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# Impact of Flood Regime on Zooplankton and Macrobenthos of Lake Nasser

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**ABSTRACT**

Benthic macroinvertebrates and zooplankton play crucial roles in trophic dynamics and serve as indicators of environmental changes in river ecosystems. This study examined the spatial and temporal distribution of these organisms in the main channel of Lake Nasser and its khores, Khor El-Ramla and Khor Dahab, during pre-flood and post-flood phases. Zooplankton communities included Copepoda, Cladocera, and Rotifera, with Copepoda dominating in the main channel and Khor El-Ramla. In Khor Dahab, Copepoda thrived post-flood, while Cladocera were more prevalent pre-flood. Common zooplankton species included *Thermodiaptomus galebi*, *Thermocyclops* sp., and *Brachionus* sp. Macrobenthic invertebrates from Annelida, Arthropoda, Mollusca, Nematoda, and Cnidaria were also identified, with Annelida and Arthropoda being dominant in the main channel. In the khores, Mollusca and Arthropoda made up significant portions of the benthic community. Key species included *Limnodrilus udekemianus* and *Melanoides tuberculata*. Hierarchical cluster analysis revealed that Khor Dahab had distinct physical and biological characteristics compared to Khor El-Ramla and the main channel. Post-flood, transparency, depth, electrical conductivity, and pH were the main factors affecting zooplankton and macrobenthos, while pre-flood conditions were influenced by depth, dissolved oxygen, and temperature.

## INTRODUCTION

Lake Nasser, one of the largest man-made reservoirs in the world, was created in 1964 with the construction of the Aswan High Dam in Upper Egypt. It is the second-largest artificial lake in Africa, following Lake Volta in Ghana, and serves as the primary source of irrigation, drinking water, and household needs. In addition to a long-term trend of rising and falling mean lake levels, there is a yearly cycle of water level fluctuations linked to the seasonal flooding of the Nile River system. The flood originates from the Ethiopian highlands in late summer **(Latif, 1984)**. The existence of side extensions, known locally as "khors," is a significant characteristic of Lake Nasser; they formed about 76% of total lake area. There are roughly 85 significant khors, 48 of which are found on the eastern shore and 37 on the western shore. Due to their large areas, several khors have been transformed into auxiliary semi-isolated lakes **(Wahab *et al*., 2018)**.

Floods significantly influence invertebrate fauna and phytoplankton in rivers. They affect community composition and individual numbers by increasing water velocity and bed load movement, which raises the suspended sediment load. Additionally, floods can harm certain individuals and can reduce the availability of food from the substrate **(Sagar, 1986)**.

Zooplankton community functions as a vital link between higher trophic levels and primary producers, or phytoplankton, in the food chain. Due to zooplankton's great density, high species/group diversity, drifting behavior, short life span, and variable stress tolerance, these organisms are used as indicators of biological, physical, and chemical processes in the aquatic environment. Zooplankton assemblage in Lake Nasser includes Copepoda, Cladocera, and Rotifera, in addition to Protozoa and meroplankton **(El-Shabrawy, 2009)**. Lake Nasser has been the subject of numerous zooplankton studies since its filling **(Samaan 1971; Samaan 1976a, b; Zaghloul 1985; Mageed 1992, 1995; Iskaros, 1993; Habib, 1995, 2000; El-Shabrawy, 2000; Taha & Mageed, 2002; El-Shabrawy & Dumont, 2003; Mageed & Heikal, 2006; Ali *et al*., 2007; El-Serafy *et al*., 2009; Abdel Mola, 2012; Khalifa *et al*., 2015a; Hegab *et al*., 2020)**. Reviewing the zooplankton of the Nile and Lake Nasser-Nubia as well as the lake sources of the Nile, **Rzoska (1976)** and **Dumont (1986)** found that the species composition has remained surprisingly constant over time and has not changed from the 19$^{th}$ century.

Since they are confined to the bottom, have lengthy life cycles, and limited mobility, benthic macroinvertebrates are significant elements of river ecosystems. They also play a significant role in trophic dynamics by cycling nutrients and supplying food for higher trophic levels, such as fish and birds **(Liang & Wang, 1999; Pan *et al.*, 2011; Timm & Mols, 2012)**. Crustaceans, gastropods, bivalves, oligochaetes, and representatives of many insect groups are examples of freshwater benthic macroinvertebrates **(Allan, 1995; Thorp & Covich, 2001; Merritt *et al*., 2008)** and they participate in numerous crucial ecological processes as decomposition and nutrient recycling. They also play a significant role in aquatic food webs such as consumers and prey **(Wallace & Webster, 1996; Covich *et al*., 1999; Vanni, 2002; Moore, 2006)**. **Engel (1988)** in his study has shown that aquatic macrophytes support higher numbers of macroinvertebrates and a wider variety of taxa than neighboring benthic habitats. **Habib and Yousuf (2015)** also noted that aquatic macrophytes give macroinvertebrates food, shelter, and oxygen. Few studies for macrobenthos have been conducted on Lake Nasser and its khors **(Latif, 1974; Iskaros 1988, 1993; Fishar, 1995; El-Shabrawy & Abd El-Regal, 1999; Iskaros & Gindy, 2009; Mola & Abdel-Gawad, 2014; Abdel Gawad &**

**Mola, 2014; Abdel Gawad, 2016; Abdel Gawad & Abdel-Aal, 2018; Iskaros *et al*., 2021; Nassif, 2021)**.

The current study aimed to identify the spatial and temporal distribution of zooplankton and macrobenthos assemblages concerning certain environmental parameters in Lake Nasser's main channel and two of its khors. Since Lake Nasser's water level fluctuates depending on the coming flood, this study also estimated and tracked changes in zooplankton and macrobenthos communities during pre- and post- floods seasons.

## MATERIALS AND METHODS

### Study area

Lake Nasser is approximately 5248km$^2$ in size, with a maximum depth of 90m and a mean depth of 21.5-25.5m. Its breadth varies from 8.9 to 18.0km at 160 and 180m above mean sea level, respectively **(Abdel Gawad, 2016)**. From Lake Nasser's main channel, five sectors (Aswan, Wadi-Abyad, El Mediq, Tushka, and Abu-Simble) were chosen (Table 1 & Fig. 1a). Additionally, during the pre- and post-flood season of 2021, samples were gathered from five sampling sites in each of Dahab Khor and El-Ramla Khor. Dahab Khor, which is one of the southern khors in Lake Nasser, is sometimes referred to as Tushka East Khor (Table 2 & Fig. 1b). A 5.43km wide natural broad water opening with no outlet connects this khor to the lake's main channel **(Abd Ellah & EL-Geziry, 2016)**. One of the northern khors in Lake Nasser is El-Ramla Khor (Table 2 & Fig. 1c), north of Dahmit Khor.

**Table 1.** Sampling sites locations at the main channel of Lake Nasser

| Section | Lat. | Long. | Distance from High Dam (Km) |
|---|---|---|---|
| Aswan | 23°56'11.61" | 32°52'7.00" | 2.9 |
| Wadi-Abyad | 23°20'43.57" | 32°56'9.43" | 74.3 |
| El Madiq | 22°54'9.56" | 32°35'23.06" | 138.6 |
| Tushka | 22°38'6.45" | 31°56'20.45" | 240 |
| Abu-Simble | 22°20'21.04" | 31°38'42.52" | 268.8 |

**Table 2.** Sampling sites locations of Dahab and El-Ramla khors

| Station | Dahab Khor | | El-Ramla Khor | |
|---|---|---|---|---|
| | Lat. N | Long. E | Lat. N | Long. E |
| 1 | 22°31'19.98" | 31°57'41.20" | 23°53'41.23" | 32°49'39.04" |
| 2 | 22°30'13.70" | 31°58'18.05"E | 23°54'19.48" | 32°48'1.33" |
| 3 | 22°29' 9.50" | 31°59'9.70" | 23°53'47.13" | 32°44'50.66" |
| 4 | 22°30'7.32" | 31°57'12.11" | 23°54'0.96" | 32°46'59.80" |
| 5 | 22°30'4.06 | 31°55'57.54" | 23°53'17.78" | 32°48'24.05" |

