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Water Quality and Relative Abundance and Diversity of Zooplankton of the Nile River in Upper Egypt

Isaac A. Iskaros[1], Hoda M. A. Wahab[2], Magdi M.M. Ali[3], Adel Abdelmaageed[1*], Nagla E. Mohamed[1]

[1]National Institute of Oceanography and Fisheries, Cairo, Egypt
[2]Zoology Department, Faculty of Science, Aswan University, Egypt
[3]Department of Aquatic Ecology, Faculty of Fish and Fisheries Technology, Aswan University, Egypt
[*]Corresponding Author: adel_abdelmageed@yahoo.co.nz

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ABSTRACT

The composition, number, and community structure of zooplankton, along with important physical and chemical parameters, were used to assess the state of the Nile water in Upper Egypt between Aswan and Sebaiyia during 2021. The study was conducted in the south 120km of the Nile's main stream in Upper Egypt, downstream of the Aswan Old Dam (between 24°04′ and 25°00′ latitudes and 32°51′ and 32°54′ longitudes). The three taxonomic groupings that comprised the bulk of zooplankton species were Rotifera (23 species), Copepoda (3 species), and Cladocera (5 species). One species of Platyhelminthes was among the other uncommon zooplankton types that were sometimes observed. The community structure of zooplankton was classified based on temperature (Cº), conductivity (EC), pH, dissolved oxygen (DO), nitrite (NO_2), nitrate (NO_3), orthophosphate (PO_4), organic matter (OM), carbonate (CO_3), and chlorophyll-a using canonical corresponding analysis (CCA). According to the zooplankton's documented temporal trend, they peaked in the springtime when phytoplankton bloomed. Otherwise, a relatively highwater flow rate coincided with the low zooplankton abundance throughout the summer-fall period, which may potentially be considered another abiotic factor affecting zooplankton development. Furthermore, the west bank locations had twice as many as the east sites that were directly exposed to industrial wastes. This suggests that wastewater discharge limited the abundance of the Nile zooplankton assemblages, primarily because rotifers and cladocerans were declining in number.

INTRODUCTION

Plankton biodiversity may shift because of the hydrology of the River Nile, one of Africa's most important and ecologically varied major river ecosystems. Therefore, the establishment of these communities, species composition, and dispersion pattern can reflect differences in seasonal succession, physico-chemical variables, and the response to industrial wastewater inputs. As the main consumers, zooplankton populations are a significant biological group that grazes phytoplankton, which is then eaten by predaceous zooplankton and other macrobenthic invertebrates. Zooplankton community structure in freshwater habitats can reveal environmental pollutants and reflect changes **(Kaya *et al.*, 2010)**. It has a relative relevance of top-down and bottom-up control because of its location in the food chain. Accordingly, they represent the last connection between bottom-up elements (phytoplankton), food cycle regulators (fish), and the condition of macrobenthic invertebrates **(Jeppesen *et al.*, 2011)**.

The quantitative composition and taxonomy of the Nile zooplankton community have been the subject of numerous studies **(Obuid Allah, 1990a; Mostafa *et al.*, 1998; Hussein *et al.*, 1999; Iskaros *et al.*, 2008; Dumont, 2009; Nassif & Helal, 2024)**. As a result, 112 species of rotifers, along with 14 copepods and 10 cladocerans, make up the majority of the Nile's zooplankton in Egypt. **Fishar *et al.* (2019)** found 61 species of zooplankton (42 Rotifera, 9 Protozoa, 7 Cladocera, and 3 Copepoda) in their study regarding zooplankton community composition in El-Rayah El-Behery, Egypt. Fifty-two zooplankton species were recently identified by **Yousef *et al.* (2024)** during their survey in Shattura Village (Sohage Governorate). They recorded 18 Rotifera, 13 Cladocera, 10 Copepoda, and 11 Ostracoda. Furthermore, by offering a vast surface area for the growth of epiphytic algae and the manipulation of organic matter, macrophytes may directly improve food on indirect ones. For several species, macrophytes also offer protection from predators and water turbulence **(Lodge *et al.*, 1988)**. **Ali *et al.* (2007)** categorized 67 of various invertebrate groups in Lake Nasser based on their biotopes. They identified 39 Rotifera, 12 Cladocera, 4 Copepoda, 4 Aquatic Insecta, 2 Protozoa, 2 Ostracoda, and a species of each of Turbellaria, Tardgrade, Annelida, and Nematoda. Thirteen species were detected in both habitats, eleven species were determined to be collectively planktonic, and 37 species were found to be solely epiphytic.

