for the bottom water at Dahmeit Khor during the pre-flood period, and 30.6 °C for surface water of Tushka Khor, during the same season. ANOVA data showed a highly significant difference ($p < 0.001$) between the pre-flood and post-flood periods, and a remarkable difference ($p < 0.05$) between the surface and bottom water. In general, the water temperature was suitable for fish growth (Talab et al. 2016; Goher et al. 2019). Secchi disc measurements (transparency) reflected the clarity of the water column and the penetration of the light to the deeper layers (Goher et al. 2015, 2018). The decrease in water clarity at Tushka Khor (250 cm, on average) compared to Dahmeit Khor (368 cm, on average) was obvious. An opposite result was observed for TSS, which increased in Tushka Khor in the south of the lake. These results may be related to the velocity of the water current, which is reduced northward where Lake Nasser is characterized by riverine and lacustrine behavior in the southern and northern sections, respectively (Goher et al. 2021b; Hassan et al. 2021). In the same context, EC and TDS notably increased in the northern Dahmeit Khor, especially during the post-flood period. This was likely because the flood water was loaded with different ions, with a temporal difference ($p < 0.001$) and CV values of 12.47% and 6.43% during post-flood and pre-flood, respectively. In general, the water of Lake Nasser khors was classified as having low EC and TDS in comparison to Nile River water downstream of the High Dam. These findings were in harmony with the findings of Imam et al. (2020).

pH is one of the most important parameters in water quality. It affects most biological and chemical processes, and determines the solubility and biology of chemical constituents such as nutrients and heavy metals (Goher

et al. 2021a; USGS 2021). Concerning the results obtained, the water of the Lake Nasser khors were alkaline and varied between 7.69–8.85 and 7.7–8.92, with CV values of 4.29% and 4.71% during the post-flood and pre-flood periods, respectively. It is worth mentioning that the pH values were within the national and global acceptable limits (6.5–9) and are suitable for usages such as drinking, irrigation, and aquatic organisms' environment. This result is in agreement with those obtained by Rizk et al. (2020), Imam et al. (2020) and Goher et al. (2021b) for Lake Nasser, and El Sayed et al. (2020) for the Nile River.

DO is the most significant factor in the aquatic ecosystem. It is a critical component not only for plant and animal survival but also for water quality and chemical reactions within water bodies (Sensorex 2021). The water of studied khors of Lake Nasser was oxygenated during the study periods. The average values of DO recorded were 6.59 and 6.09 mg/L, with CV values of 26.94% and 19.03%, respectively, during the post-flood and pre-flood periods. The slight decrease of DO values during the pre-flood period was attributed to the elevation of water temperature that reduced the solubility of oxygen in the water (Goher et al. 2019; Hassouna et al. 2019). The BOD and COD, which are functions of organic water pollution (Goher et al. 2014), were at low levels of 3.15 and 1.91 mg/L, on average, with CV values of 11.06% and 3.54% for BOD during the post-flood and pre-flood periods, respectively; and 5.3 and 4.75 mg/L, on average, with CV values of 27.11% and 39.37% for COD, respectively, during the post-flood and pre-flood periods. Based on the general average of BOD and COD in Dahmeit khor (2.35 and 5.18 mg/l, respectively) and Tushka khor (2.72 and 4.86 mg/l, respectively), the results obtained revealed that the water of the khors of Lake Nasser was not contaminated with organic pollutants, and they were, in general, below the standard levels of 3 and 10 mg/L for BOD and COD, respectively. However, the relative increase of BOD during the post-flood period may be attributed to the abundance of microorganisms in Lake Nasser water after flooding, as reported by Goher et al. (2021b).

The basic nutrient salts, except PO_4 , increased in the post-flood period with a highly significant temporal difference ($p < 0.001$) between post-flood and pre-flood periods which coincides with those obtained by Goher et al. (2021b). Generally, ammonia and nitrate were seen to fluctuate widely, with ranges of 39.44–867.0 $\mu\text{g/L}$ and 18.4–803.2 $\mu\text{g/L}$, respectively, with a high coefficient of variations of 88.1% and 55.67% for NH_4 and 103.46%, and 68.17% for nitrate in post-flood and pre-flood periods, respectively. In contrast, low levels of NO_2 and PO_4 were observed with average values of 12.62 and 8.58 $\mu\text{g/L}$, and 9.52 and 22.1 $\mu\text{g/L}$ in post-flood and pre-flood periods,

Table 2 Water characteristics of Dahmeit khor during postflood and prefflood periods