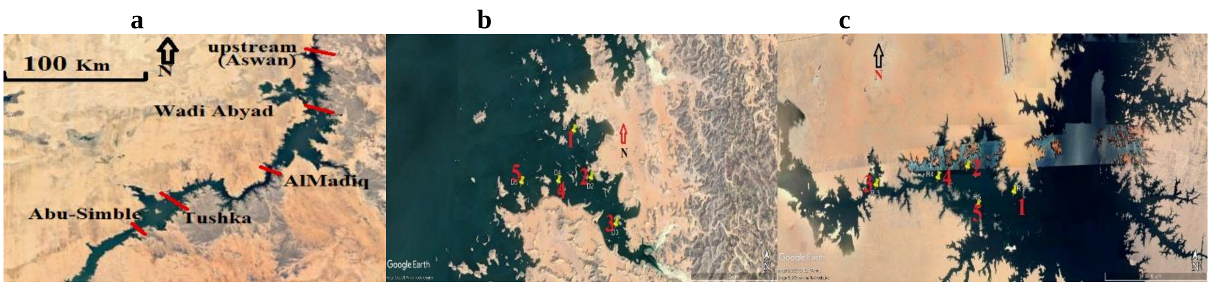



**Fig. 1.** Map showing sampling sites on **a)** main channel **b)** Dahab Khor **c)** El-Ramla Khor of Lake Nasser

## Collection of samples

### Zooplankton

Thirty liters of surface water were filtered through 55µ plankton net, 25cm in diameter and 80cm in length. The samples were concentrated into 100ml plastic bottles and immediately fixed with 5% formalin for subsequent analysis. Three subsamples (one ml each) of the homogenized plankton samples were then transferred into a counting cell in the laboratory, where the zooplankton species were identified using a binocular research microscope with magnification ranging from 40 to 100X. The species identification of the subsamples was conducted using the following references: **Ruttner-Kolisko (1974)**, **Pennak (1978)**, **Pontin (1978)**, **Wallace and Snell (1991)** and **Foissner and Berger (1996)**. The density of the zooplankton species was expressed as the number of organisms per cubic meter.

### Macrobenthic fauna

Using an Ekman Grab bottom sampler, samples were gathered. Following collection, samples were promptly conserved in 10% neutral formalin solution for further analysis after being carefully cleaned in a tiny hand net made of bolting silk with a mesh size of 0.5mm. Under a microscope, groups of macroinvertebrates were detected, and they were assigned to various taxa and species. Each species was counted, and the number of organisms per square meter was used to estimate the population density.

**Data analysis**

The Primer 5 programme was used to estimate the total zooplankton species (S), species richness (d), evenness (J), and diversity index (H) in each of the assessed main channel sectors, Khor El-Ramla and Khor Dahab. Using the Brodgar Programme, version 2.4.8 (Highland Statistics, 2005); canonical correspondence analysis (CCA) was used to examine the link between biotic and abiotic elements in the main channel and the two selected khors before and after the flood period.

## RESULTS AND DISCUSSION

### Zooplankton

Thirty-one zooplankton species were identified in the main channel, Khor El-Ramla and Khor Dahab of Lake Nasser throughot the study period (Table 3). **El-Shabrawy and Dumont (2003)** recorded 27 zooplankton species in larger khors and coastal zone of Lake Nasser's main channel and mentioned that the detected species are like the species community documented from the Nile since the $19^{th}$ century **(Dumont, 1986)**, indicating qualitative stability in zooplankton assemblage of the river system. Zooplankton communities in different Lake Nasser parts during the present study, composed of Copepoda, Cladocera and Rotifera. Rotifera, had the greatest number of species (20 species), Cladocera recorded 8 species, and Copepoda was represented by only 3 species in addition to copepodite stages and nauplius larvae. Therefore, many authors mentioned that Copepoda dominates the zooplankton in the Lake Nasser population in addition to Cladocera and Rotifera **(Zaghloul, 1985; Iskaros, 1993; El-Shabrawy & Dumont, 2003; Mageed & Heikal, 2006; El-Serafy *et al.*, 2009, Khalifa *et al*., 2015a)**.

The zooplankton of the main channel is formed of 20 species, 2 copepods, 5 cladocerans and 13 species of Rotifera. Only 15 species of zooplankton were detected in each Khor El-Ramla and Khor Dahab. **Khalifa *et al*. (2015b)** recorded 36 zooplankton species at Khor Wadi Abyad and Khor Tushka. **El-Serafy *et al.* (2009)** recorded 41 species (26 Rotifera, 12 Cladocera and 3 Copepoda) at 32 stations of six khors in Lake Nasser. Copepoda were the dominant group in the main channel and Khor El-Ramla of Lake Nasser, comprising 73.2, 57.4, 72.1 and 57.8% of total zooplankton in post and pre-flood seasons, respectively, and in Khor Dahab during post-flood with 74.4% of total zooplankton. While Cladocera formed the main group in Khor Dahab during pre-flood forming 69% of total zooplankton. The zooplankton community recorded 26 species during post-flood and declined to 23 species during pre-flood. **El-Serafy *et al*. (2009)** recorded maximum number of zooplankton species during post-flood season being 34 species and decreased to 31 species during flood season.

**Table 3.** Average density of total zooplankton species (Org. $m^{-3}$) in the main channel and khors of Lake Nasser during the study period

| Sector | Main channel | | El-Ramla Khor | | Dahab Khor | |
|---|---|---|---|---|---|---|
| **Season** | **Post-flood** | **Pre-flood** | **Post-flood** | **Pre-flood** | **Post-flood** | **Pre-flood** |
| **Rotifera** | | | | | | |
| *Asplanchna girodi* | 0 | 0 | 6567 | 0 | 0 | 0 |
| *A. priodonta* | 1889 | 151 | 0 | 0 | 0 | 0 |
| *Brachionus angularis* | 133 | 0 | 0 | 0 | 0 | 0 |
| *B. calyciflorus* | 494 | 0 | 0 | 1472 | 480 | 8153 |
| *B. caudatus* | 0 | 0 | 0 | 396 | 0 | 679 |
| *B. falcatus* | 944 | 944 | 0 | 0 | 0 | 0 |
| *B. patulus* | 267 | 0 | 0 | 0 | 0 | 0 |
| *B. urceolaris* | 0 | 4079 | 0 | 0 | 0 | 0 |
| *Collotheca ornate* | 1911 | 2719 | 0 | 0 | 0 | 0 |
| *Collotheca* sp. | 0 | 0 | 0 | 1472 | 0 | 0 |
| *Conochilus hippocrepis* | 0 | 0 | 0 | 3312 | 0 | 0 |
| *Filina longiseta* | 0 | 0 | 0 | 0 | 240 | 0 |
| *F. opoliensis* | 456 | 0 | 0 | 0 | 0 | 0 |
| *Keratella cochlearis* | 10033 | 1416 | 0 | 0 | 8000 | 0 |
| *K. tropica* | 22553 | 755 | 0 | 0 | 3100 | 0 |
| *Lecane bulla* | 0 | 0 | 0 | 0 | 0 | 702 |
| *L. closterocerca* | 378 | 0 | 0 | 0 | 0 | 0 |
| *Philodina roseola* | 511 | 1813 | 0 | 0 | 0 | 0 |
| *Synchaeta oblonga* | 0 | 0 | 0 | 2576 | 0 | 0 |
| *Trichocerca collaris* | 1855 | 0 | 0 | 0 | 0 | 0 |
| Total Rotifera | **41424** | **11879** | **6567** | **9229** | **11820** | **9534** |
| **Cladocera** | | | | | | |
| *Alona* sp. | 0 | 0 | 5378 | 0 | 6000 | 0 |
| *Bosmina longirostris* | 5394 | 32519 | 0 | 44982 | 0 | 75233 |
| *Chydorus sphaericus* | 9194 | 0 | 6398 | 3963 | 480 | 1223 |
| *Ceirodaphnia cornuta* | 23002 | 89836 | 0 | 0 | 0 | 0 |
| *C. dubia* | 0 | 0 | 19024 | 86313 | 2560 | 91584 |
| *Daphnia longispina* | 1644 | 7289 | 15569 | 18185 | 720 | 32113 |
| *Diaphanosoma excisum* | 4572 | 82986 | 0 | 0 | 0 | 0 |
| *D. mongolianum* | 0 | 0 | 36066 | 2729 | 4780 | 216912 |
| Cladocera embryo | 0 | 1737 | 0 | 0 | 0 | 0 |
| Total Cladocera | **43805** | **214367** | **82435** | **156173** | **14540** | **417064** |
| **Copepoda** | | | | | | |
| *Mesocyclops ogunnus* | 0 | 0 | 7757 | 6030 | 9200 | 8334 |
| *Thermocyclops neglectus* | 76101 | 92293 | 3963 | 793 | 1680 | 9444 |
| *Thermodiaptomus galebi* | 5877 | 17902 | 33067 | 10655 | 1240 | 12252 |
| Copepodites | 10393 | 75409 | 98969 | 73981 | 34280 | 112306 |
| Nauplius larvae | 140710 | 106947 | 86626 | 135428 | 30040 | 34921 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Total Copepoda | 233081 | 292551 | 230381 | 226887 | 76440 | 177257 |
| **Total zooplankton** | **318310** | **518797** | **319383** | **392289** | **102800** | **603856** |