The study aimed to investigate zooplankton assemblages along the mainstream of the Nile in Upper Egypt, as well as the main water physical and chemical properties, in order to demonstrate the dynamics of the zooplankton community and evaluate the effect of wastewater discharge on the Nile water zooplankton populations. It will enhance our comprehension of the limnology of the Nile basin and help us better comprehend the regulation of zooplankton overall.

The current study aimed to document the abundance of specific free-living organism's fractions in macrophyte-free water and compare them with epiphytic invertebrate sample sites. Moreover, focused on determining the selectivity of natural food and fish-secure food materials from the free-living or epiphytic invertebrate sample locations, examine the stomach contents of fish. Furthermore, assessing the link between the recorded taxa and the key physical and chemical characteristics, including temperature, pH, transparency, dissolved oxygen, conductivity, nutrients, organic matter, and calcium carbonate. The current study also intended to assess how free-living and epiphytic invertebrates are affected by industrial and domestic wastewater.

MATERIALS AND METHODS

1. Study area

The research region is located downstream of the Aswan Old Dam and spans 24° 04` to 25° 00` latitudes and 32° 51` to 32° 54` longitudes. Fig. (1) and Table (1) provide a description of the study region and sampling regime. Samples were collected from three locations at each station. Between January and October of 2021, a total of 72 samples were gathered over the course of four seasons (18 samples per season).

2. Field sampling and laboratory analysis

Water temperatures, conductivity, and pH were measured using the CRISON Multimeter MM40+ (APHA, 2005); dissolved oxygen was measured *in situ* using an oxygen electrode (Jenway oxygen meter, model 1070 Jenway, UK); water samples were collected using the Van-Dorn Bottle, and water contents (NO_2-N, NO_3-N, and PO_4-P) were determined using the methods outlined in **APHA (2005)**. The sampling was done on a seasonal basis over the course of a year in 2021.

Water was filtered through a Whatman GF/C glass fiber filter to determine the quantity of chlorophyll-a, and then 95% methanol was used for extraction. Using spectrophotometry, absorbance was determined at three distinct wave lengths (630, 645, and 663nm). The concentration of chlorophyll-*a* was determined using the **Marker *et al.* (1972)** method. The loss on ignition method was used to determine organic materials in the silt. The back- titration method was used to determine the carbonates.

3. Collection and treatment of zooplankton

Using a closed plankton net, free-living invertebrates were gathered as planktonic. Samples were vertically pulled from 5 meters below the surface in each sampling location to calculate numerical abundance **(Wetzel & Liknes, 2001)**. The formula v=πr2 d, where r=net ring radius (0.15m) and d=tow distance (5 m), was used to get the volume of water filtered (v). Formalin was used to preserve the materials right away, reaching a final concentration of about 5%. Three sub-samples were examined after each 250mL concentrated original sample was thoroughly mixed in the lab. In order to identify and count the various zooplankton individuals as the number of individuals per cubic meter (org. m^{-3}), a one milliliter sub-sample was obtained using a wide mouth pipette and then transferred into a counting cell. After sampling macrophytes and washing them, associated invertebrates (also known as epiphytic) were gathered. A 5% neutral formalin solution was used to preserve the epiphytic zooplankton samples. The following publications were reviewed to identify the zooplankton species: **Harding and Smith (1960)**, **Hutchinson (1967)**, **Pennak (1978)** and **Shehata and Bader (1985)**.

4. Statistical analysis

Canonical Correspondence Analysis (CCA) was performed to determine the relationships between the environmental variables and zooplankton groups. It was carried out using XL STAT program (2018).