Parameters	Post flood (winter 2019)						Pre flood (summer 2020)									
	Surface water			Bottom water			Surface water			Bottom water						
	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD				
T, °C	23.10	23.70	23.32	0.25	21.70	23.70	22.98	0.76	27.03	27.70	27.39	0.26	20.80	24.87	22.66	1.82
Trans. cm	230.00	480.00	376.00	92.36	–	–	–	–	290.00	450.00	360.00	70.00	–	–	–	–
EC, µS/cm	256.00	322.00	288.20	25.36	266.00	324.00	292.60	25.00	232.00	238.00	235.40	2.41	244.00	259.00	252.80	6.94
TDS, mg/l	166.40	209.30	187.33	16.48	172.90	210.60	190.19	16.25	150.80	154.70	153.01	1.57	158.60	168.35	164.32	4.51
TSS, mg/l	4.13	6.42	5.22	0.86	4.22	6.67	5.36	0.93	3.89	5.41	4.63	0.66	4.14	5.53	4.75	0.59
TS, mg/l	171.33	215.72	192.55	17.20	177.85	217.27	195.55	17.06	156.02	158.59	157.64	1.00	164.13	173.54	169.07	4.40
pH	8.03	8.32	8.17	0.12	7.69	8.46	8.16	0.32	8.72	8.84	8.77	0.05	7.70	8.18	7.92	0.20
DO, mg/l	4.40	8.00	5.60	1.41	2.80	6.80	4.88	1.45	5.24	7.52	6.37	1.10	3.45	7.22	5.19	1.80
BOD, mg/l	1.60	4.00	2.48	1.00	1.84	3.60	3.01	0.83	1.44	3.30	2.25	0.73	0.89	2.96	1.65	0.83
COD, mg/l	4.37	6.09	5.46	0.65	5.48	6.38	5.91	0.35	4.47	4.84	4.68	0.15	4.38	4.84	4.69	0.19
NH ₄ , µg/l	39.44	153.00	118.05	47.38	134.30	867.00	332.52	306.81	79.90	221.00	151.98	56.79	57.80	193.80	152.66	56.05
NO, µg/l	9.20	22.80	14.80	5.76	4.80	18.80	12.72	6.00	4.00	6.00	4.56	0.83	2.80	32.00	9.68	12.50
NO ₂ , µg/l	52.00	92.80	74.56	15.17	18.40	135.20	76.32	46.55	30.40	83.20	55.04	22.06	44.80	158.40	85.60	54.01
PO ₄ , µg/l	5.50	9.90	7.48	1.63	6.60	34.10	14.08	11.31	19.54	27.68	23.95	3.61	22.79	30.93	28.49	3.36
TP µg/l	17.92	28.94	24.39	4.11	22.96	94.85	44.47	28.66	42.65	50.16	46.17	3.49	46.79	58.14	53.36	4.35
SiO ₄ , mg/l	6.81	7.37	7.09	0.22	6.67	7.37	6.95	0.28	3.56	5.84	4.41	0.90	4.28	6.12	5.14	0.74
CO, mg/l	0.00	3.60	1.98	1.61	0.00	3.60	1.44	1.36	1.50	4.50	3.00	1.50	0.00	1.50	0.60	0.82
HCO, mg/l	106.22	121.28	115.46	6.03	108.84	128.70	118.47	9.06	97.88	101.35	99.18	1.45	106.53	117.71	113.21	4.73
Cl, mg/l	10.06	10.48	10.22	0.18	10.14	10.92	10.47	0.33	9.60	9.78	9.68	0.07	9.64	9.84	9.71	0.08
SO ₄ , mg/l	5.76	5.98	5.83	0.09	5.67	5.89	5.78	0.09	5.36	5.73	5.55	0.15	5.51	5.75	5.60	0.09
Ca, mg/l	14.60	16.30	15.08	0.70	14.20	16.80	15.08	1.03	14.26	14.47	14.33	0.08	14.58	14.98	14.79	0.17
Mg, mg/l	8.98	10.87	9.75	0.77	9.08	10.82	9.93	0.80	8.63	8.83	8.71	0.07	8.55	8.86	8.65	0.13
Na, mg/l	13.32	16.65	14.35	1.32	13.52	16.82	14.57	1.35	12.36	12.79	12.55	0.16	12.52	12.85	12.64	0.13
K, mg/l	3.89	4.56	4.25	0.30	4.02	4.68	4.31	0.32	4.12	4.36	4.27	0.10	4.22	4.34	4.27	0.05
Chl- <i>a</i> , µg/l	43.06	112.82	73.82	28.32	56.87	121.48	81.87	24.61	39.44	153.00	118.05	47.38	134.30	367.00	232.52	102.53

respectively, with CV values of 34.74% and 82.11% for NO_2 , and 72.59% and 29.44% for PO_4 .

Similar to the observed distribution pattern of nutrient salts, the major ions, except SO_4 , recorded higher values after flooding. The average values were 108.27 and 98.45 for HCO_3 , 9.83 and 9.39 for Cl, 14.28 and 13.37 for Ca, 9.23 and 8.47 for Mg, 13.34 and 11.71 for Na, and 4.44 and 4.14 mg/L for K, on average, in postflood and preflood periods, respectively. In turn, SO_4 showed higher values during the preflood period, recording 6.14 mg/L on average, compared to 5.91 mg/L during the postflood period. Anions and cations, except CO_3 , had low CV values ranging between 2.74% for Mg during the preflood period, and 10.78% for Na during the postflood period. Most anions and cations were highly positively correlated with EC and TDS ($r = 0.84\text{--}0.94$, $n = 40$; $p < 0.001$). In contrast, they showed a significantly negative correlation with temperature ($r = -0.53$ to -0.74 , $n = 40$; $p < 0.001$). The levels of the major anions and cations in the khor water do not cause any adverse, negative, or harmful effects on potability (EWQS 2007; USEPA 2018; WHO 2017), agriculture according to FAO (Ayers and Westcot 1985), or aquatic organisms (USEPA 2021; CCME 2007).

In addition to transparency, EC and TDS; as mentioned above; pH and DO showed a significantly high difference between Dahmeit and Tushka khors ($p < 0.001$), while ANOVA Data of COD recorded a significant difference ($p < 0.05$). The average values of pH, DO, COD, HCO_3 and Na were (8.25 and 8.77; CV 4.48 and 1.48%), (5.51 and 7.27 mg/l; CV 26.4 and 14.17%), (5.18 and 4.86 mg/l; CV 12.46 and 5.1%), (111.6 and 95.15 mg/l; CV 8.39 and 5.02%) and (13.52 and 11.52 mg/l; CV 9.59 and 6.45%) in Dahmeit khor and Tushka khor, respectively. On the contrary the other parameters such as NH_4 , NO_3 , NO_2 , PO_4 , SiO_2 , CO_3 , Cl, Ca and Mg did not show any significant difference.

In general, water quality refers to specific desired levels of the chemical, physical, and biological characteristics of water, based on identified uses for aspects of life (UNP 1997). Accordingly, the hydrographic characteristics and chemical constituents of Lake Nasser khors were within the national (EWQS 2007) and global (USEPA 2018, 2021; WHO 2007; Ayers and Westcot 1985; CCME 2007) permissible levels for the identified uses. This finding confirms the good quality of Lake Nasser water and establishes that the water of Lake Nasser is considered a blank site (standard sample) for any change or contamination of the water downstream of the High Dam. Additionally, the most effective factor for altering the measured parameters was flooding, where most of the water constituents showed a significantly high temporal difference ($p < 0.001$), except for DO, which recorded similar levels during both periods. In contrast, most parameters, except temperature and pH

values, did not show remarkable variations between surface and bottom water. It is worth mentioning that there were highly significant differences ($p < 0.001$) for most parameters between Dahmeit Khor and Tushka Khor.

