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Macrobenthic Invertebrates in the Northern Part of Lake Nasser: Community Structure, Relative Abundance and Diversity, Egypt

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ABSTRACT

Associations between macrobenthic invertebrates and 17 environmental variables at 12 sites in 4 khors were analyzed, with their main channel located in the northern part of Lake Nasser during winter and summer, 2022. The results showed that the different sites vary significantly in their macrobenthic invertebrates community, and these differences are strongly related to variations in depth, bottom texture (sand, silt and clay), transparency, total suspended solids (TSS), temperature, hydrogen ion concentrations (pH), dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), nitrate (NO_3-N), ammonium (NH_4-N), total phosphorus (TP), carbonate (CO_3), bicarbonate (HCO_3) and chlorophyll-a. Twenty-five taxa represented the macrobenthic community at the littoral sites, compared to twelve species found in the offshore areas. The total mean values at the littoral sites reached 335 organisms/ m^2 with a biomass of 4.4GFW/ m^2, while the offshore ones hosted 118 organisms/ m^2 with 2.5GFW/ m^2. The relationship between the different macrobenthic phyla with different species and environmental parameters was determined by using canonical correspondence analysis (CCA).

INTRODUCTION

Lake Nasser is one of the largest man-made lakes in Africa and was created after the completion of the Aswan Dam in 1969. The lake is classified as a subtropical, monomictic and eutrophic lake **(Hussian *et al.*, 2015)**. The only source of its water is the River Nile. The outflow from the lake continues northward as part of the Nile. The Nile flood comes once a year in mid-summer, originating from the Ethiopian plateau once a year in mid summer, and extends until late autumn. Lake Nasser is of a great importance for Egypt. It covers more than 95% of Egypt's freshwater budget.

Benthic invertebrate populations are an important factor in lake productivity and are often used to assess the ecosystem's overall health **(Reynoldson *et al.*, 1995)** since these communities are sensitive to environmental pollutants. The studied macrobenthic invertebrate populations under investigation are among the most diverse and abundant components of the freshwater biota. These include representatives of many organisms, such as aquatic insects (e.g. larvae of Diptera, nymphs of Odonata and Ephemeroptera, larvae of Trichoptera and adult stage of Corixidae), Mollusca (Gastropoda and Bivalvia), Annelida (Oligochaetae) and Crustacea (Decapoda) **(Merritt *et al.*, 2008)**. They form the basis of the food web for freshwater habitats worldwide. More importantly, these biotas integrate the change in physical, chemical, and ecological properties of their habitat, and they play a key role in material cycling and energy flow. Furthermore, they appear to be crucial when considered for assessing ecology and biodiversity **(Silva *et al.*, 2014)**.

There are few quantitative estimates of Lake Nasser's zoobenthos. The first study of macrobenthic invertebrates in Lake Nasser was carried out by **Entz (1978)**, who noted a gradual change in the components of the benthic fauna, especially molluscs and oligochaetes, with the development of the lake. Detailed research was carried out by **Iskaros (1988, 1993)** in relation to the environmental conditions and identified 40 species for the first time. **Fishar (1995)** recorded 39 species of zoobenthos, 19 species previously recorded by Iskaros were not included in Fishar's list. **Iskaros and El-Dardir (2010)** identified 10 species (4 chironomid larvae, 3 oligochaetes and 3 molluscs) at offshore stations in ten sectors, with a depth of more than 50m. **Mola and Abdel-Gawad (2014)**, **Wahab *et al.* (2018)** and **Iskaros *et al.* (2021)** conducted a survey of macrobenthic invertebrates, recording 24, 26, and 27 species, respectively. These taxa were previously known to other researchers. **Abdel-Gawad (2016)** recorded 10 species of molluscs; of these, 3 species, namely *Cleopatra bulimoides*, *Corbicula fluminals* and *Ferrissia* sp. were initially recorded from Lake Nasser. These species are characteristic features of slowly flowing water **(Brown, 1980; Ibrahim *et al.*, 1999)**.

The aim of this study was to document the most important biological parameters of the northern part of Lake Nasser. These parameters related to composition, abundance, and diversity were studied and discussed based on qualitative and quantitative analysis in relation to the prevailing environmental conditions. The findings suggest that these parameters could potentially create an additional link in the food chain within the large High Dam Reservoir.

MATERIALS AND METHODS

1. Study area

The shoreline of Lake Nasser is very irregular and has numerous side extensions known as "Khors". There are 85 long khors, including 48 on the eastern side and 37 on the western side. Its area is approximately 76% of the entire lake surface. The climate of this area is characterized by dryness and hot summer with the maximum temperature of up to 47°C.

Forty-eight sediment and water samples were collected from four main khors in Lake Nasser, namely, El-Ramla, Kalabsha, Rahma, and Wadi-Abyad, as shown in Table (1) and Fig. (1). The study's investigation program was carried out in winter and summer of 2022. Six locations were examined: the main channel of the lake in front of the khor, the entrance to the khor, and the middle of the khor. Two stations were selected at each location (littoral and offshore).

Table 1. Dimensions of the four northern khors in Lake Nasser at 180m above mean level **(Latif, 1974)**

Khor	Length km	Surface area km^2	Perimeter km	Volume km3
El-Ramla	25.72	101.2	284	0.96
Kalabsha	47.20	620.0	517	7.16
Rahma	23.58	95.2	232	2.15
Wadi-Abyad	18.30	48.7	184	1.11

Map of Egypt with Lake Nasser and Nile River *Map of Lake Nasser with studied khors* *Sketch of the studied sites*