RESULTS

1. Water quality

The highest water temperature values were recorded at site V (St.2) during winter, spring, summer, and autumn (23.2, 30.6, 28.7, and 25.1°C, respectively), while the lowest value of 18.1°C was recorded during winter at site II (St.1). Moreover, the highest EC values were recorded at the east of Gezira site II (St.1) during winter, spring, summer and autumn (375, 326, 487, and 397µS cm^{-1}, respectively) owing to the disposal of Sail drain wastewater. The lowest pH value of 7.6 was recorded during spring at site V (St.2), while the highest record of 9.0 was reported at site I (St.1). The lowest DO values were recorded at the east of Gezira site III (St. 1) during winter, spring, summer and autumn (7.3, 5.3, 0.5, and 0.8mgL^{-1}, respectively). On the other hand, the highest DO value of 11.9mgL^{-1} was recorded at site XIV (St.5) during winter. The highest NO_2 values were recorded at site V (St.2) during winter, spring, summer, and autumn (10.2, 14.7, 18.3, and 15.1µgL^{-1}, respectively). On the other hand, the lowest NO_2 value of 2.1µgL^{-1} was recorded at site XIII (St.5) during summer. The highest NO_3 values were recorded at the site V (St.2) during winter, spring, summer, and autumn (212.3, 393.6, 96.6, and 752.1µgL^{-1}, respectively). The highest PO_4 values were recorded at the east of Gezira site II (St.1) during winter, spring, summer, and autumn (30.3, 39.2, 41.2, and 47.9µgL^{-1}, respectively). Furthermore, the highest chlorophyll-*a* values were recorded at site X (St.4) during winter, spring, summer, and autumn (11.7, 12.2, 7.9, and 25.6 mgL^{-1}, respectively), as shown in Table (2).

2. Zooplankton

A total of 32 zooplankton species belonging to Rotifera (23 species), Copepoda (3 species), Cladocera (5species) and Platyhelminthes (1 species) were recorded from the Nile sector between Aswan and Sebaiyia. They contributed to approximately 48.0, 32.4, 18.3, and 1.3% of the total zooplankton, respectively (Table 3). The highest densities of zooplankton (Fig. 2) were recognized at the western bank sites of XIII, XV (St.5) and VII (St.3), which sustained an annual average of 46689, 51950, and 53720 orgs. m^{-3}, respectively. These values decreased to the minimum at the eastern side sites and in particular at the downstream sites of V (St.2) (discharge point of Kom Ombo drain) (avg.16527 orgs m^{-3}), VI (St.2) (downstream of Kom Ombo drain) (avg. 19758 org. m^{-3}) and XI (St.4) (downstream of Egyptian ferroalloys drain) (avg. 21199 org. m^{-3}). The annual average counts of the total zooplankton for the whole Nile sector amounted to 31392 org. m^{-3}. Zooplankton populations were more abundant during spring (avg. 54993 org. m^{-3}) with a peak at the same western sites afore-mentioned, which sustained 93458, 87792, and 101244 org. m^{-3}, respectively (Fig. 3) during the flourishing of phytoplankton. These values decreased gradually throughout summer (avg. 28733 org. m^{-3}), autumn (avg. 23953 org. m^{-3}), and further in winter (avg. 17887 orgs. m^{-3}) when the water temperature fluctuated between 19.6 and 23.4°C.

Rotifera were the most abundant taxon in all seasons, comprising about 48.0% of zooplankton populations. The Nile sector between Aswan and Sebaiyia harbored an average number of 15070 org.m^{-3}. The western sites of XIII, XV (St.5), XVI (St.6), and VII (St.3) had twice or more (ranges: 21417- 29736 org. m^{-3}) than the average numbers of most eastern sites, particularly at the discharge points or the downstream ones (range: 6726-12036 org. m^{-3}). Twenty-three Rotifera species were encountered from the Nile sector between Aswan and Sebaiyia, out of them, 3 genera and 3 species were predominated the community, namely *Keratella* Gesses, *Lecane* Nitzsch, *Trichocerca* Lamarch, *Anuraeopsis fissa* Gosse, *Conochilus hippocrepis* Schrank and *Cephalodella catellina* Muller. They constituted collectively about 72.5% of the total rotifers, while the other species appeared less common or rare. Rotifera peaked during spring (Fig. 4) (avg. 27736 org. m^{-3}) due to the increased density of the afore-mentioned species and the minimum in winter (avg. 8591 org. m^{-3}).