3.2 Assemblages of aquatic organisms

In a complex natural environment, such as Lake Nasser, where several factors operate simultaneously, it is not easy to generalize and designate some factors as being more important than others. The yearly flood of the Nile, which occurs in August and originates from the Ethiopian Highlands is the most important factor affecting the ecosystem of Lake Nasser, and hence it may affect the temporal distribution, abundance, and community composition of organisms in the lake (e.g., planktonic algae, epiphytic algae, zooplankton, macroinvertebrates, etc.) (Samaan and Gaber 1976; El-Serafy et al. 2009; Abdel Gawad and Abdel-Aal 2018; Goher et al. 2021b). The changes in the density of the aquatic organisms (Fig. 2), and the macrophyte abundance in Lake Nasser khors (Tushka and Dahmeit) during the flood cycle could be summarized as follows:

3.2.1 Planktons

The density and composition of phytoplankton can indicate the trophic status and affect the food web structure in aquatic ecosystems (Jeffrey and Vesik 1997; Leterme et al. 2006). The associations between phytoplankton and zooplankton are well known. Specifically, the distribution and biomass of phytoplankton is not solely affected by the physicochemical properties of water, but grazing by zooplankton is also an important factor (Kawecka and Eloranta 1994; Burkepile and Hay 2006; Pascal and Fleeger 2013; Yuan and Pollard 2018). This concept is established in the present study by the negative relationship between those two groups, as shown in Fig. 2A, B.

The phytoplankton assemblages observed in Tushka and Dahmeit Khors were comprised of seven phyla: Cyanobacteria, Bacillariophyta, Charophyta (planktonic), Chlorophyta, Cryptophyta, Miozoa, and Ochrophyta. The Ochrophyta was only recorded during the postflood period and with only one species. In general, the density in the preflood period was higher than in the postflood period, and extended over threefold higher at sites T3 and T5 (Fig. 2 A&B), which may have contributed to the N/P ratio in the preflood period (~ 6 to 17), and the high temperatures during summer. Redfield (1958), Goldman et al. (1979), and Harris (1986) considered the atomic N/P ratio for phytoplankton to be approximately 16, and Trombetta et al. (2019) indicated that high temperatures induced phytoplankton growth. The total density in Tushka Khor ranged

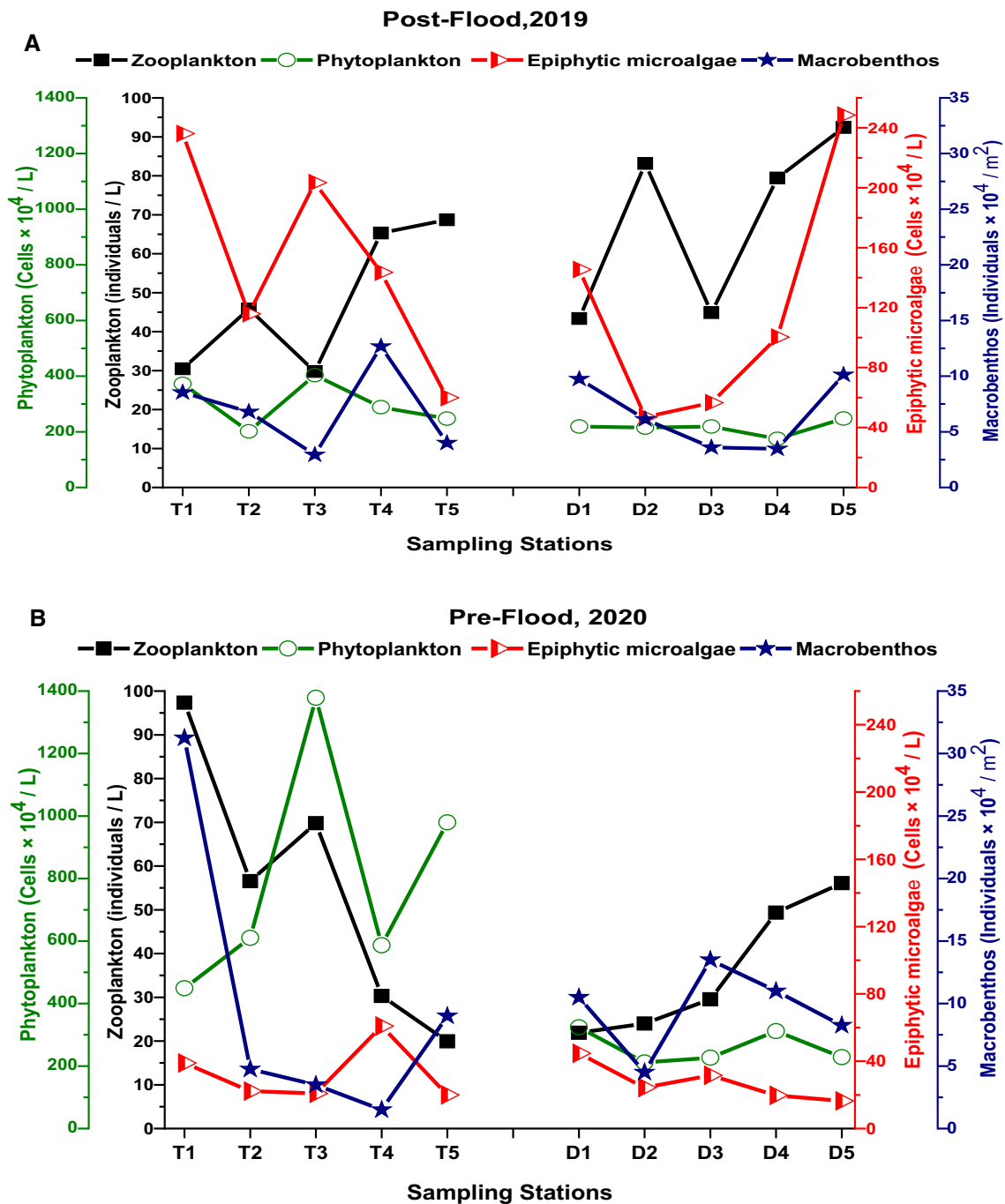


Fig. 2 Changes in density of aquatic organisms in the postflood period (A) and the prefflood period (B) in Tushka and Dahmeit khors