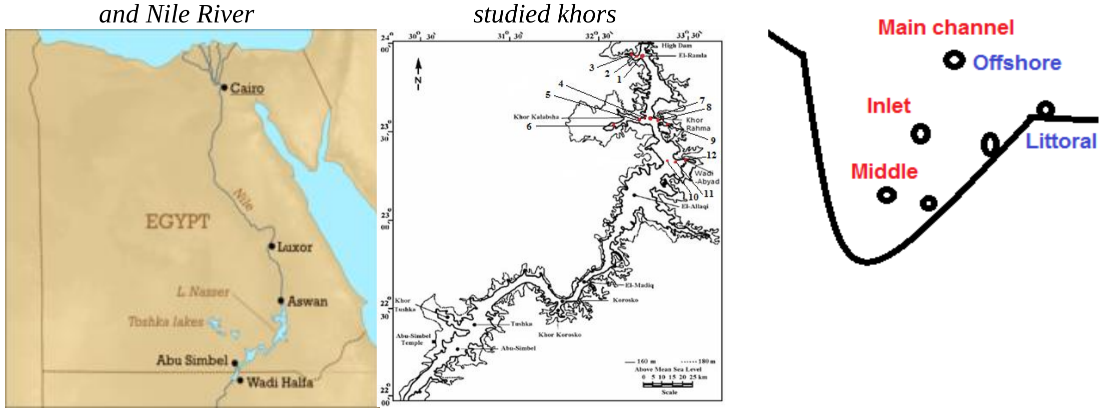


Fig. 1. Sampling sites of the studied northern sector of Lake Nasser

Morphometric characteristics and water quality

Water depth was measured using a portable echosounder device (Lowrance Sonar-X-25 and Navman, fish 4500). Water samples were collected from the near bottom of each station using a water sampler and then filled into well-cleaned plastic bottles. Water temperature (WT) and pH were measured on-site using the Con 500 conductivity/ TDS/ temperature meter and the combined meter pH/ EC/ TDS/ temperature meter (Mi 805). Transparency (Trans) was measured using a Secchi disk (25cm). Physical and chemical analyses were performed according to the guidelines of **APHA (2005)**. Total suspended solids (TSS) content was measured by evaporating a known volume of a well-mixed sample. Dissolved oxygen (DO) content was determined using a modified Winkler method and calculated as a percentage. Biological oxygen demand (BOD_5) was determined using the 5-day incubation method. Chemical oxygen demand (COD) was determined using the potassium dichromate method. CO_3 and HCO_3 were evaluated immediately after water samples were collected using phenolphthalein and methyl orange indicators. Nitrate was measured as nitrite after cadmium reduction, while NH_4 was determined using the phonate method. Total phosphorus (TP) was estimated as reactive phosphate after persulfate digestion using the ascorbic acid–molybdate method.

Chlorophyll-*a* concentrations were determined according to the method of **Marker *et al.* (1980)**. Sediment samples were collected from the top 20cm layer of the bottom using the Ekman device. Grain size analysis was carried out using the dry sieving technique **(Folk, 1980)**.

Data analysis

The data were statistically analyzed to assess the characteristics of the different locations. Taxa of bottom fauna were described and related to major environmental gradients by canonical correspondence analysis (CCA) using the Brodgar software for multivariate analysis and multivariate time series analysis (ver. 2.0+) developed by Highland Statistics Ltd. **(Zuur *et al.*, 2007, 2009)**. Shannon Wiener index (H) of general diversity was used to show the macrobenthic invertebrate diversity during the season by using Shannon Wiener's equation H = ΣPi (Inpi). The evenness index (E) was used to measure how evenly the number of individuals is distributed E= H/(in S). Species richness (SR) was used to calculate the number of species during the season. For macrobenthic invertebrates: At each site, two random samples were collected from both the littoral and offshore areas, using the same grab with an opening of $625cm^2$ ($1/ 16m^2$). The collected samples were then thoroughly washed from mud in a metallic sieve with a mesh size of 0.44mm. The bottom organisms were sorted directly in the field and then preserved in a 5% formalin solution. In the laboratory, the numbers of the different species or genera were determined. The fresh weights (gm. fresh wt./ m^2) (GFW/ m^2) of the different groups were also estimated by retaining the organisms on a filter paper for five minutes before weighing them to get rid of water adhering to their bodies. The shells of molluscs were removed to determine their flesh weights.