## Distribution of zooplankton

The density of zooplankton in Lake Nasser is contingent upon the fluctuations in the water level, which varies upon the annual lake flood **(El-Serafy *et al*., 2009)**. Regarding the main channel of the lake, Fig. (2) shows that the standing crop of zooplankton was higher (518797 Org.m$^{-3}$) during pre-flood period, whereas it decreased during post-flood to 318310 org.m$^{-3}$. In khors El-Ramla and Dahab, the highest average densities of zooplankton were 392289 and 603856 Org. m$^{-3}$ during pre-flood and decreased to 319383 and 102800 Org.m$^{-3}$ during post-flood, respectively (Figs. 3, 4). **Hegab *et al.* (2020)** recorded the high zooplankton density in Lake Nasser during flood season and sharply decreased during post-flood. High water level in Lake Nasser expands the shallow water zones, giving fish greater spawning area, high fish production predates on plankton leading to a decrease in plankton density **(Khalifa *et al*., 2000)**.

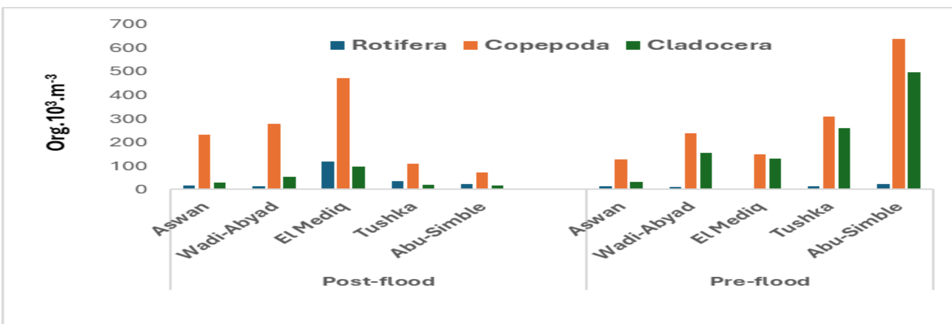



**Fig. 2.** Total density of zooplankton groups (Org. 10$^{3}$.m$^{-3}$) on the main channel of Lake Nasser during different flood seasons

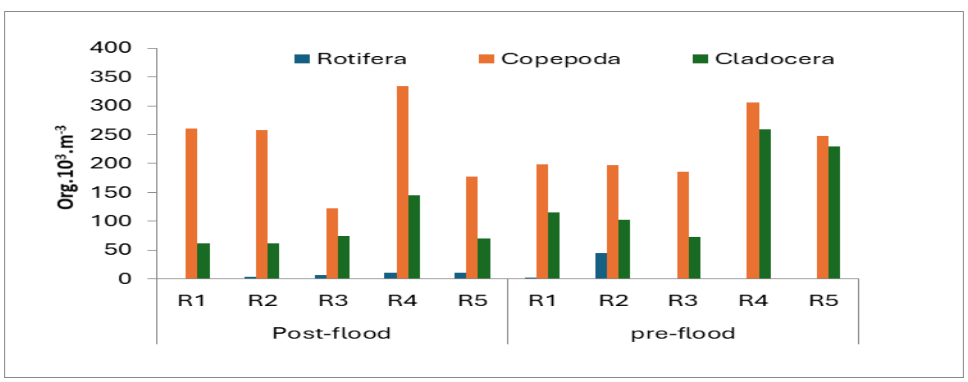



**Fig. 3.** Total density of zooplankton groups (Org. 10$^{3}$.m$^{-3}$) in Khor El-Ramla of Lake Nasser during different flood seasons

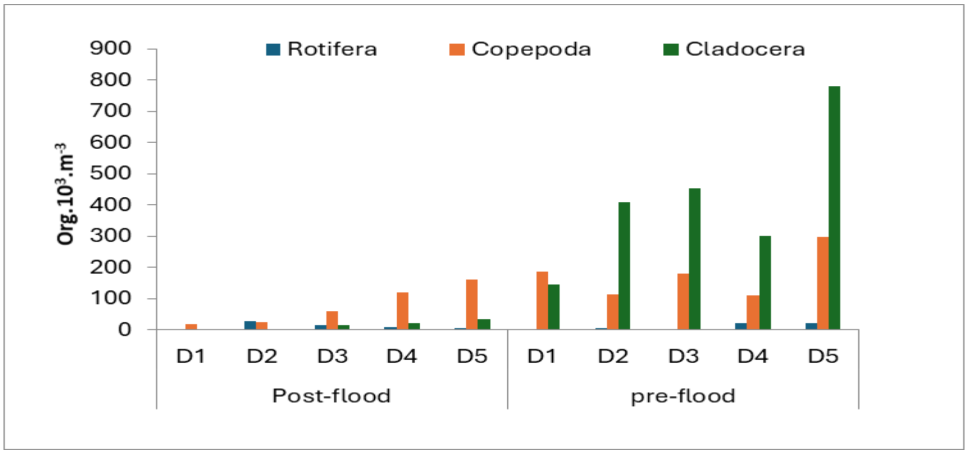



**Fig. 4.** Total density of zooplankton groups (Org. $10^3.m^{-3}$) in Khor Dahab of Lake Nasser during different flood seasons

**Copepoda**

Copepoda forms the main zooplankton group in Lake Nasser **(Mageed & Heikal 2006; El-Serafy *et al*. 2009; El-Shabrawy, 2009; Khalifa *et al.*, 2015a)**. Moreover, copepods represent the main dominant group in Khor El-Ramla in the two sampling seasons, whereas it represents the main dominant group in Khor Dahab only in post-flood. Generally, Copepoda dominated mesotrophic lakes **(Green, 1965)**.

In the main channel, naupilus larvae were the most abundant form of Copepoda represented by about 60.4% (140710 org.$m^{-3}$) during post-flood period and decreased to 36.6% (106947 org.$m^{-3}$) during pre-flood period. In addition, in Khor El-Ramla, nauplius larvae highly flourished (37.6 - 59.7%) while in Khor Dahab, Cyclopoid copepodites were the dominant copepod form (44.9-63.4%) in post and pre-flood, respectively. **Mageed and Heikal (2006)** and **Khalifa *et al.* (2015a, b)** reported that nauplii represent the majority of Copepoda in Lake Nasser main channel or khors. **Iskaros *et al.* (2008)** and **El-Enany (2009)** mentioned the abundance of nauplius larvae over copepods in Lake Nasser which mainly feed on phytoplankton. Phytoplankton is rich in Lake Nasser during flood period because of the increase of nutrient salts **(Latif, 1984)**. **Lavens and Sorgeloos (1996)** found that some zooplankton species, especially copepods, produce dormant eggs under unfavorable conditions (e.g. flood).