from 201.6 to 403.7×10^4 cells/L⁻¹ during the postflood period (Fig. 2A), and from 448.8 to 1378.3×10^4 cells/L⁻¹ during the prefflood period (Fig. 2B). The highest density was found at site T3 during both the post and prefflood periods. In Dahmeit Khor, the total density changed in the postflood period from 174.5 to 247.6×10^4 cells/L⁻¹ (Fig. 2A), and in the prefflood period from 211.4 to 323.7×10^4 cells/L⁻¹ (Fig. 2B). These results are confirmed by the higher average Chlorophyll-*a* values

found during the prefflood period ($171.11 \mu\text{g/L}^{-1}$), compared to $58.22 \mu\text{g/L}^{-1}$ during the postflood period. The highly positive correlation of Chlorophyll-*a* with PO₄ ($r = 0.59$, $n = 40$; $p < 0.001$) may indicate that phosphorus was the limiting factor. This finding was confirmed by the N/P ratio (> 16 , on average). Koerselman and Meuleman (1996) stated that nitrogen is the limiting factor at $N/P < 14$, and that at N/P ratios between 14 and 16 either N or P can be limiting, while $N/P > 16$ indicates that

phosphorus is the limiting factor. It is noteworthy that on the basis of nutrients content (Tables 2 and 3), Lake Nasser khors are considered eutrophic, and the levels of Chlorophyll-*a* found supported this observation and were in harmony with the findings of Hussian et al. (2015) and Hussian and Haroon (2019). According to Carlson and Simpson (1996) the eutrophic lakes contain a level of Ch-*a* and TP of more than 7.3 µg/l and 24 µg/l, respectively which is lower than the recorded levels in the studied area. Where, the Ch-*a* and TP contents in the two khors exceed these values, recording 126.56 and 102.76 µg/l (on average) and 42.1 and 42.44 µg/l (on average) in Dahmeit Khor and Tushka Khor, respectively.

Generally, the structure of phytoplankton in the two khors was similar. Cyanobacteria (22 spp.) were seen to dominate the phytoplankton assemblages by 69–77% and 80–92% of the total density in Tushka Khor, and by 73–79% and 66–89% in Dahmeit Khor, in postflood and pre-flood periods, respectively. The second most dominant group was the chlorophytes (51 spp.) making up 8–13.3% and 6–14% of the samples in Tushka, and 9–13.6% and 5.6–32% in Dahmeit during the postflood and pre-flood periods, respectively. Meanwhile, the diatom (31 spp.) share of the phytoplankton assemblages were 11–15% and 1.5–8.5% in Tushka Khor, and 10.8–12.5% and 2.5–7% in Dahmeit during the postflood and pre-flood periods, respectively.

During the postflood period, the highest densities of phytoplankton were found among *Chroococcus disperses*, *Chroococcus minimus*, *Cylindrospermopsis raciborskii*, *Merismopedia tenuissima*, and a *Pseudoanabaena* sp., comprising 0.6–64% of the total density. Meanwhile, during the pre-flood period, the phytoplankton community was dominated by *Aphanocapsa elachista* var. *conferta*, *C. minimus*, *Chroococcus minutus*, *C. raciborskii*, *M. tenuissima*, *Oscillatoria tenuis* var. *tergestina*, *Chlamydomonas globosa*, *Scenedesmus bijugatus* var. *alterans*, and a *Rhodomonas* sp., comprising 0–78% of the total density. These results were in agreement with previous findings of phytoplankton assemblages in Lake Nasser, and Egyptian ecosystems in general (e.g., Samaan and Gaber 1976; Latif 1984; Abd El-Monem 1995; Taha and Mageed 2002; Abdel-Hamid et al. 2014; Abd El-Karim 2014; Hussian et al. 2015; Abdel-Hamid et al. 2017; Abdel Gawad and Abdel-Aal 2018; Abdel-Aal 2021; Goher et al. 2021b; Zaher and Aly 2021).

The zooplankton assemblages observed in Dahmeit and Tushka Khors during the post and pre-flood periods were represented by twenty four species in three phyla: Copepod (2 spp.), Cladocera (6 spp.), and Rotifer (16 spp.). The total zooplankton density ranged from 30 to 69 ind. L⁻¹, and from 43 to 92 ind. L⁻¹, in Tushka and Dahmeit, respectively in the postflood period (Fig. 2A). In the pre-flood

period, the total density was generally lower and ranged from 20 to 97 ind. L⁻¹ in Tushka, and 22 to 56 ind. L⁻¹ in Dahmeit Khor (Fig. 2B). A noticeable increase was observed in downstream total zooplankton during the postflood period in both Tushka and Dahmeit Khors, and in pre-flood Dahmeit Khor (Fig. 2A&B). This observation may be due to the addition of high plankton densities resulting from the flood (Parmar et al. 2016). On the contrary, the downstream zooplankton density was decreased during the pre-flood season at Tushka (Fig. 2B), which is due to the movement of zooplankton away from the hot surface water during the summer (Goher et al. 2021b).

Generally, the relations in zooplankton structure consisted of Copepoda > Cladocera > Rotifera. In Tushka Khor, the average share of these phyla relative to the total density amounted to 72%, 14%, and 14% during the postflood period, whereas during the pre-flood period, it amounted to 59.15%, 22.7%, and 18.14%, respectively. While in Dahmeit Khor, these phyla amounted to 81.75%, 12.5%, 5.7%, and 56%, 16.17%, 27.69% during post and pre-flood periods, respectively. The presence and dominance of zooplankton species were spatial, where *Asplanchna priodonta*, *Ceiodaphnia cornuta*, and *Collotheca ornate* were the dominant species at Dahmeit Khor, comprising 0–9.7% and 0–23.4% of the total densities during the postflood and pre-flood periods, respectively. While, *Daphnia longispina*, *Diaphanosoma excisum*, and *Keratella cochlearis* were the dominant species at Tushka Khor, comprising 0–11.1% and 0–27.6% of the total densities during the postflood and pre-flood periods, respectively. Nauplius larvae was the most dominant form of copepod in both khors, with a high density ranging from 35.7% to 78.7% of total zooplankton density during the postflood period, and from 28 to 47% during the pre-flood period. These results agreed with the findings of El-Shabrawy and Dumont (2003), El-Serafy et al. (2009), Khalifa et al. (2015) and Goher et al. (2021b). Additionally, El-Enany (2009) found copepods comprised 68.8% of the total zooplankton in six khors of Lake Nasser. The dominance of copepods in Lake Nasser khors is due to the abundance of nauplius larvae which feed primarily on phytoplankton.