RESULTS

1. Physico-chemical parameters

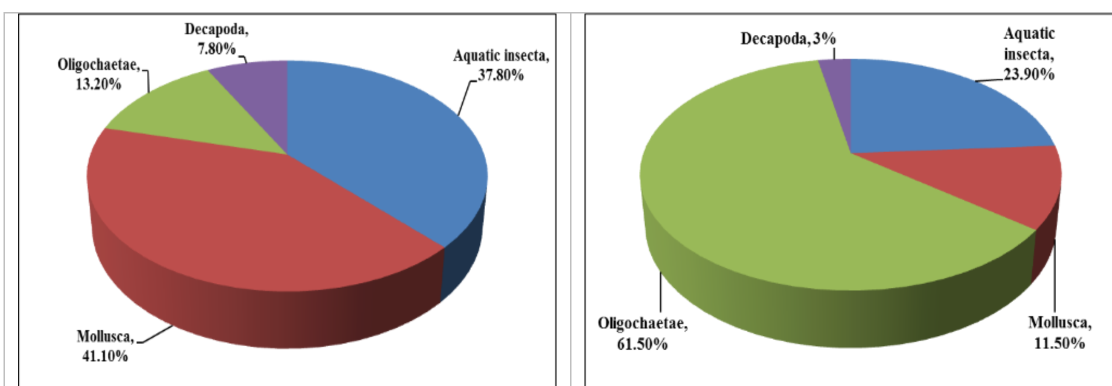
The temporal water temperature differences were relatively high in summer (range: 29.7- 35.1°C) compared to late winter (range: 16.7- 24.5°C). The transparency of the water indicated good conditions for light penetration, with relatively high Secchi disc visibilities, especially in late winter (3.0- 5.0m). The TSS showed large differences between the values of the main channel and khors sites, varying between 13.0 and 22.0mg/ l in late winter and between 6.0 and 22.0mg/ l in summer (Table 2). The hydrogen ion concentrations (pH) values were almost above 7, indicating slightly alkaline water conditions of the lake water. Strong fluctuations in pH values were observed; it was between 6.5 and 8.14 in summer and between 6.4 and 8.2 in late winter. The values of chlorophyll-*a* concentrations tended to be relatively higher in late winter in all examined locations, varying between 6.4 and 28.62mg/ l. In summer, these values did not exceed 6.23mg/ l. The drop in water temperature in late winter was in turn accompanied by a significant increase in oxygen concentrations, particularly at site 1 to site 8 (7.2- 11.6mg/ l), followed by a sharp decrease at the following sites (9- 12) (4.0- 6.0mg/ l). However, in summer, this was offset by higher DO values (10.8- 11.2mg/ 1) in the four locations mentioned above. COD increased in late winter at all study sites and its values varied between 4.1 and 6.0mg/ l compared to 2.4 and 5.8mg/ l during summer. BOD did not show significant fluctuations when its values were between 1.6 and 4.2mg/ l in late winter and between 1.2 and 4.2mg/ l in summer. NO_3-N showed a wide range of fluctuations with relatively large differences between minimum and maximum values, especially in late winter (70.22- 285.24µg/ l) compared to summer (142.32- 155.76µg/ l). These fluctuations reflected the seasonal development of dissolved inorganic fractions of macronutrients (phosphorus and nitrogen). Ammonia (NH_4-N) concentrations decreased to 277.20µg/ l during winter at most of the studied sites, except site 3. However, high concentrations of NH_4-N were recorded in summer, varying between 164.57 and 282.52µg/ l. High TP concentrations were detected in summer (140.32- 287.36µg/ 1), and the minimum values were estimated in late winter (118.75- 156.47µg/ 1). The results of carbonate and bicarbonate show a high relative content during winter, where CO_3 content was between 2.5 and 25.0mg/ l, while in summer, it was approximately between 5.0 and 35,0mg/ l. The data obtained for bicarbonate ranged between 160.0 and 190.0mg/ l in late winter compared to 135.0- 180.0mg/ 1 in summer. The grain size analysis showed that the examined bottom sediments samples in the different locations consist mainly of silty clayey sand. The sand fraction formed the main size of the sediment at both the littoral sites (77.4- 98.8%) and offshore shares (73.0- 94.0%). Silt fraction was increased with the depth and showed a higher value at the main channel of Khor Rahma (22.0%). On the other hand, clay fraction had the same sand fraction trend in its distribution at the littoral sites of the main channel (1.2-11.6%).

2. Macrobenthic invertebrates

Twenty-five taxa represented the macrobenthic invertebrate community at the littoral sites of the northern sector of Lake Nasser. Fifteen of these taxa were aquatic insects (10 larvae of Chironomidae, 2 nymphs of Odonata, 1 adult Corixidae, and an unknown nymph of Ephemeroptera, and larvae of Trichoptera); 6 were related to Mollusca, 3 to Oligochaetae and 1 to Decapoda. The offshore sites harbored only twelve taxa; namely, the 3 oligochaetes, 5 chironomid larvae, 2 molluscs, 1 unknown of Ephemeroptera and 1 decapod. According to their relative abundance at the first sites, they numerically accounted for approximately 37.8, 44.1, 13.2, and 7.8% of the total macrobenthic invertebrates. In the second area, these values changed significantly as follows: oligochaetes accounted for 61.5%, followed by aquatic insects, molluscs, and decapods (Table 3 & Fig. 2). The highest densities and biomass of macrobenthic invertebrates (Fig. 3) were observed at the littoral sites 1 (average 848ind./ m^2 with 10.4GFW/ m^2) of Khor El-Ramla and 5 (average 804ind./ m^2 with 8.0GFW/ m^2), where there were some macrophyte patches, whose numerous stiff leaves protect countless animals from predators, and also provide a large surface area for the growth of epiphytic food-organisms **(Hann, 1995)**. On the other hand, the community decreased at the other sites which were characterized by a rare or vegetation-free bottom zone, especially in the offshore sites. In addition, the average values of the total counts at the littoral sites during winter and summer reached 335ind./ m^2, with a biomass of 4.4GFW/ m^2 compared to 117ind./ m^2 and a biomass of 2.5GFW/ m^2 at the offshore locations.

Table 2. Comparison between range (minimum, maximum), average, and standard division (SD) values of bottom water of physical, chemical, and biological parameters for the northern sector of Lake Nasser with irrigation **(FAO, 1994)**, drinking **(WHO 2008)** and aquatic life **(CEQG, 2011)**

Parameter		Unite	Min	Max	Avg.	SD	Drinking water (WHO, 2008)	Irrigation (FAO, 1994)	Aquatic life (CEQG, 2011)
Water quality and sediment analysis									
Water Temperature		°C	17.00	33.60	26.23	6.12		8.0-28.0	25.0
TSS		mg l^{-1}	6.00	22.00	12.29	4.69		+250	
Depth		m	6.00	50.00	19.67	10.87			
Transparency		cm	3.00	5.50	3.67	0.73			
pH			6.50	8.20	7.66	0.47	8.5	6.5-9.0	6.5-8.5
DO		mg l^{-1}	6.00	11.60	9.28	1.79		5.5	8.0
BOD		mg l^{-1}	1.20	4.20	3.02	0.98		5.0	4.0
COD		mg l^{-1}	2.40	6.00	4.44	1.02		7.0	25.0
CO_3^{2-}		mg l^{-1}	2.50	35.00	15.73	7.20	3.0		
HCO_3^-		mg l^{-1}	135.00	190.00	170.21	12.64	610.0		
NO_3^--N		µg l^{-1}	70.22	255.24	146.12	40.90	10	2930	5000
NH_3-N		µg l^{-1}	55.80	282.52	165.59	70.76	5000	1370	200
TP		µg l^{-1}	118.75	287.36	160.24	39.93	1500	2000	
Chlorophyll-*a*		mgl^{-1}	4.05	28.62	9.96	12.82			
Sand		%	73.0	98.8	88.4	12.98			
Silt		%	0.2	22.0	6.7	11.19			
Clay		%	1.0	16.9	4.9	8.287			
Macroinvertebrates									
Total benthos	Number	Ind./m^2	16	1392	226	741.2			
	Biomass	GFW/m^2	0.1	16.1	3.5	8.43			
Aquatic insects	Number	Ind./m^2	16	464	77	242.9			
	Biomass	GFW/m^2	0.1	6.3	0.8	3.40			
Mollusca	Number	Ind./m^2	16	928	76	510.1			
	Biomass	GFW/m^2	0.1	2.1	0.25	1.11			
Oligochaete	Number	Ind./m^2	16	368	58	192.2			
	Biomass	GFW/m^2	0.1	12.2	2.1	6.49			
Decapoda	Number	Ind./m^2	16	272	15	148.0			
	Biomass	GFW/m^2	0.3	7.5	0.35	4.14			