In the main channel of the lake, Copepoda are represented by two species: the carnivorous cyclopoid *Thermocyclops neglectus* and the herbivorous calanoid *Thermodiaptomus galebi*, along with their larval stages (nauplius larvae and copepodites). *Thermocyclops neglectus* flourished in post and pre-flood seasons representing about 32 and 31% of total copepods, respectively (Table 1). **El-Shabrawy (2009)** recorded *Thermocyclops neglectus* and *Mesocyclops ogunnus* (carnivorous cyclopoids) and *Thermodiaptomus galebi* (herbivorous calanoid), which was the dominant copepod in the study of **El-Shabrawy and Dumont (2003)**. In the two studied khors, the cyclopoid *Mesocyclops ogunnus* was also noticed in addition to the previously mentioned species *T. Neglectus* and *T. galebi* (Table 1).

**Cladocera**

Cladocera flourished in Lake Nasser's main channel during pre-flood with a density of 214367 Org./$m^3$ and declined to 43805 Org./$m^3$during post- flood season. *Ceirodaphnia cornuta* was the most abundant species during pre- and post-flood, contributing about 42 and 52.5% of total Cladocera, respectively.

The average density of total Cladocera in Khor Dahab (215802 Org. /$m^3$) was higher than that in Khor El-Ramla (119304 Org./$m^3$). **El-Serafy *et al.* (2009)** recorded that the highest average number of Cladocera at Khor Tushka East reached 22190 Org./$m^3$ and decreased at Khor Kalabsha to 13390 Org./$m^3$, then it reached the lowest number at Kurusku (8080 Org./$m^3$). In El-Ramla Khor, *Diaphanosoma mongolianum* was the dominant cladoceran during post-flood with 43.8% of total group and during pre-flood *Ceirodaphnia dubia* (55.3%) dominated. *Alona* sp. and *Diaphanosoma mongolianum* were the dominant species of Cladocera in Dahab Khor during post and pre-flood with 41.3 and 52% of total group, respectively. **Mageed and Heikal (2006)** found that *Ceriodaphnia* spp. represent the main bulk of Cladocera in Lake Nasser, while **El-Serafy *et al.* (2009)** observed that *Bosmina longirostris* is considered the common form of Cladocera. *Diaphanosoma mongolianum* flourished at the surface and at a depth of 10–5m in Lake Nasser, with densities of 2750 and 2340 org./$m^3$, respectively. Meanwhile, *Ceriodaphnia dubia* was abundant at a depth of 20–15m, with a density of 2219 org./$m^3$ **(Khalifa *et al.*, 2015a)**. Additionally, *Ceriodaphnia dubia* dominated the Cladocera community in Khor Wadi Abyad **(Khalifa *et al.*, 2015b)**.

**Rotifera**

In the main channel Rotifera recorded 13% of total zooplankton during post-flood, and it decreased to only 2.3% during pre-flood. In khors, rotifers ranged between 1.6 and 11.5% of total zooplankton. Rotifera was the least detected group in Lake Nasser and its different khors as recorded in many studies **(Mageed & Heikal, 2006; El-Shabrawy, 2009; Khalifa *et al.*, 2015a, b; Abdel-Aal *et al*., 2023)**. In Khor El-Ramla, the highest density of rotifers was recorded at 9229 org./$m^3$ during the pre-flood season, which decreased to 6567 org./$m^3$ post-flood. In contrast, Khor Dahab saw the highest density of rotifers at 11,820 org./$m^3$ during the post-flood season, while the lowest count of 9534 org./$m^3$ occurred in the pre-flood season. Thirteen species of Rotifera were recorded in the main channel dominated by *Brachionus urceolaris* (34% of total Rotifer) during pre-flood period and *Keratella tropica* (54% of total Rotifer) during post-flood season. Only *Asplanchna girodi* was recorded in Khor El-Ramla during post-flood, which increased to five species during pre-flood dominated by *Conochilus hippocrepis.* In Khor Dahab, three and four species were detected during pre- and post-flood dominated by

*Keratella cochlearis* and *Brachionus calyciflorus* forming about 67.7 and 85.5% of total Rotifera, respectively. During post and pre-flood seasons, *Keratella cochlearis* was the dominant rotiferan species, forming about 83 and 77% of total Rotifera, respectively. While *Keratella tropica* flourished during flood mkaing up 52.6% of total Rotifera **(Hegab *et al*., 2020)**. *Asplanchna priodonta* and *Collotheca ornate* were the common rotifer species at Dahmeit Khor, while *Keratella cochlearis* was the main rotiferan form at Tushka Khor **(Abdel-Aal *et al*., 2023)**.

**Zooplankton analysis**

Diversity indices of zooplankton community in the main channel sectors, Khor El-Ramla and Khor Dahab, were estimated in each of the studied periods (Table 4). Regarding the seasonal variations of main channel sectors, the highest number of species (S) and species richness (d) were recorded in post-flood season, while the highest evenness (J), and diversity index (H) values were calculated in pre-flood season among the different sectors of main channel. On the other hand, high values of species (S) and species richness (d), evenness (J), and diversity index (H) in Khor El-Ramla sites were revealed in post-flood season, except for site 1. In Khor Dahab, the highest value of each of species (S) and species richness (d), evenness (J), and diversity index (H) were estimated in pre-flood season within the majority of the studied sites.

**Table 4.** Diversity indices of zooplankton community in the main channel, Khor El-Ramla and Khor Dahab of Lake Nasser

| Area | Sites | Post-Flood | | | | Pre-Flood | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **S** | **d** | **J** | **H** | **S** | **d** | **J** | **H** |
| Main Channel | Aswan | 17 | 1.276 | 0.532 | 1.507 | 11 | 0.829 | 0.802 | 1.924 |
| | Wadi Abyd | 15 | 1.098 | 0.596 | 1.613 | 12 | 0.852 | 0.794 | 1.973 |
| | El-Madiq | 17 | 1.191 | 0.643 | 1.823 | 11 | 0.797 | 0.801 | 1.921 |
| | Tushka | 13 | 0.998 | 0.65 | 1.667 | 12 | 0.829 | 0.778 | 1.933 |
| | Abu-Simbel | 18 | 1.46 | 0.626 | 1.81 | 13 | 0.859 | 0.71 | 1.821 |
| Khor El-Ramla | R1 | 8 | 0.552 | 0.854 | 1.775 | 10 | 0.711 | 0.781 | 1.798 |
| | R2 | 11 | 0.788 | 0.83 | 1.991 | 10 | 0.706 | 0.76 | 1.75 |
| | R3 | 11 | 0.818 | 0.813 | 1.949 | 10 | 0.722 | 0.644 | 1.484 |
| | R4 | 13 | 0.916 | 0.828 | 2.125 | 9 | 0.604 | 0.731 | 1.605 |
| | R5 | 9 | 0.642 | 0.894 | 1.964 | 8 | 0.535 | 0.888 | 1.847 |
| Khor Dahab | D1 | 5 | 0.404 | 0.723 | 1.164 | 10 | 0.708 | 0.816 | 1.879 |
| | D2 | 8 | 0.643 | 0.626 | 1.302 | 11 | 0.759 | 0.69 | 1.654 |
| | D3 | 9 | 0.699 | 0.793 | 1.742 | 10 | 0.674 | 0.735 | 1.692 |
| | D4 | 9 | 0.672 | 0.697 | 1.53 | 9 | 0.617 | 0.821 | 1.805 |
| | D5 | 14 | 1.065 | 0.735 | 1.939 | 12 | 0.791 | 0.752 | 1.868 |

**S=Total species, d=species richness and J=evenness, H= diversity index.**

## Macrobenthic fauna

Seventeen macrobenthic invertebrate (MBI) species were identified in the main channel of the lake. Only twelve and thirteen species were recorded at Dahab and El-Ramla Khors, respectively. Some studies mentioned that the numbers of macrobenthos species in the main channel of Lake Nasser were more than that of its khors **(Abdel Gawad & Mola, 2014; Mola & Abdel Gawad, 2014)**. The benthic fauna community was represented by five main phyla, Annelida, Arthropoda, Mollusca, Nematode, and Cnidaria. Annelida (4 species) was the dominant phylum representing 51.3% of the total number of macrobenthic in main channel of Nasser Lake. Arthropoda (6 species) was the second group representing 33.9%, Mollusca (3 species) representing 12.9%, Nematode representing 1.7%, and Cnidaria forming about 0.03%, the last two phyla were detected only in the main channel. Macrobenthic fauna belong to three main phyla in the two studied khors, Mollusca (7 species), Arthropoda (5 species) and Annelida (3 species). Mollusca formed about 44 and 61% at Dahab and El-Ramla khors, respectively. Arthropods constituted about 46 and 29%, while Annelida represented about 10 and 9.5% at two khors, respectively.