3.2.2 Macrophytes and attached epiphytic microalgae

The study of the diversity and distribution of aquatic macrophytes in a lake can provide crucial information about its productivity. These plants were recorded as an important component of the aquatic ecosystem, not only as a food source for aquatic invertebrates and fish (Sharshar and Haroon 2009) but also because they act as an efficient accumulator of nutrient elements and heavy metals (Elmorsi et al. 2019) which helps improve water quality. Additionally, they impact the growth, distribution, and

diversity of other aquatic organisms which have an effect on the functioning of wetland ecosystems (Haroon et al. 2020; Othman and Haroon 2020; Tahoun et al. 2021). The history of the diversity and distribution of Lake Nasser macrophytes was discussed by Haroon and Abd Allah (2021). They detected only three submerged macrophytes species (*Myriophyllum spicatum*, *Potamogeton schweinfurthii*, and *Najas marina*) at different sites in the lake throughout the period from 2013 to 2020, but these had a major impact on the lake ecosystem as mentioned by Ali and Soltan (2006).

During the present study period, only two submerged macrophytes species from two genera (*Myriophyllum spicatum* L., *Potamogeton schweinfurthii* A. Benn) were detected in the study area. During the winter *M. spicatum* L. (Haloragaceae) was found to be the most dominant and widely distributed, and was present in 100% of the sampling sites. In contrast, *P. schweinfurthii* A. Benn (Potamogetonaceae) was very rare and was recorded at only one site, T1. During the spring *M. spicatum* L. was the only recorded macrophyte species at the study site, which indicates the adaptability of this invasive species and its ability to thrive under different environmental conditions.

Many studies have stated the important role of epiphytic algae in primary productivity (e.g., Kupferberg 2003; Adam et al. 2017) and enhancement of macrophyte growth by providing nutrients via decomposition processes (Carvalho et al. 2015). However, the abundance of macrophytes may affect microalgae growth through allelopathic compounds (Körner 2006; Haroon and Abdel-Aal 2016). Generally, the epiphytes assemblages in Tushka and Dahmeit Khors comprised of four phyla: Cyanobacteria (25 spp.), Bacillariophyta (57 spp.), Chlorophyta (38 spp.), and Miozoa (5 spp.). The relation of epiphytic microalgae structure in both khors reversed between the two periods. In the postflood period, the shares of different groups in Tushka were Bacillariophyta (47–75%), Chlorophyta (19–42%), Cyanobacteria (5–10%), and Miozoa (0.1–0.7%), while the shares in Dahmeit were Chlorophyta (53–63%), Bacillariophyta (19–40%), Cyanobacteria (4–18%), and Miozoa (1–8%). Meanwhile, the shares of the different groups during the preflood period were Chlorophyta (71–74%), Bacillariophyta (19–25%), Cyanobacteria (1–4%), and Miozoa (0.1–0.7%) in Tushka Khor, and Bacillariophyta (47–58%), Chlorophyta (14–33%), Cyanobacteria (12–22%), and Miozoa (3–6%) in Dahmeit Khor. Other studies noticed the dominance of bacillariophyceae (e.g. Corlett and Jones 2007; Abdel-Hamid et al. 2017; Goher et al. 2021b), as diatoms stick to the macrophytes by producing extracellular polymeric substances (Tiffany 2011). The importance of bacillariophyceae is due to their use as bioindicators for the ecological status of aquatic environments (Pouličková

et al. 2004). The total density of epiphytic algae observed during the postflood period ranged from 59.9 to 236.2×10^4 Cells/g⁻¹ of macrophytes in Tushka Khor, and from 46.9 to 248.5×10^4 Cells/g⁻¹ of macrophytes in Dahmeit Khor (Fig. 2A). The highest densities were found at sites T1 and D5. During the preflood period, the total macrophyte density was lower and changed in Tushka from 20 to 60.9×10^4 , as well as in Dahmeit which changed from 16.4 to 44.7×10^4 Cells/g⁻¹ (Fig. 2B). The high concentrations of DO (8.20 mg/L), nitrates (387.36 µg/L), and silicates (7.65 mg/L) (Tables 3) during the postflood period may reveal the increasing density of epiphytic microalgae in Tushka Khor (Fig. 2A). The highest densities of epiphytic microalgae species were recorded for *Lyngbya limnetica* Lem., *Dictosphaerium pulchellum* Wood, *Oscillatoria perornata* Skuja, a *Mougeotia* sp., an *Oedogonium* sp., *Scenedesmus caudatus* Corda, *Cyclotella ocellata* Pant, *Gomphonema ventricosum* W. Gregory, *Melosira granulata* (Her.) Ralfs, *Navicula cryptocephala* Kutz, *Neidium dubium* (Ehrenberg) Cleve, and *Syndra ulna* (Nitzsch) which were at both khors and comprising 0–48.8% of the total density during the preflood period and 0.0–35.4% of the total density during the postflood period. The dominance of these epiphytes was confirmed by several previous studies (e.g., Hassan et al. 2014; Haroon et al. 2020; Abdel-Aal 2021).

3.2.3 Macrobenthic invertebrates

The benthic invertebrates in Lake Nasser khors exhibited marked spatial and seasonal variations. This was attributed to variations in the prevailing physicochemical conditions and their biological productivity. Twelve macrobenthic invertebrates species were identified in Dahmeit and Tushka Khors during the study period and were represented by four main phyla; Annelida (four spp.), Arthropoda (five spp.), Mollusca (two spp.) and Nematode (one sp.). Annelida was the dominant phylum during the present study and represented 70% by the number of the total macrobenthic fauna at Nasser Khors, followed by Mollusca (19%), Arthropoda (10%), and then Nematode which represented 1% of the total macrobenthic fauna at Lake Nasser khors. These results were in accordance to Wissa (2002), Sleem and Hassan (2010) and Khalifa and Bendary (2016) who recorded that Annelida and Mollusca were the main components of benthic fauna in the Nile River. This macrobenthic decline may be attributed to the nature of the bottom sediments and the availability of food sources, as they were considered the most significant factors determining macrobenthos distribution (Iskaros and El-Dardir 2010).