Littoral sites | Offshore sites

Fig. 2. Macrobenthic invertebrate phyla recorded in the northern sector of Lake Nasser and their presence contribution (%)

Table 3. Macrobenthic invertebrate species recorded in the northern sector of Lake Nasser and their presence contribution (%) (a: littoral and b: offshore)

Species	%		Species	%	
	a	b		a	b
Tanytarsus Van der Wulp	9.3	0.4	*Micronecta plicata*	0.1	0.0
Dicrotienipes modestus Kieffer	5.4	0.0	Nymph of Ephemeroptera	1.6	1.7
Procladius Skuse	4.0	9.8	Larvae of Trichoptera	0.9	0.0
Nilodorum Kieffer	1.2	1.3	*Valvata nilotica* Jickeli	16.7	3.8
Cryptochironomus Kieffer	1.0	3.4	*Melanoides tuberculata* Muller	8.5	7.7
Chironomus Meigen	0.6	0.0	*Bulinus truncatus* Audouin	9.7	0.0
Microtendipes Kieffer	0.5	0.0	*Physa acuta* Draparnaud	4.8	0.0
Clinotanpus Kieffer	0.1	3.9	*Sphearium hartmanni* Jickeli	1.0	0.0
Ablabesmyia Johannsen	0.1	0.0	*Pisidum pirothi* Jickeli	0.4	0.0
Polypedilum Kieffer	0.1	0.0	*Branchiura sowerbyi* Beddard	11.9	44.4
Pupue of Chironomidae	0.3	0.4	*Limnodrilus udekemianus* Claparede	1.2	13.3
Pseudoagrion niloticum Dumont	9.1	1.7	*Limnodrilus hoffmeisteri* Claparede	0.1	3.8
Perithemis Hagen	3.5	1.3	*Cardina nilotica* Roux	7.8	3.0

Zoobenthos abundance in the northern sector varied significantly between different sites, with notable differences between winter and summer. In winter, the values of the total macrobenthic invertebrates at the littoral sites were 477ind./ m^2, with a biomass of 6.8GFW/ m^2, compared to 121ind./ m^2, with 2.65GFW/m^2 at the offshore sites. Molluscs and aquatic insects were abundant at the littoral sites, while the density of oligochaetes was more or less comparable at both the littoral and offshore sites. The highest density of 1392ind./ m^2, measured at the littoral sites of both site 1 of Khor El-Ramla and site 5 of Khor Kalabsha, was mainly due to the increased numbers of molluscs, followed by aquatic insects. Mollusca contributed 43.4 (average 207ind./ m^2) of the total benthos, while aquatic insects accounted for 40.0% (average 191 insects/ m^2). At the offshore locations, these values fell sharply to an average of 23 gastropods/ m^2 and 37 insects/ m^2. On the other hand, oligochaetes accounted for about 10.9% (average 52orgs./ m^2) at the littoral sites, but their relative abundance at the offshore sites increased to 69.8% (average 57ind./ m^2). During the summer, macrobenthic invertebrates decreased to an average of 193ind./ m^2, with 2.0GFW/ m^2 at the littoral sites and to 114ind./ m^2 with 2.4GFW/ m^2 in the offshore area, apart from oligochaetes at the littoral site 6 of Khor Kalabsha and the offshore site 7 of Khor Rahma, which have sustained the highest values of 224ind./ m^2, with 4.8GFW/ m^2 and 368ind./ m^2 with 12.2GFW/ m^2, respectively.

Remarkably, different groups of aquatic insects flourish well in winter, especially in January, as known from previous studies in Lake Nasser **(Iskaros, 1988, 1993; Iskaros *et al.*, 2021)**. Therefore, they were recorded in low numbers in late winter and summer and were completely rare or disappeared, except for the larvae of Chironomidae and nymphs of Odonata, which were quite common in the earlier season, accounting for about 58.1 and 15.3%, respectively (average 111 larvae/ m^2 with 0.3GFW/ m^2 and 37.2 & 81.6% (average 71 nymphs/ m^2 with 1.6GFW/ m^2) of the total insects. Furthermore, chironomid larvae reached their highest density at the littoral sites 7 (400 larvae/ m^2) and 9 (336 larvae/ m^2) of Khor Rahma owing to the increased abundance of *Tanytarsus* sp., which accounted for approximately 55.5% of the total larvae. *Dicrotendipes modestus* and *Procladius* sp. follow in large numbers with 29.1 and 10.9%, respectively. On the other hand, the odonate nymphs reached their peak at the littoral site 2 of Khor El-Ramla (352 nymphs/ m^2), produced by an increased number of *Pseudagrion niloticum* (288 nymphs/ m^2).

Mollusca peaked during late winter, particularly at the littoral site 1 of Khor El-Ramla (784ind./ m^2 with 1.0GFW/ m^2) and site 5 of Khor Kalabsha (576ind./ m^2 with 1.2GFW/ m^2) due to the development of high densities of *Valvata nilotica* which accounted for 51.9% (average 108 gastropod/ m^2) of the total molluscs, followed by *Bulinus truncates* (25.5%). The relative abundance of other species varied between 1.4 and 12.0%. On the other hand, *Melanoides tuberculata* was the only gastropod that flourished well during summer, especially at the littoral sites 6 and 10 of Khor Kalabsha and Khor Wadi-Abyad (112 and 144 gastropod/ m^2, respectively), accounting for about 66.2% of the total molluscs.