Copepoda were the second abundant group in all seasons, comprising 32.4% of zooplankton populations. The Nile sector between Aswan and Sebaiyia harbored an average number of 10176 orgs.m^{-3}. Copepoda were represented by three cyclopoids, namely *Thermocyclops hyalinus* Rehberg and *Mesocyclops leuckarti* Claus, both carnivorous as adult, and the herbivorous calanoid *Thermodiaptomus galebi* Barrois. They contributed about 25.8% of copepods counts. The western sites (Sts. 3, 5 & 6) had twice or more (range: 12656-17612 org. m^{-3}) than the average numbers of eastern sites (Sts. 1, 2 & 4), particularly at the discharge points and downstream ones (range: 4359-7456 org. m^{-3}). Spring was the most productive season for copepods (avg.16677 org. m^{-3}) with a peak at site VII (St.3) (29736 org. m^{-3}) as well as sites XIV (St.5) and XVI (St. 6) (26904 ind./m^{-3} for each) (Fig. 5). Copepods dropped to the minimum numbers in the following seasons. Nauplius larvae and copepodite stages proved to be the most common, contributing about 40.7 and 33.4% of the total copepod counts, respectively. Nauplius larvae recorded an average of 4145 nauplii m^{-3} for all the sites with a peak at comparable values in sites XV, XVIII, and VII those located at Stations 5, 6, and 3, respectively. Both the points of discharge and downstream sites sustained the lowest counts (range: 797-3452 nauplii m^{-3}). On the other hand, copepodite stages recorded an average number of 3401 org. m^{-3} for all the sites with a peak at the afore-mentioned sites, in addition to site XIV (St. 5) (range: 5000-5723 org. m^{-3}), compared with the discharge points and downstream sites (range:1350-3496 org. m^{-3}). Nauplius larvae peaked in spring (avg. 7080 nauplii m^{-3}) followed by summer (avg. 4897 nauplii m^{-3}). The spring was also represented by a peak of copepodite stages (avg. 4700 org.m^{-3}) followed by winter (avg. 3986 org.m^{-3})

Cladocera represented the third important group among the zooplankton populations in the Nile sector between Aswan and Sebaiyia. They contributed about 18.3% of the total zooplankton with an average of 5733 orgs. m^{-3}. The order comprised 4 families with five species, namely *Bosmina longirostris* Muller, *Daphnia longispina* Muller, *Ceriodaphnia cornuta* Sars, *Diaphanosoma excisum* Sars, and *Chydorus* *sphaericus* Muller. There was a spatial tendency toward an increase in abundance of most western sites (range: 6372- 9558 org. m^{-3}). In contrast, Cladocera decreased at the eastern sites and at the points of discharge and the downstream ones (range: 2832-5133 org. m^{-3}). Spring and summer were the most productive seasons for Cladocera's (avg. 9558& 6647 org. m^{-3}, respectively) with peaks recorded at the western sites (Sts 5 & 6) which harbored values fluctuated between 9912 & 14868 org. m^{-3}. On the other hand, they dropped to a minimum in autumn (avg. 4464 org. m^{-3}) and winter (avg. 2262 org. m^{-3}) (Fig. 6). Female cladocerans carrying eggs or Juvenile instars appeared throughout most of the year.

Platyhelminthes was represented by 1 species (*Microdalyella* sp.) which belongs to the family Dalyellidae. Its annual average numbers amounted to 413 org.m^{-3}. Its highest density appeared at sites I & II (St.1) particularly during spring (5664 org.m^{-3} for each).

In the present study, (Table 4) a total of 24 species in addition to other immature stages representing the zooplankton community were recorded in the stomach contents of different fish species collected from the River Nile.

3. Free and epiphytic invertebrates

Among zooplankton population (Table 5), 22 species of rotifers preferred macrophytes (*Ceratophyllum demersum*, *Najas horrida*, *Myriophyllum spicatum*, *Potamogeton crispus*, *P. perfoliatus*), a species as planktonic form and 12 species were found in both biotopes. *Trichocerca* spp., *Lepadella* spp., *Lecane* spp., *Euchlanis* spp., *Cephalodella* spp. and *Brachionus* spp. are mostly found in littoral forms while *Keratella* spp., *Asplanchna* sp. and *Hexaarthra* sp. are common in plankton. Two species of Cladocera and 2 species of Copepoda were recorded either in the littoral vegetation shallow water zone or in the littoral vegetation - free deeper water zone.