Generally, the highest densities of macrobenthos at Dahmeit and Tushka Khors were recorded during the

preflood period (Fig. 2), which is in agreement with the findings of Abdel Gawad and Abdel-Aal (2018). The population density of the macrobenthic fauna in Tushka Khor ranged from 293 to 1267 ind/m⁻² during the post-flood period (Fig. 2A), and from 150 to 3125 ind/m⁻² during the preflood period (Fig. 2B). The highest two peaks were at stations T1 (3125 ind/m⁻²; preflood) and T4 (1347 ind/m⁻²; postflood), due to the intensive number and dominance of Annelida and Mollusca, which may be attributed to the high DO concentrations (6.74 and 8.84 mg/L⁻¹), which causes flourishing of benthic communities, especially oligochaeta, according to Slavevska-Stamenković et al. (2010). Meanwhile, in Dahmeit Khor, the population density of the macrobenthic fauna ranged from 347 to 1013 ind/m⁻² during the postflood period (Fig. 2A), and from 450 to 1350 ind/m⁻² during the preflood period (Fig. 2B). The predominance of oligochaetes in the lake is possibly due to their ability to adapt to various habitats and to their tolerance of low oxygen or anoxic conditions. The dominance of oligochaetes seen in this study is in accordance with the findings of Abdel Gawad and Abdel-Aal (2018). During this study, *Limnodrilus udekemianus* was ranked as the highest percentage of total macrobenthic density, consisting of 34% and 68.3% in Tushka Khor, and 88.9% and 89.2% in Dahmeit Khor, during preflood and postflood periods, respectively. These findings were in agreement with Wahab et al. (2018).

3.3 Relation between the water variables and aquatic organisms

CCA identified various relationships between different organisms and water physicochemical characteristics, which varied according to sampling site and organism (Figs. 3 & 4). For example at Tushka Khor, the temperature had strong positive associations with Chlorophyll-*a*, total epiphytic microalgae, Cladocera, and Annelida ($r = 0.964, 0.749, 0.583$ and 0.758 , respectively) during the preflood period, while during the postflood period it showed a positive association with only Cladocera ($r = 0.57$), and a negative association with Copepoda ($r = -0.72$). For samples collected from Dahmeit Khor during the postflood period; pH, NO₂, SiO₂, NH₄, PO₄, and temperature were found to be the most effected factors, followed by TDS, BOD, and COD. For example, pH was positively correlated with total phytoplankton count, Cryptophyta (phytoplankton), Cladocera, Total epiphytic microalgae, E-Epi, Total Macrobenthos count, and Nematoda ($r = 0.51, 0.69, 0.62, 0.6, 0.6, 0.95, \text{ and } 0.72$, respectively), however it was negatively correlated with Cyanophyta, epiphytic microalgae, Copepoda, Cryptophyta (phytoplankton), Bacillariophyta (phytoplankton) ($r = -0.96, -0.52, -0.89, \text{ and } -0.79$ respectively).

Different relations were detected between different recorded organisms. For example: the total phytoplankton count was positively correlated with Rotifera, indicating that phytoplankton abundance can be stimulated by zooplankton, as recorded by Gołdyn and Kowalczyńska-Madura (2007). However, it was negatively correlated with Mollusca and total zooplankton ($r = -0.67$ and -0.68 , respectively). Also, total zooplankton was positively correlated with total Annelida and Nematoda counts ($r = 0.91$ and 0.522 , respectively), while it was negatively correlated with total epiphytic microalgae. ($r = -0.85$). Cyanophyta (phytoplankton) was positively correlated with Rotifera, total epiphytic microalgae, Chlorophyta (epiphytic microalgae) and Arthropoda ($r = 0.74, 0.85, 0.56, \text{ and } 0.74$, respectively).

These results indicated the cumulative effects of numerous environmental factors, organism requirements, and growth stages on behavior. It was therefore difficult to detect the main factors affecting distribution and diversity of aquatic organisms in the study area. These results were similar to findings reported by Abdel Gawad and Abdel-Aal (2018) Haroon et al. (2020), Tahoun et al. (2021) and Goher et al (2021b), where they recorded variable relations among epiphytes, macrophytes, phytoplankton, zooplankton, and macrobenthos at the Damietta branch and Rosetta branch of the Nile River, and at Lake Nasser.

3.4 Expected impacts of GERD

The GERD reservoir is intended to hold around 74 BCM of water at its full supply level (Ahmed and Elsanabary 2015). The design of GERD's storage capacity was increased from an initial 11 BCM to 67 BCM (at 145 m height), then to 70 BCM, and finally to 74 BCM in 2012. Although the storage of water behind the GERD began in July 2020s and continued for the third time in 2022s with a storage capacity of 22 BCM of water (Ethiopian Monitor 2022), the effects on the Nile River and the High Dam Lake have not yet been determined. Until now, there has been no agreement on the expected effects of GERD on the downstream countries among scientists and riparian states. Some expect the positive effects of GERD for growth and prosperity, and others with the fact that GERD will be a curse in both Egypt and Sudan (Li et al. 2022).

Adverse impacts include the reduction of water level and storage volume in Lake Nasser, which may results on rapidly differences in the bathymetric chart of the lake (Abd Ellah and El-Geziry 2016). A reduction of energy generation of Aswan High Dam (AHD) especially through the filling period of GERD reservoir is, also, expected. The annual losses from AHD Lake is expected to increase by about 6% in case of AHD alone and the water salinity (TDS) will increase (Abdelhaleem and Helal 2015; El-