In addition, oligochaetes varied significantly among different sites over the studied period with values being relatively higher during summer, particularly at the offshore site 7 of Khor Rahma (368ind./ m^2) and during winter at site 1 of Khor El-Ramla (240ind./ m^2). This increase was mainly due to the highest density of *Branchiura sowerbyi*, which accounted for 80.2 & 42.4%, respectively, of the total oligochaetes, while the values of *Limnodrilus udekemianus* and *L. hoffmeisteri* varied between 1.9 and 32.8%. The crustacean, *Cardinea nilotica*, occurred at a few sites in late winter and summer at a few number of sites, with high densities at the littoral site 5 of Khor Kalabsha (272ind./ m^2 and 7.5GFW/ m^2) and site 1 of Khor El-Ramla (240ind./ m^2 and 4.2GFW/ m^2).

DISCUSSION

Man-made lakes, similar to other surface water ecosystems, provide a variety of benefits to people, including water supply, irrigation, flood control, fishing, and other forms of recreation. There are four such lakes in Africa, such as Viz Volta (Ghana), Kariba (Zimbabwe), Kainji (Nigeria), and Nasser (Egypt), each of which has an area of more than 1000km^2 **(Brown, 1980)**. The construction of the Aswan High Dam between 1959– 1969 led to the creation of the second-longest man-made lake in Africa. Its total area is approximately 6276km^2 at the repository level of 183m above mean sea level, of which 83% is in Egypt and the rest is in Sudan. Lake Nasser has numerous lateral side flooded areas, commonly referred to as khors (85 khor), which account for about 76% of its total area. In the northern part of Lake Nasser, the object of the present study includes four khors with their main channel, namely El Ramla, Kalabsha, Rahma, and Wadi-Abyad. They together account for about 41.4% of the total surface area of the thirteen main khors lying in Lake Nasser, while the surface area of Khor Kalabsha alone, which is relatively wider and shallower, accounts for about 10% (620km^2) of the total surface area of the lake.

Macrobenthic invertebrates related to aquatic insects, oligochaetes, molluscs, and crustaceans have been frequently recorded in Lake Nasser **(Iskaros, 1988, 1993; Fishar, 1995, Iskaros & Dardir, 2010; Mohamed, 2018, Wahab *et al.*, 2018; Iskaros *et al.*, 2021)**. These groups dominated the macrobenthic invertebrate community during the period of the present study. A change in one of these groups was reflected in its overall frequency. It is well known that the quality and quantity of macrobenthic invertebrates is largely influenced by the surrounding environmental conditions, including biotic and abiotic factors, and is influenced by a complex inter-relationship between these various factors **(Angradi*et al.*, 2006; Jiang *et al.*, 2010)**. Additionally, the substrate condition is highly important for regulating habitat complexity, food availability, and protection from predators **(Hepp *et al.*, 2012)**.

At the littoral areas of the northern locations of Lake Nasser, relative densities of sand (average 91.7 %), silt (average 2.2 %) and clay (average 6.0 %), together with the submerged macrophytes, form the main components of the bottom sediment provided preferred conditions for the existence of several macrobenthic invertebrates taxa, such as site 1 and site 5 of Khors El-Ramla and Kalabsha, respectively. Furthermore, CCA showed that the bottom texture was the most important factor affecting the distribution of macrobenthic phyla in the littoral areas (Fig. 4). The CCA biplot showed that depth was positively correlated with insects and oligochaetes (0.24 for each), especially *Limnodrilus udekemianus* and *L. hoffmeisteri* (0.30 and 0.45, respectively). The later species, which survives in muddy tubes made of silt and clay fractions, prefer this type of texture. *Branchiura sowerbyi* was positively correlated with clay fraction (0.32), in contrast to pupae of Chironomidae (-0.33) (Figs. 5, 6). *Pisidum pirothi* was positively correlated with the silt (0.45) and clay (0.45) fractions, while strongly negatively correlated with the sand fraction (-0.65) (Fig. 7). The CCA results of the present study is also supported by **Hepp *et al.* (2012)** who reported that, the nature of the bottom sediments has a selective influence on the quality of benthos and several species live in close association with some type of substrate. In the present study, the transparency was determined, with the highest values observed in late winter (range: 3.0-5.5 m) compared to summer (ranges 3.0-4.0m). Two main factors influence the degree of water transparency in Lake Nasser **(Entz, 1974)**, namely allochtonic inorganic silt, mud of riverin origin and autochtonic suspended organic matter (plankton and detritus). **Zaghloul (1985)** and **Iskaros (1993)** mentioned that, the northern part of Lake Nasser with its khors had the highest transparency values, especially in autumn and winter, which was associated with the introduction of turbid water by floods in the southern part of the lake. However, the lowest values occured in spring and summer due to phytoplankton blooms. The latter author concluded that, the increased density of zooplankton in Khor Kalabsha during winter and autumn, in parallel with the increased transparency, allows good nutrition of the chironomid larvae, which appeared to be abundant during this period in the present study. The CCA analysis revealed that transparency was the most important factor influencing the distribution of macrobenthic phyla both in the offshore areas and for molluscs and oligochaetes species in the littoral ones.

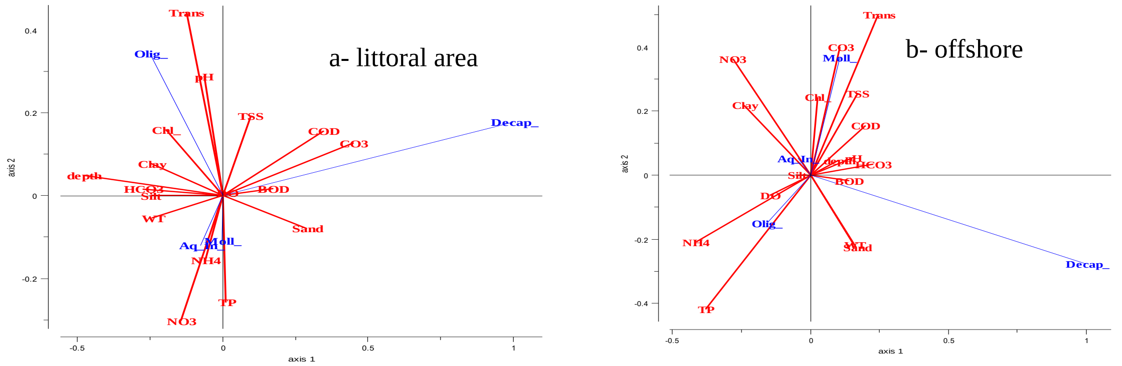


Fig. 4. CCA ordination a biplot diagram based on bottom fauna phyla with 17 environmental variables at Lake Nasser. Cods: Decap, Decapoda; Aq.in., aquatic insects; Olig., Oligochaeta; Moll., Mollusca