## Distribution of macrobenthic fauna

In the main channel, the highest number of species (13) was recorded in pre-flood season and decreased to 11 species in post-flood season. **Abdel Gawad and Abdel-Aal (2018)** observed that the pre-flood season attained the highest number of macroinvertebrates and species richness. The post-flood season recorded the greatest average of macrobenthos (2436 org.m$^{-2}$), while in pre-flood, all macrobenthic taxa were elevated, except for Annelida and Cnidaria groups (Fig. 5). El-Madiq (5900 org.m$^{-2}$), Tushka (2780 org.m$^{-2}$), and Wadi-Abyad sectors had the greatest total counts of macroinvertebrates prior to the flood, whereas the greatest densities of 16960 and 8130 org.m$^{-2}$ during the post-flood season were recorded in the El-Madiq and Abu-Simble regions, respectively. Mollusca accounted for 47.8% of the total macrobenthic fauna at Dahab Khor in post-flood, followed by Arthropoda (40.9%) and Annelida (11.4%). In contrast, **Abdel Gawad and Abdel Aal (2018)** reported that the Annelida group predominated at Khor Dahmit and Khor Tushka West during the post-flood period. The highest density of macrobenthic invertebrates (MBI) was recorded at stations D2 and D5, with 1700 org./m$^2$ and 1648 org./m$^2$, respectively, attributed to the flourishing of Mollusca. The lowest density of MBI (144 org./m$^2$) was observed at station D3 (Fig. 6). During the pre-flood period, MBI were dominated by Arthropoda (50.4%), followed by Mollusca (40%) and Annelida (9.3%). Stations D3 and D5 were the richest, recording 608 and 576 org./m$^2$, respectively (Fig. 6). According to **Mola and Abdel Gawad (2014)**, during the summer (before the flood), the highest documented number of Arthropoda (Insect larvae) was found near Khor Kurusku.

Khor El-Ramla was poor with MBI compared to Dahab Khor, **Abdel Gawad and Mola (2014)** mentioned that population density of macrobenthic invertebrates was greater in southern sectors than in northern sectors. Mollusca was represented with high percentages at two khors, while Annelida dominated in main channel. These differences between the main channel and khors can be explained by the fact that each khor has unique ecological characteristics and environmental circumstances that set it apart from Lake Nasser's main channel **(Elba *et al.*, 2014)**. In post-flood season, Mollusca represented about 67% of macrobenthic fauna at Khor El-Ramla, followed by Arthropoda (20%) and Annelida (12.9%). The highest density of macrobenthic invertebrates (MBI) was recorded at station R1, with 1056 org./m², while the lowest density was observed at station R5, with 144 org./m² during the post-flood period (Fig. 7). Station R1 reported the highest MBI with 1056 org. $m^{-2}$, whereas station R5 recorded the lowest number of 144 org. $m^{-2}$ in post-flood (Fig. 7). Annelida were absent from stations R1 and R5, while arthropods, particularly Chironomidae larvae, peaked at station R1. This may be attributed to the inverse relationship between chironomid larvae and oligochaetes, as some chironomid larvae feed on oligochaetes **(Abdel Gawad, 2001)**.

In pre-flood, Mollusca occupied about 91% and Annelida, Arthropoda represented 5.6 and 3.7%, respectively. Site R5 has a peak with MBI due to increased numbers of Mollusca, and all members of MBI disappeared totally from R3 (Fig. 7).

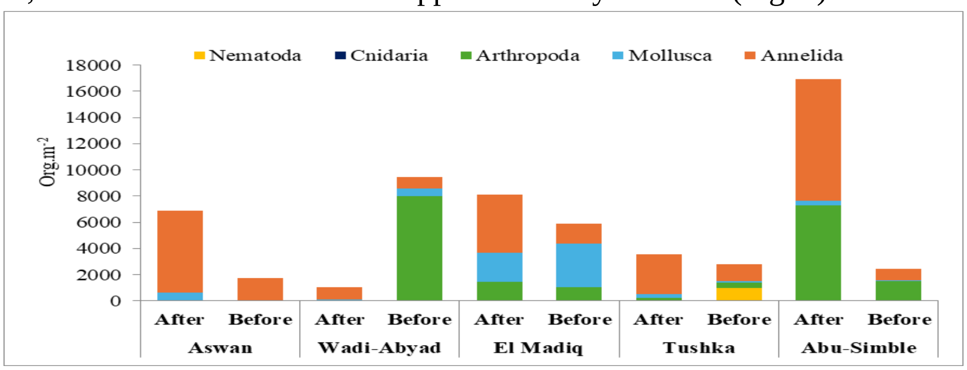



**Fig. 5.** Population density of macrobenthic invertebrates (Org.$m^{-2}$) at each sampling site of the main channel during different flood periods

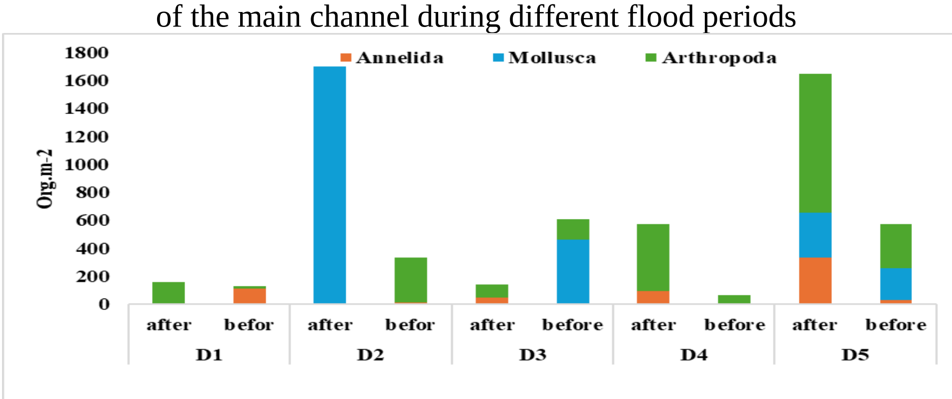



**Fig. 6.** Population density of macrobenthic invertebrates (Org. $m^{-2}$) at each sampling site of Dahab Khor during different flood periods

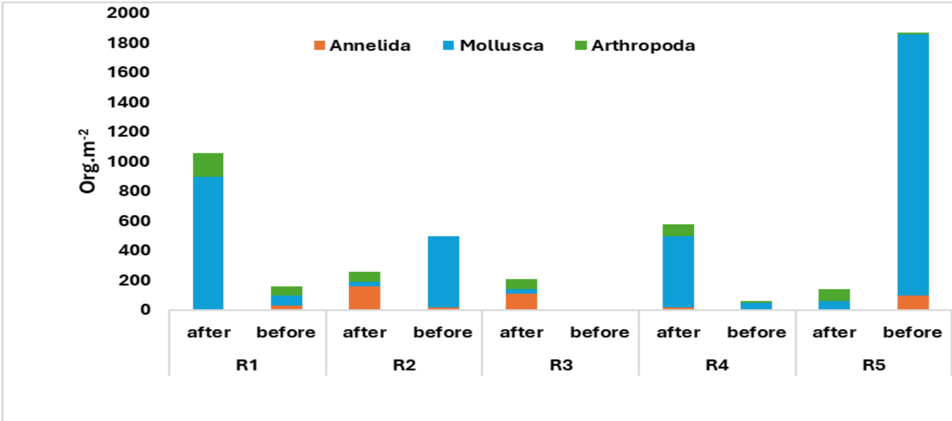



**Fig. 7.** Population density of macrobenthic invertebrates (Org.m$^{-2}$) at each sampling site of El-Ramla Khor during different flood periods