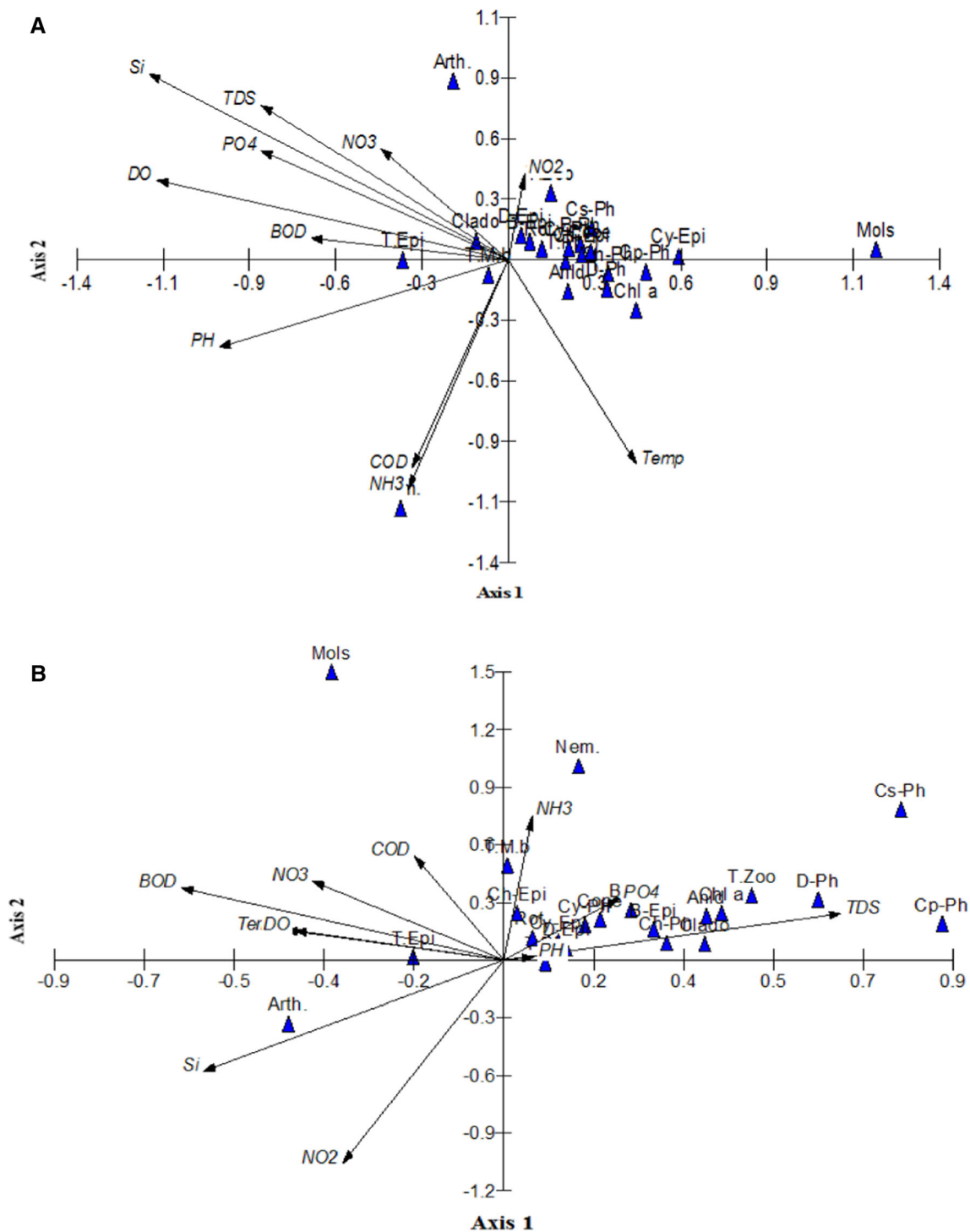


Fig. 3 Canonical Correspondence Analysis (CCA) joint plot ordination diagram for the abiotic variables (arrows) with the biotic variables (points) during the postflood (A = Dahmeit Khor and B = Tushka Khor). The biotic variables are abbreviated as follow: Chlorophyll a (Chl a), Total Phytoplankton count (T.Ph), Cyanophyta of phytoplankton (Cy-Ph), Chlorophyta of phytoplankton (Ch-Ph), Bacillariophyta of phytoplankton (B-Ph), Dinophyta of phytoplankton (D-Ph), Cryptophyta of phytoplankton (Cp-Ph), Total epiphytic

microalgae count (T.Epi), Cyanophyta of epiphytic microalgae (Cy-Epi), Chlorophyta of epiphytic microalgae (Ch-Epi), Bacillariophyta of epiphytic microalgae (B-Epi), Dinophyta of epiphytic microalgae (D-Epi), Total zooplankton count (T.Zoo), Copepoda (Cope), Cladocera (Clad), Rotifera (Rot), Total Macrobenthos count (T.M.b), Annelida (Anld), Arthropoda (Arth), Mollusca (Mols) and Nematoda (Nem)