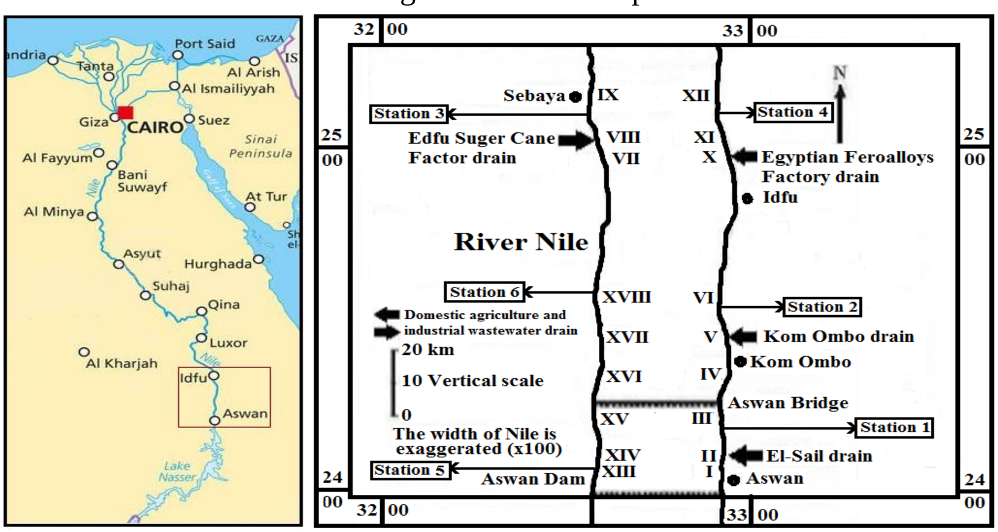

Fig. 1. Sampling sites in the River Nile water between Aswan and Sebaiyia during 2021

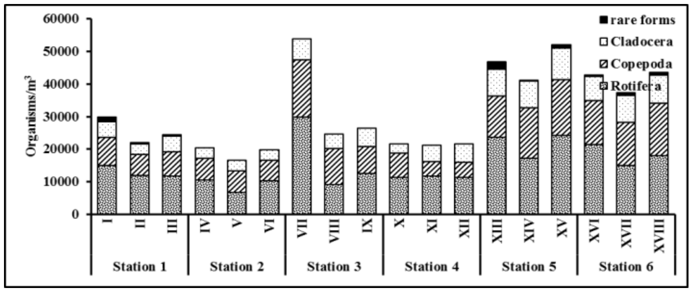

Fig. 2. Distribution of zooplankton groups (orgs.m^{-3}) recorded in the River Nile between Aswan and Sebaiyia during 2021

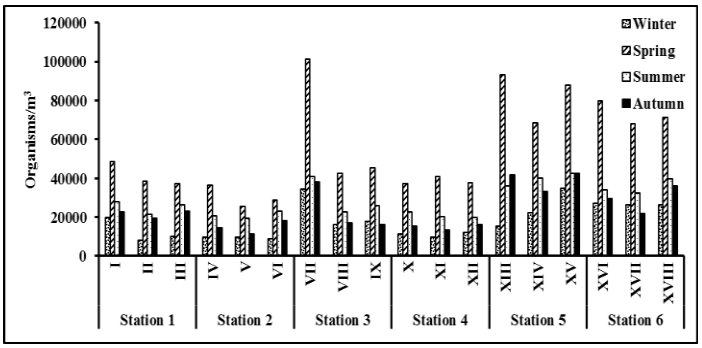

Fig. 3. Seasonal variations of zooplankton groups (orgs. m^{-3}) recorded in the River Nile between Aswan and Sebaiyia during 2021

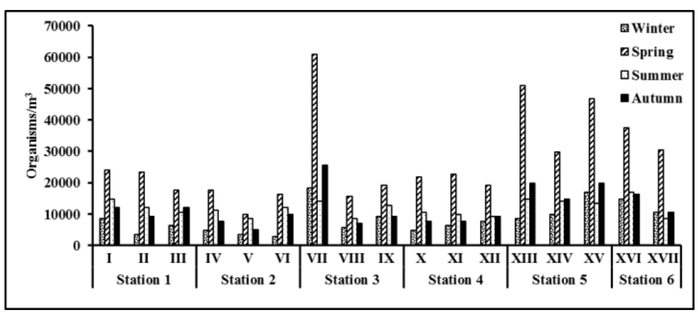

Fig. 4. Seasonal variations of Rotifera (org.m^{-3}) recorded in the River Nile between Aswan and Sebaiyia during 2021