## Annelida

Annelida recorded the maximum density of 9280 org. m$^{-2}$ at Abu-Simble sector of main lake channel in post-flood season, which is mainly attributed to the dominance of *Limnodrilus udekemianus*, but the lowest density of 840 Org.m$^{-2}$ was detected at the same site in pre-flood season. *Limnodrilus udekemianus* was the dominant oligochaete form at the investigated sites. It constituted about 65 and 14.2% of total macroinvertebrates recorded in the whole area in post and pre-flood seasons, respectively. Few members of *Branchiura sowerbyi* appeared in some sectors during the whole study period, while *Nais* sp. and *Hellobdella conifer* appeared in few numbers at some sectors in pre-flood season only and disappeared after flood. **Wahab *et al.* (2018)** mentioned that oligochaetes mainly consist of *Limnodrilus udekemianus, L. hoffmeisteri,* and *Branchiura sowerbyi*, which flourished during winter and autumn at some northern khors of Lake Nasser.
*Limnodrillus* sp. was the most dominant species, comprising over 61% and 44% of the total annelids in Khor El-Ramla, and about 43% and 80% of Annelida in Khor Dahab during the post-flood and pre-flood periods, respectively. According to **Iskaros and El-Dardir (2010)**, oligochaetes predominate in Lake Nasser due to their adaptability to various environments and their tolerance for low oxygen or anoxic conditions. *Branchiura sowerbyi* was more abundant post-flood in both khors than in the pre-flood period. *Hellobdella conifer*, observed only in the pre-flood period, was found in the studied khors, similar to its presence in the main channel (Table 5).

## Mollusca

Mollusca collected from the main channel of the lake showed a maximum density of 3320 org./m² at the El Madiq sector during the pre-flood season, primarily due to the flourishing of *Gyraulus ehrenbergi*, the dominant gastropod in the study area. It formed nearly 18 and 6.6% of total macroinvertebrates in pre- and post- flood, respectively.

**Abdel Gawad and Abdel-Aal (2018)** mentioned that *G. ehrenbergi* was the second dominant species of gastropods after *Bulinus truncates* during different flood seasons (before, during and after flood) at Dahmit and Tushka West khors. Pre-flood season was the richest season with *Gyraulus ehrenbergi*, while *Corbicula fluminalis* was weakly represented and *Melanoides tuberculata* was completely missed.

Mollusca in the khors flourished during pre-flood period, with *Melanoides tuberculata* and *Valvata nilotica* as the dominant species. *Valvata nilotica* formed about 50% and more than 70% of the total Mollusca at Khor El-Ramla and Khore Dahab, respectively. As in main channel, *Gyraulus ehrenbergi* was recorded at the studied khors and it was higher during pre-flood. *Bulinus truncates* was recorded at the khor El-Ramla at the two sampling seasons and in Khore Dahab only in post-flood. **Mola and Abdel Gawad (2014)** recorded this species at some of Lake Nasser Khors. *Physa acuta* was only detected at El-Ramla Khor during post-flood. Moreover, **Fishar (1995)** also recorded this species as rare form of Mollusca in Lake Nasser.

**Arthropoda**

In the main channel of Lake Nasser, Arthropoda reached a high density of 11,020 org./m² during the pre-flood season, largely due to the flourishing of Ostracoda. Chironomidae larvae were particularly abundant in the post-flood season, with the Abu Simble sector hosting the highest density of these larvae. Chironomidae pupae also thrived in the main channel, while *Baetis* sp., *Caenis* sp., *Ischnura* sp., and water ticks were rarely detected. **Wahab *et al.* (2018)** found that among the benthic community of Lake Nasser, Chironomid larvae were the most significant organisms, whereas Chironomidae pupae, Odonata and Ephemeroptera nymphs, and Trichoptera and Hemiptera larvae were less frequent. Similar findings were reported in the studies of **Wissa (2002)**, **Ahmed *et al*. (2002)**, **Ahmed (2007)** and **Bendary (2013)** addressing the River Nile. While, the study of **Wissa (2012)** recorded similar outcomes investigating El-Rahway drain and that of **Nassif (2012)** addressing Ismailia Canal.

Chironomid Larva and the ostracod *Chlamidothica unispinosa* were the dominant arthropods in the two investigated khors (Table 5). Many studies on Lake Nasser and some of its khors mentioned that the most significant organisms in the benthic community in Lake Nasser were chironomid larvae **(Fishar, 2000; Wahab *et al*., 2018; Nassif, 2021)**. *Cardina nilotica* was only recorded in the two khors during post-flood season; this species was detected in the study of macrobenthic in four of Lake Nasser's khors during 2013 **(Mola & Abdel Gawad, 2014)**.

## Nematoda

Nematoda was represented by an odd species that appeared in the main channel of the lake in the two studied seasons and highly flourished at pre-flood season (Table 5). They were the lowest detected group of the epiphytic microinvertbrates **(Mola *et al*., 2018)**.

## Cnidaria

Cnidaria was only formed of *Hydra* sp., which appeared in few numbers in post-flood season and completely disappeared in pre-flood in the main channel. Nematoda and Cnidaria were completely absent at the two studied khores. **Mola and Abdel Gawad (2014)** missed the presence of Nematoda and Cnidaria in four khors of Lake Nasser (Tushka West, Kurusku, Wadi Abyad, and Kalabsha).

**Table 5.** Average Density of total macrobenthic species (Org.m$^{-2}$) in the main channel and the studied khors of Lake Nasser

| **Sector** | **Main channel** | | **El-Ramla Khor** | | **Dahab Khor** | |
|---|---|---|---|---|---|---|
| **Season** | **Post-flood** | **Pre-flood** | **Post-flood** | **Pre-flood** | **Post-flood** | **Pre-flood** |
| **Annelida** | | | | | | |
| *Limnodrilus* sp. | 23782 | 3164 | 176 | 64 | 208 | 128 |
| *Nais* sp. | 0 | 2508 | 0 | 0 | 0 | 0 |
| *Helobdella conifer* | 0 | 80 | 0 | 64 | 0 | 32 |
| *Branchiura sowerbyi* | 196 | 520 | 112 | 16 | 272 | 0 |
| **Total Annelida** | **23978** | **6272** | **288** | **144** | **480** | **160** |
| **Arthropoda** | | | | | | |
| Chironomidae larvae | 6380 | 1260 | 128 | 160 | 1280 | 576 |
| Chironomidae pupa | 2500 | 480 | 0 | 0 | 0 | 0 |
| *Baetis* sp | 40 | 0 | 0 | 0 | 0 | 0 |
| *Caenis* sp. | 0 | 80 | 0 | 0 | 80 | 0 |
| *Ischnura* sp. | 0 | 80 | 0 | 0 | 0 | 0 |
| Ostracoda | 0 | 9100 | 0 | 0 | 0 | 0 |
| *Chlamidothica unispinosa* | 0 | 0 | 288 | 160 | 288 | 288 |
| Trichoptera larvae | 0 | 0 | 0 | 0 | 48 | 0 |
| *Cardina nilotica* | 0 | 20 | 32 | 0 | 32 | 0 |
| Water Tick | 20 | 0 | 0 | 0 | 0 | 0 |
| **Total Arthropoda** | **8940** | **11020** | **448** | **320** | **1728** | **864** |
| **Mollusca** | | | | | | |
| *Melanoides tuberculata* | 60 | 0 | 64 | 128 | 300 | 112 |
| *Valvata nilotica* | 0 | 0 | 944 | 1008 | 1160 | 576 |
| *Gyraulus ehrenbergi* | 2400 | 4012 | 240 | 144 | 80 | 0 |
| *Helisoma duryi* | 0 | 0 | 0 | 32 | 0 | 0 |
| *Spharium simile* | 0 | 0 | 64 | 944 | 0 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| *Bulinus truncates* | 0 | 0 | 160 | 80 | 480 | 0 |
| *Physa acuta* | 0 | 0 | 32 | 0 | 0 | 0 |
| *Corbicula fluminalis* | 1120 | 40 | 0 | 0 | 0 | 0 |
| **Total Mollusca** | **3580** | **4052** | **1504** | **2336** | **2020** | **688** |
| **Nematoda** | **20** | **1000** | **0** | **0** | **0** | **0** |
| **Hydra sp.** | 20 | 0 | 0 | 0 | 0 | 0 |
| **Total Macrobenthos** | **36538** | **22344** | **2240** | **2800** | **4228** | **1712** |

## Macrobenthos analysis

Many diversity indices of macrobenthos species number (S), species richness (d), evenness (J), and diversity index (H) at different studied sectors in the main channel of the lake and each sampling site of the two khors were calculated in pre- and post-flood seasons (Table 6). The highest of all diversity indices values were detected during pre-flood season within the most sectors of the main channel. At El-Ramla Khor, R4 attained the highest diversity index (H) and evenness in post-flood, and R5 recorded highest values of species number (S) and species richness (d) during pre-flood. In contrast, at Khor Dahab, D5 recorded the highest values species number (S), species richness (d) and diversity index (H) during post-flood, whereas evenness (J) slightly increased in pre-flood.