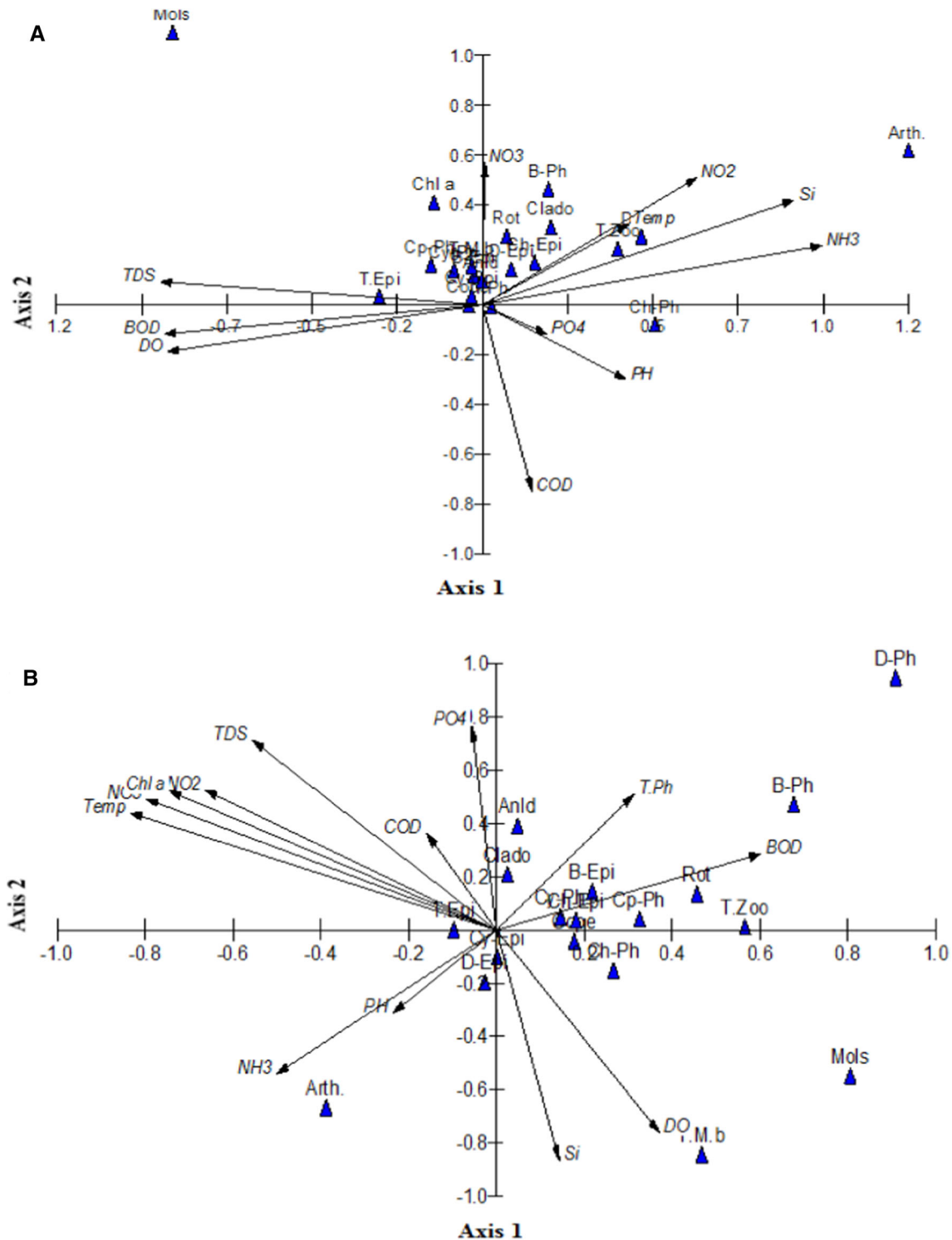


Fig. 4 Canonical Correspondence Analysis (CCA) joint plot ordination diagram for the abiotic variables (arrows) with the biotic variables (points) during the pre-flood (A = Dahmeit Khor and B = Tushka Khor). The biotic variables are abbreviated as follow: Chlorophyll a (Chl a), Total Phytoplankton count (T.Ph), Cyanophyta of phytoplankton (Cy-Ph), Chlorophyta of phytoplankton (Ch-Ph), Bacillariophyta of phytoplankton (B-Ph), Dinophyta of phytoplankton

(D-Ph), Cryptophyta of phytoplankton (Cp-Ph), Total epiphytic microalgae count (T.Epi), Cyanophyta of epiphytic microalgae (Cy-Epi), Chlorophyta of epiphytic microalgae (Ch-Epi), Bacillariophyta of epiphytic microalgae (B-Epi), Dinophyta of epiphytic microalgae (D-Epi), Total zooplankton count (T.Zoo), Copepoda (Cope), Cladocera (Clad), Rotifera (Rot), Total Macrobenthos count (T.M.b), Annelida (Anld), Arthropoda (Arth) and Mollusca (Mols)

Nashar and Elyamany 2018). Moreover, the river water temperature expected to be colder with about 0.5–1.5 °C and the velocity reduced by 5 to 42%. The changes in physicochemical characteristics of the water, frequently, are not favorable to the aquatic organisms in a given river, especially if there is an expected reduction in the water quality (Yacoub 2022). Additionally, The GERD blocks sediments that would naturally renew the downstream ecosystems (Ahmed and Elsanabary 2015), which may lead to eroding in the river bed and banks which can undermine bridges, dams and other riverbank structures (Ahmed and Elsanabary 2015). Besides the concerns threats the river transportation, Nile tourism and fish farms. Concerning the agriculture sector, a reduction in the cultivated lands by 29.47% and 23.03% in Upper Egypt Delta is expected (CU 2013).

On the other side, the GERD can benefit Sudan and Egypt by removing up to 86% of silt and sedimentation, which increase the active storage capacity and operating life of the AHD. Also, the GERD will regulate the steady water flow throughout the year and it will avoid unexpected flooding to downstream countries. According to Wheeler et al. (2016) and Siddig et al. (2020), a positive impact is expected for Sudan due to the water flow regulation, where the hydropower generation in Sudan is expected to increase to around 20% and agriculture expanded and increasing the accumulated gross domestic product (GDP) by about US\$ 27–29 billion until 2060. In all cases, Egypt will be affected by the lack of water coming through the Blue Nile, especially during the drought years, which may affect the water level in Lake Nasser and will have negative environmental impacts.

In addition to increasing the gap between the available water resources and the required needs, which will have many economic and social impacts. Therefore, Egypt needs to rationalize water consumption, use modern methods of agriculture, and increase the reuse of wastewater. This is in addition to coordination and cooperation with Ethiopia and Sudan to prevent a decrease in the water level in a lake to levels that may cause serious effects on Egypt's water security.

4 Conclusion

The findings of this study which held just before the start of filling the GERD confirm the good quality of Lake Nasser water. The majority of water constituents, except DO, showed a highly significant temporal difference ($p < 0.001$) between the two studied periods and between Dahmeit and Tushka Khors. The diversity, density and distribution of aquatic organisms (phytoplankton, zooplankton, macrophytes, epiphytic microalgae, and

macrobenthos) were affected by environmental factors, organism behavior, growth stage, nutritional requirements, and allelopathic interactions between different organisms, indicating the cumulative effect of numerous variables which are all mainly affected by the flood cycle. The results in this study consider as a reference for the following studies on Lake Nasser khors after the complete filling of the GERD, where there are many expectations on the long-term downstream consequences of filling GERD. Although there are many possible scenarios for the effects of the Renaissance Dam on both Egypt and Sudan. However, all studies confirm the increase in the water deficit in Egypt as a result of the reduction of water discharge of the Blue Nile due to the water storage behind the Renaissance Dam, which may cause many environmental, economic, and social serious impacts. Consequently, the responsible authorities and the Egyptian government must develop urgent and long-term solutions to overcome any potential adverse effects.

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Declarations

Conflict of interest The authors have no conflict of interests to declare.

Consent to participate All authors voluntarily agree to participate in this research study.

Consent to publish All authors voluntarily approved the publication of this research study.

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