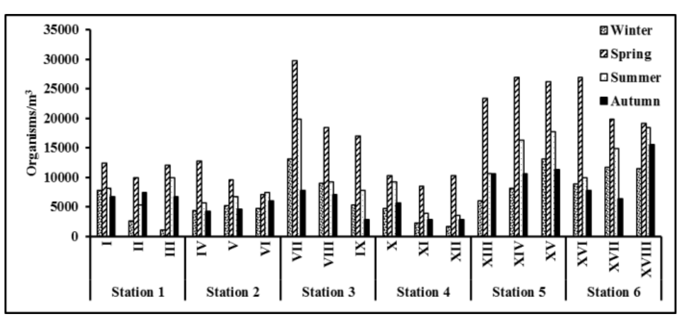

Fig. 5. Seasonal variations of Copepoda (org.m^{-3}) recorded in the River Nile between Aswan and Sebaiyia during 2021

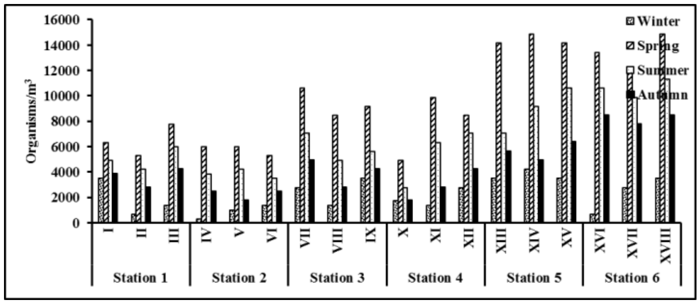

Fig. 6. Seasonal variation of Cladocera (org. m^{-3}) recorded in the River Nile between Aswan and Sebaiyia during 2021

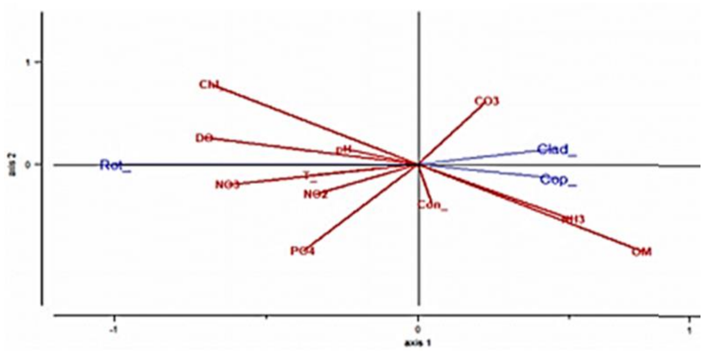

Fig. 7. The CCA applied on samples of groups of zooplankton invertebrates with 11 physicochemical parameters in the River Nile between Aswan and Sebaiyia during 2021. Cods: Rot (Rotifera) Cop (Copepoda), and Clad (Cladocera)

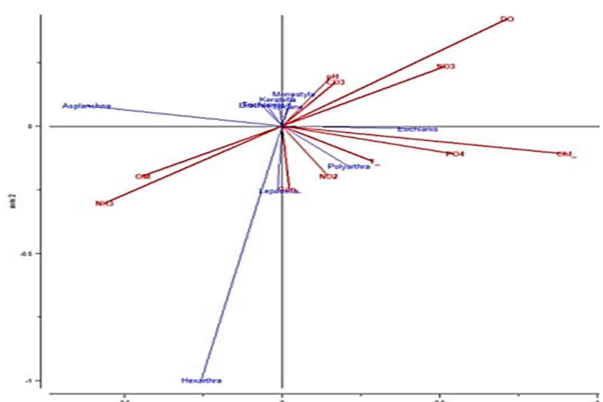

Fig. 8. The CCA applied on samples of genera of Rotifera with 11 physicochemical parameters at the River Nile between Aswan and Sebaiyia during 2021