**Table 6.** Diversity indices of macrobenthic community in the main channel, Khor El-Ramla and Khor Dahab of Lake Nasser

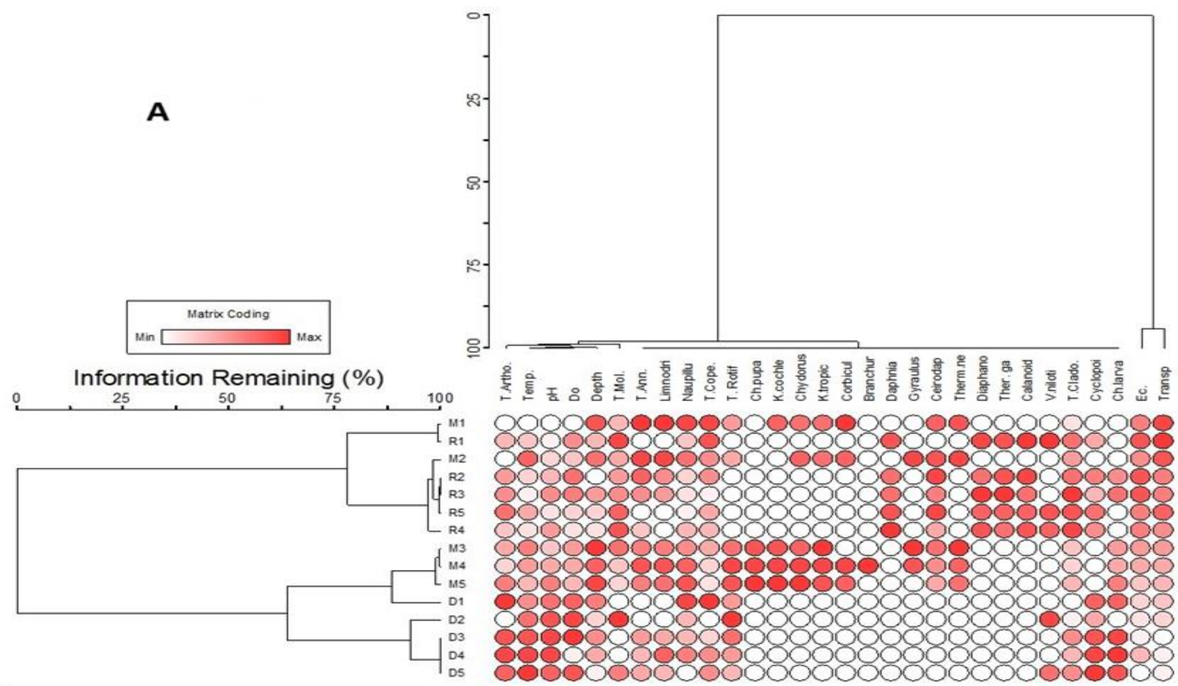
| Area | Sites | Post-Flood | | | | Pre-Flood | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **S** | **d** | **J** | **H** | **S** | **d** | **J** | **H** |
| Main Channel | Aswan | 3 | 0.226 | 0.288 | 0.317 | 3 | 0.268 | 0.667 | 0.732 |
| | Wadi Abyd | 3 | 0.289 | 0.337 | 0.37 | 5 | 0.437 | 0.38 | 0.612 |
| | El-Madiq | 6 | 0.555 | 0.595 | 1.066 | 9 | 0.921 | 0.687 | 1.51 |
| | Tushka | 7 | 0.734 | 0.394 | 0.766 | 8 | 0.883 | 0.781 | 1.624 |
| | Abu-Simbel | 8 | 0.719 | 0.521 | 1.083 | 7 | 0.77 | 0.722 | 1.404 |
| Khor El-Ramla | R1 | 5 | 0.575 | 0.715 | 1.15 | 3 | 0.394 | 0.961 | 1.056 |
| | R2 | 4 | 0.012 | 0.926 | 1.283 | 5 | 0.644 | 0.682 | 1.098 |
| | R3 | 4 | 0.562 | 0.974 | 1.35 | 0 | 0 | 0 | 0 |
| | R4 | 8 | 1.101 | 1.646 | 3.421 | 2 | 0.24 | 0.812 | 0.563 |
| | R5 | 2 | 0.201 | 0.99 | 0.686 | 10 | 1.177 | 0.542 | 1.248 |
| Khor Dahab | D1 | 4 | 0.59 | 0.961 | 1.332 | 2 | 0.206 | 0.544 | 0.377 |
| | D2 | 3 | 0.269 | 0.872 | 0.958 | 2 | 0.172 | 0.277 | 0.192 |
| | D3 | 3 | 0.402 | 0.772 | 0.848 | 4 | 0.468 | 0.732 | 1.015 |
| | D4 | 4 | 0.472 | 0.638 | 0.884 | 1 | 0 | 0 | 0 |
| | D5 | 10 | 1.215 | 0.849 | 1.956 | 5 | 0.629 | 0.896 | 1.442 |

**S=Total species, d=species richness and J=evenness, H= diversity index.**

## Cluster analysis

### Similarity

The results of the hierarchical cluster analysis during post-flood period indicated that the sampling sites clustered into two groups at a similarity level of roughly 63% (Fig. 8A). The analysis showed that the community structures of M1 and R1, M3 and M4, D3, D4 and D5 and R2 and R3 were more similar, with a similarity value getting almost 100% of its physical and biological characteristics. On the other hand, in pre-flood, the cluster indicated that the sampling sites clustered into two groups at similarity level of about 55%. The dendrogram (Fig. 8B) indicated that M1 and R1 shared approximately 85% similarity, while R2 and R4 were 100% similar to M2. Additionally, D2 and D4 showed about 100% similarity to D5. The analysis revealed that Khor Dahab exhibits physical and biological characteristics that differ slightly from those of Khor El-Ramla and the main channel of Lake Nasser.



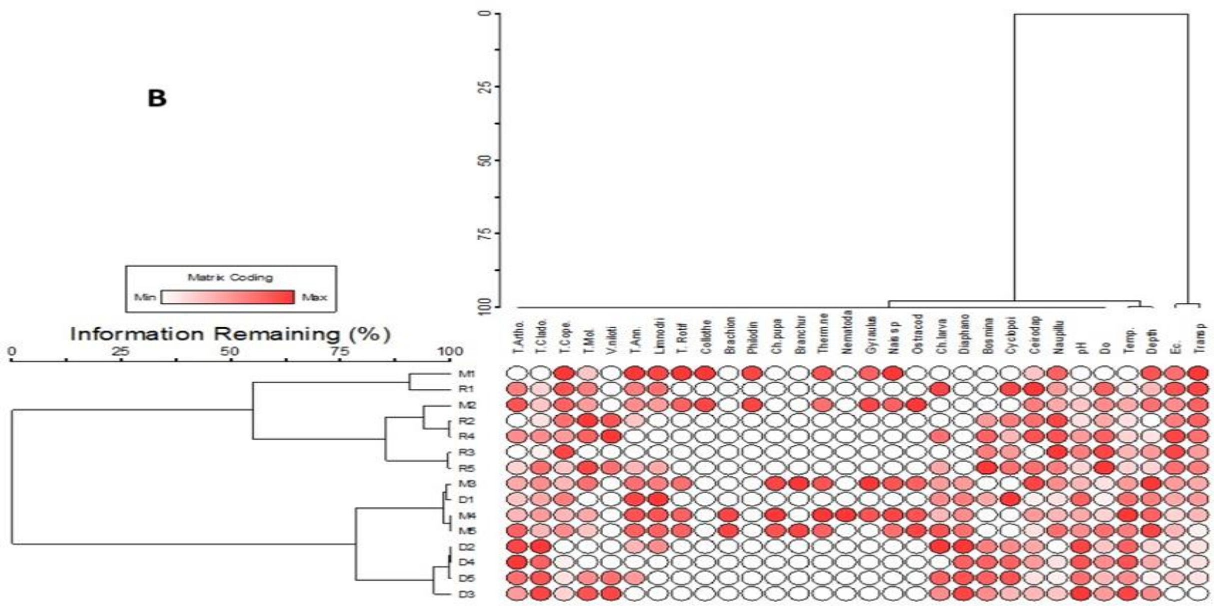



**Fig. 8.** Dendrogram of hierarchical clustering among the estimated main channel of Lake Nasser, Dahab and El-Ramla Khors sampling sites based on zooplankton and macrobenthos biodiversity. **(A)** post-flood, **(B)** pre-flood