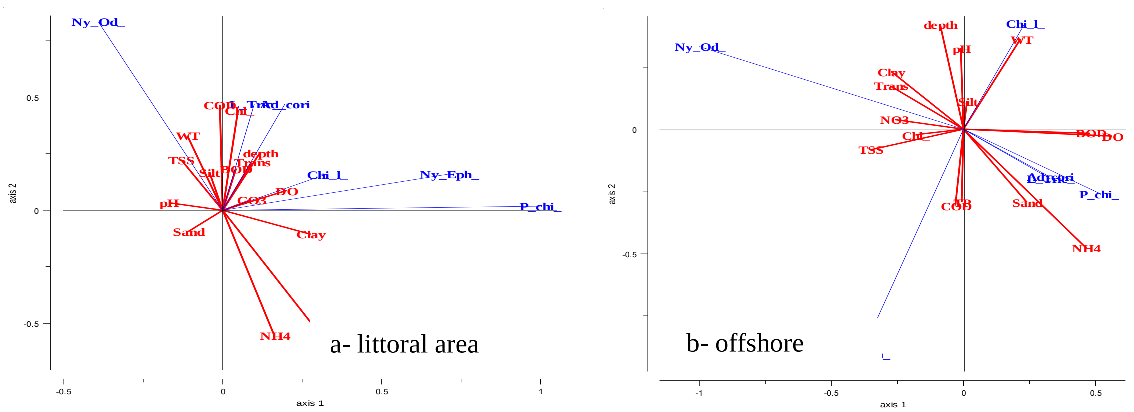


Fig. 5. CCA ordination a biplot diagram based on aquatic insects with 17 environmental variables at Lake Nasser. Cods: Chi.l., Chironomid larvae; P.chi., Papae of Chironomidae; Ny.Od, Nymphs of Odonata; Ny.Eph., Nymphs of Ephemeroptera; L.Tric., Larvae of Trichoptera; Ad.cori., Adult Corixidae

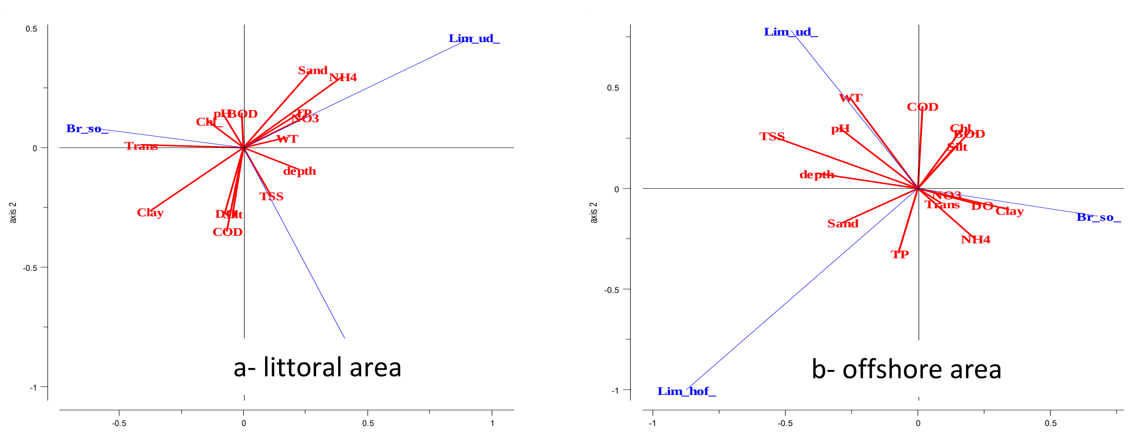


Fig. 6. CCA ordination a biplot diagram based on oligochaets with 17 environmental variables at Lake Nasser. Cods: Br.so.,Branchiura sowerbyi; Lim.ud., Limnodrilus udekemianus; Lim.hof., Limnodrilus hoffmeisteri.

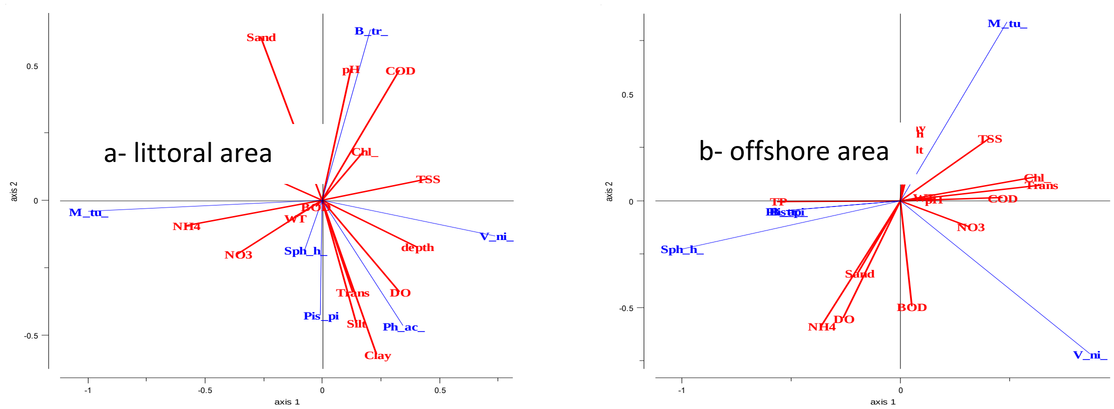


Fig. 7. CCA ordination a biplot diagram based on molluscs with 17 environmental variables at Lake Nasser. Cods: V.ni., *Valvata nilotica*; Ph.ac., *Physa acuta*; B.tr., *Bulinus truncatus*; M.tu., *Melanoides tuberculata*; Sph.h., *Spheariuim hartmoni*; Pis.pi, *Pisidum pirothi*