## Canonical correspondence analysis (CCA)

### Post-flood season

Six environmental factors with common groups and species of zooplankton and macrobenthos were analyzed using canonical correspondence analysis (CCA) during post-flood (Fig. 9). Analysis showed that the main factors influencing zooplankton and macrobenthos species distribution are transparency, depth, pH and EC. As shown in CCA biplot diagram, depth positively correlated with Annelida, *Gyraulus ehrenbergi*, *Corbicula fluminalis*, *Thermocyclops neglectus* and *Keratella tropica*. *Ceirodaphnia cornuta* was correlated positively with transparency. Arthropoda and *Cyclopoid copepodite* were highly positively correlated with dissolved oxygen.

### Pre-flood season

Depth was the most important factor affecting macrobenthos and zooplankton species. It recorded a positive correlation with *Brachionus urceolaris*, *Philodina roseola*, Chironomidae pupa and Nematoda and they were negatively correlated with DO. The CCA biplot diagram showed that DO positively correlated with cyclopoid copepodite and *Bosmina longirostris*, and Arthropoda was correlated positively with temperature (Fig. 10).

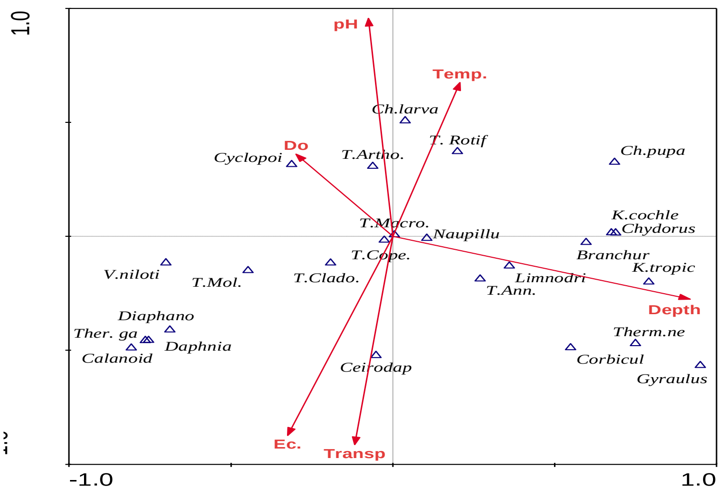



**Fig. 9.** Canonical correspondence analysis (CCA) ordination biplot based on groups and common species, along with environmental variables, at two khores and the main channel of Lake Nasser during the post-flood period. Codes used are as follows: Trans. = Transparency, Do = Dissolved Oxygen, Ec. = Electrical Conductivity, Temp. = Temperature, T. Rotif. = Total Rotifera, T. Clado. = Total Cladocera, T. Cope. = Total Copepoda, K. cochle. = *Keratella cochlearis*, K. tropic. = *Keratella tropica*, Daphnia = *Daphnia longispina*, Ceirodap. = *Ceirodaphnia cornuta*, Chydorus = *Chydorus sphaericus*, Diaphano. = *Diaphanosoma excisum*, Naupillu. = Naupillus larvae, Calanoid = Calanoid copepodite, Cyclopoi. = Cyclopoid copepodite, Ther. ga. = *Thermodiaptomus galebi*, Therm. ne. = *Thermocyclops neglectus*, T. Macro. = Total Macrobenthos, T. Ann. = Total Annelida, T. Artho. = Total Arthropoda, T. Mol. = Total Mollusca, Ch. larva = Chironomidae larva, Ch. pupa = Chironomidae pupa, Corbicul. = *Corbicula fluminalis*, Limnodri. = *Limnodrilus*, Branchur. = *Branchiura sowerbyi*, V. niloti. = *Valvata nilotica*

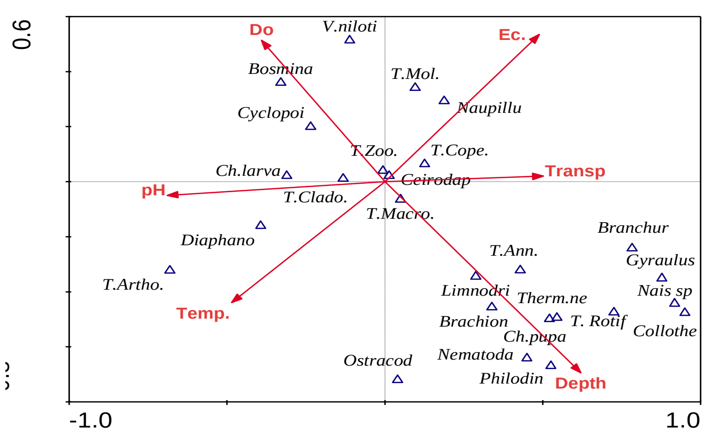



**Fig. 10.** Canonical correspondence analysis (CCA) ordination biplot based on groups and common species, along with environmental variables, at two khores and the main channel

of Lake Nasser during the pre-flood period. Codes used are as follows: Trans. = Transparency, Do = Dissolved Oxygen, Ec. = Electrical Conductivity, Temp. = Temperature, T. Rotif. = Total Rotifera, T. Clado. = Total Cladocera, T. Cope. = Total Copepoda, Brachion. = *Brachionus urceolaris*, K. cochle. = *Keratella cochlearis*, K. tropic. = *Keratella tropica*, Ceirodap. = *Ceirodaphnia cornuta*, Daphnia = *Daphnia longispina*, Chydorus = *Chydorus sphaericus*, Diaphano. = *Diaphanosoma excisum*, Naupillu. = Naupillus larvae, Calanoid = Calanoid copepodite, Cyclopoi. = Cyclopoid copepodite, Ther. ga. = *Thermodiaptomus galebi*, Therm. ne. = *Thermocyclops neglectus*, T. Macro. = Total Macrobenthos, T. Ann. = Total Annelida, T. Artho. = Total Arthropoda, T. Mol. = Total Mollusca, Ch. larva = Chironomidae larva, Ch. pupa = Chironomidae pupa, Limnodri. = *Limnodrilus*, Branchur. = *Branchiura sowerbyi*, V. niloti. = *Valvata nilotica*.

## CONCLUSION

Zooplankton community in Lake Nasser is dominated by Copepoda in addition to Cladocera and Rotifera. The highest number of zooplankton species was recorded during the pre-flood period and decreased during the post-flood in the three studying spots. Macrobenthic fauna in different Lake Nasser parts are formed from Annelida, Arthropoda, and Mollusca, in addition to members of Nematode and Cnidaria detected only in main channel of the lake. The most important factors affecting zooplankton and macrobenthos distribution during the post-flood season are transparency, depth, pH, electrical conductivity, and dissolved oxygen. While depth, dissolved oxygen, and temperature are the most effective parameters on the distribution of zooplankton and microbenthic fauna. Cluster analysis showed that Khor Dahab has different physical and biological features from Khor El-Ramla and the main channel of Lake Nasser. The Nile flood is the main factor affecting the ecology of Lake Nasser because the oscillation of the lake water level affects zooplankton and macrobenthos composition and density.

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