The CCA biplot showed that *Branchiura sowerbyi*, *Valvata nilotica*, *Melanoides tuberculata* and *Pisidum pirothi* were positively correlated with transparency (0.54, 0.53, 0.41, and 0.55, respectively). In this context, **Abdel-Gawad (2016)** reported that water transparency was also an important factor affecting the distribution of Mollusca at Khors Dahmit and TushKain Lake Nasser. The water temperature range in the northern part of Lake Nasser was between 16.7 and 35.1°C, with a minimum in late winter and a maximum during summer. The difference in water temperature throughout the year is considered a controlling factor related to the tolerance range of the species. This has been empirically supported by CCA analysis, which suggests that water temperature was the most important factor affecting the distribution of benthic phyla in littoral areas, particularly in molluscs species. The CCA biplot showed that water temperature correlated negatively with *Physa acuta* and *Bulinus truncatus* (-0.43 and -0.54, respectively). These results suggest that the survival and development of this biota are regulated by temperature, consistent with the findings in Lake Nasser **(Iskaros, 1983, 1993; Iskaros *et al.*, 2021)**, in Aswan Reservoir **(Iskaros *et al.*, 2011)**, and in the Nile River **(El-Otify & Iskaros, 2018)**. Similarly, **Brown (1980)** observed that the growth and reproduction of molluscs depend significantly on water temperature.

The high concentrations of the total suspended solids (TSS) affect light penetration, productivity, turbidity and habit quality. These high concentrations cause lakes to fill up more quickly. In the present study, TSS decreased with the increase in water temperature and varied between 6.0 and 22.0mg/ 1 during summer but increased in late winter at all the studied sites (range: 10.0- 22.0mg/ l). The CCA analysis revealed that TSS was the most important factor affecting the distribution of mollusc species in the offshore areas. In this regard, **Chapman *et al.* (2017)** explained that these parameter benchmarks will protect sensitive life stages of lake fish and will protect their supporting food webs, in other words, the function of aquatic communities in the lake will be protected and maintained. According to **Payne (1986)**, the oxygen budget in deep lakes depends on a complex of processes involving oxygen from the atmosphere, oxygen produced by aquatic biota and the oxidation of organic matter. The present results showed that the bottom water was well-oxygenated at the different studied sites, except that a low oxygen content (4.0mg/ l) was estimated at site 9 in late winter.

In the present study, CCA analysis showed that DO was the most effective factor in controlling molluscs species in offshore areas. The CCA biplot showed that *Melanoides tuberculate* was negatively correlated with DO (-0.38), as well as Trichoptera larvae (-0.39). **Brown (1980)** reported that oxygen is probably the most important limiting factor in snail distribution in Africa. Biological oxygen demand (BOD) and chemical oxygen demand (COD) refer to the content of organic matter in water that is degradable through the biological activity of microorganisms and through chemical processes, respectively **(Mustapha *et al.*, 2013)**. In the present study, the values of BOD concentrations varied between 1.2 and 4.2mg/ l, indicating that the bottom water varied between clean water and somewhat clean water according to **Toufik and Korium (2015)**. On the other hand, the maximum COD concentration of 6.0mg/ l is excellent for assessing water quality **(GD, 2013)**.

CCA analysis revealed that BOD was the most important factor affecting the distribution of oligochaetes species in the littoral areas. COD, on the other hand, influences the distribution of oligochaetes, aquatic insects and molluscs species in offshore areas. The CCA biplot showed that *Limnodrilus hoffmeisteri* and *Pisidum pirothi* were either negatively correlated with BOD or the COD, respectively (-0.33 and -0.30 for each, respectively), while nymphs of Ephemeroptera were mainly dependent on the COD (0.34). The pH values in the different locations were always on the alkaline side, with a maximum value of 8.2 in late winter and a minimum during summer (6.5). The CCA analysis revealed that pH was the most important factor affecting the distribution of aquatic insects and oligochaetes species in the littoral and offshore areas, respectively. The CCA biplot showed that *Limnodrilus udekemianus* was positively correlated with pH (0.31). **Iskaros and El-Otify (2013)** recorded the pH values in Aswan Reservoir between a minimum of 7.34 during winter and a maximum of 7.95 in spring. They found that the increased density of macrobenthic invertebrates was usually accompanied by increased pH values, as the case in the present study. The maximum levels of chlorophyll-*a* were estimated in late winter, particularly at site 3 (28.60mg./ m^2) compared to summer (4.05-6.23mg/ m^3). The increase of macrobenthic invertebrates in late winter is generally accompanied by a parallel increase in phytoplankton density **(Hussian *et al.*, 2015)**. This was highlighted by the dependence of macrobenthic phyla and molluscs species in the littoral, and offshore areas, respectively, as shown by the CCA analysis. Chlorophyll- a is an index of photoautotrophic biomass associated with reservoir primary production of the reservoir that reflects water quality and net phytoplankton growth and loss from grazing processes of macrobenthic invertebrates groups **(Brinkhurst & Jamieson, 1971; Mason, 1973)**.

Nitrate (NO_3-N) is the most highly oxidized form of nitrogen, and it is used as essential for phytoplankton growth **(Mohamed *et al.*, 2016)**. NO_3-N concentrations were low in late winter, except at most of the studied sites, but a dramatic increase was expected at sites 1, 3, and 7, namely 199.86, 216.80, and 285.24µg/ 1, respectively. No significant changes were found between the different study locations in summer (142.3-156.05µg/ l). The maximum ammonia concentrations (NH_4-N) were measured during summer (164.57- 282.52µg/ 1), since the content of DO, which inhibits the rate of chemical oxidation of NH_4-N, is lower. On the other hand, their low concentrations of NH_4-N in late winter (55.80- 277.20µg/ l) can be attributed to the oxidation of NH_4-N by DO into NO_2-N and NO_3-N. Total phosphorus (TP) is generally a limiting nutrient for algae growth and, therefore, controls the primary productivity of the water body. The TP increased during summer at all the examined locations and fluctuated between 140.0 and 28736µg/ l, while in late winter, these values did not exceed 156.47µg/ l.

These levels of different nutrients in the different locations examined provided a suitable growth situation for different zoobenthos phyla. For example, CCA analysis showed that NH_4-N was the most effective factor in the distribution of macrobenthic phyla in the offshore areas, and the CCA biplot diagram revealed that NO_3-N and NH_4-N had a negative correlation with molluscs (-0.31 and -0.40, respectively). Furthermore, the CC analysis assessed that NH_4-N was the most important factor influencing the distribution of aquatic insects forms in both the littoral and at offshore locations, moreover its influence on the distribution of molluscs and oligochaetes species at the later zones. While NO_3-N also appeared to be an important factor for aquatic insect species in the offshore areas as well as for molluscs species in both the littoral and offshore areas. The CCA biplot shows that *Valvata nilotica*, *Pisidum pirothi* and pupae of Chironomidae were found to mainly depend on NO_3-N (0.35, 0.50 and 0.32, respectively), while the former species together with *Melanoides tuberculata* and nymphs of Odonata were correlated negatively with NH_4-N (-0.46, -0.43 and -0.44, respectively). *Branchiura sowerbyi* was correlated negatively with nitrogen sources. TP was another important nutrient that influenced the distribution of aquatic insect forms and oligochaete species in the littoral and offshore areas, respectively. CCA biplot showed that odonate nymphs were strongly negatively correlated with TP (-0.63), while the opposite was true for *Limnodrilus hoffmeisteri* (0.37). These observations are in accordance with the results of **Yuan (2010)**, **Iskaros and El-Otify (2013)** and **Iskaros *et al.* (2021)**. In this context, **Ali *et al.* (2007)** elucidated that the diversity and composition of aquatic invertebrates could be determined by nutrients.

Carbonate (CO_3) exhibits high relative content during summer (5.0- 35.0mg/ l), compared to late winter (2.5- 25.0mg/ 1). Bicarbonate (HCO_3) shows concentrations ranging between 135.0 and 180.0mg/ l in summer compared to late winter (160.0- 190.0mg/ l). The CCA analysis showed that CO_3 and HCO_3 were other important factors affecting the distribution of macrobenthic phyla in the offshore areas, and the CCA biplot showed that CO_3 was positively correlated with decapods (0.46). Regarding these results, **Silva *et al.* (2014)** concluded that the environmental and spatial factors may act separately in structuring macrobenthic invertebrate assemblages.

The Shannon (H) diversity analysis presented in Tables (4, 5) shows significant differences between the twelve examined locations in both littoral and offshore areas. Therefore, the highest total species number (S:12 and 10), abundance (N: 728 and 668) and species richness (SR:1.669 and 1.582) were estimated at sites 1 and 5, compared to other sites that may be associated with unfavorable conditions for their development arising from the rare appearance or disappearance of submerged macrophytes. The results of such a study would provide a useful clue to determine the influence of physical and chemical factors that are of utmost importance in the composition of macrobenthic invertebrates. Several studies are needed for a better understanding of these biota which serve as important food for various fish species in Lake Nasser, especially after the construction of the Renaissance Dam in Ethiopia.

Table 4. Total species (S), total individual (N), species richness (SR), evenness index (EI), Shannon diversity index (H') recorded at the littoral sites

Sample	S	N	SR	E	H'(LOGE)
Site 1	12	728	1.669	0.7983	1.984
Site 2	6	352	0.8527	0.7475	1.339
Site 3	5	88	0.8934	0.8635	1.39
Site 4	9	232	1.469	0.9186	2.018
Site5	8	668	1.582	0.7864	1.635
Site 6	8	304	1.224	0.7714	1.604
Site 7	7	360	1.019	0.6719	1.307
Site 8	6	96	1.095	0.8836	1.583
Site 9	10	296	1.076	0.6561	1.511
Site 10	5	288	0.7063	0.9603	1.546
Site 11	7	168	1.171	0.8325	1.62
Site 12	7	136	1.221	0.8766	1.706

Table 5. Total species (S), total individual (N), species richness (SR), evenness index (EI), and Shannon diversity index (H') recorded at the offshore sites

Sample	S	N	SR	E	H'(LOGE)
Site 1	9	264	1.435	0.8941	1.965
Site 2	1	8	0	****	0
Site 3	3	40	0.5422	0.9602	1.055
Site 4	2	24	0.3147	0.9183	0.6365
Site5	0	0	****	****	0
Site 6	0	0	****	****	0
Site 7	11	624	1.554	0.8896	2.133
Site 8	10	184	1.726	0.9218	2.123
Site 9	5	56	0.9937	0.9165	1.475
Site 10	7	56	1.491	1	1.946
Site 11	0	0	****	****	0
Site 12	0	0	****	****	0

CONCLUSION

It is widely accepted that the quality and quantity of macrobenthic invertebrates are largely influenced by environmental conditions, including biotic and abiotic factors, and are influenced by a complex interrelationship between these various factors. The macrobenthic invertebrates in the northern sector of Lake Nasser were relatively densely populated. In terms of numbers, aquatic insects and molluscs were the main components at the littoral sites (37.9 and 41.1%, respectively), while oligochaetes were dominant at the offshore sites (61.5%). The littoral sites had the highest densities of macrobenthic invertebrates (average 335ind./ m^2 and 4.4GFW/ m^2) compared to the offshore sites (average 117ind./ m^2 and 2.5GFW/ m^2). They recorded their highest densities in late winter due to increased densities of molluscs and aquatic insects, while they were less common in summer, paralleling the greatest emergency of aquatic insects due to the increase in water temperature. On the other hand, their abundance at the offshore sites remained low during most of the study period, ascribed to the lack of suitable substrate.

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