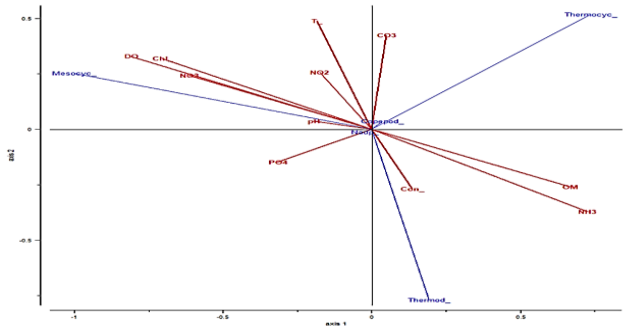

Fig. 9. The CCA applied on samples of genera of Copepoda with 11 physicochemical parameters at the River Nile between Aswan and Sebaiyia during 2021

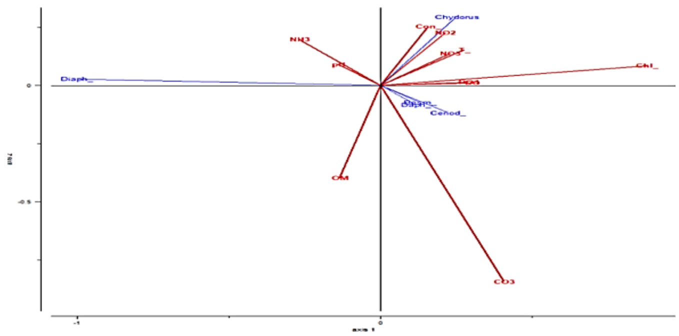

Fig. 10. The CCA applied on samples of genera of Cladocera with 11 physicochemical parameters in the River Nile between Aswan and Sebaiyia during 2021

Table 1. Description of the sampling regime

<table>
<tr><th>Station no.</th><th>City</th><th>Direction</th><th>Type of discharge</th><th>Sample location</th><th>Sample location no.</th><th>Description</th></tr>
<tr><td rowspan="3">St. #1</td><td rowspan="3">Aswan</td><td rowspan="3">East Bank</td><td rowspan="3">Industrial discharge from El-sail drain</td><td>Upstream of the discharge point</td><td>I</td><td>Little aquatic plants, tourism ships</td></tr>
<tr><td>At the discharge</td><td>II</td><td>No aquatic plants</td></tr>
<tr><td>Downstream of the discharge point</td><td>III</td><td>Little aquatic plants</td></tr>
<tr><td rowspan="3">St. #2</td><td rowspan="3">Kom Ombo</td><td rowspan="3">East Bank</td><td rowspan="3">Industrial discharge from Drain of sugar-cane and chipboard factories</td><td>Upstream of the discharge point</td><td>IV</td><td>Little aquatic plants, tourism ships</td></tr>
<tr><td>At the discharge</td><td>V</td><td>No aquatic plants</td></tr>
<tr><td>Downstream of the discharge point</td><td>VI</td><td>Little aquatic plants</td></tr>
<tr><td rowspan="3">St. #3</td><td rowspan="3">Idfu</td><td rowspan="3">West Bank</td><td rowspan="3">Industrial discharge points of sugarcane and paper pulp factories</td><td>Upstream of the discharge point</td><td>VII</td><td>Little aquatic plants</td></tr>
<tr><td>At the discharge</td><td>VIII</td><td>No aquatic plants</td></tr>
<tr><td>Downstream of the discharge point</td><td>IX</td><td>Little aquatic plants</td></tr>
<tr><td rowspan="3">St. #4</td><td rowspan="3">Idfu</td><td rowspan="3">East Bank</td><td rowspan="3">Industrial discharge points of Ferroalloys factory</td><td>Upstream of the discharge point</td><td>X</td><td>Little aquatic plants</td></tr>
<tr><td>At the discharge</td><td>XI</td><td>No aquatic plants</td></tr>
<tr><td>Downstream of the discharge point</td><td>XII</td><td>Little aquatic plants</td></tr>
<tr><td rowspan="3">St. #5</td><td rowspan="3">Aswan</td><td rowspan="3">West Bank</td><td rowspan="6">Reference Stations (without human activities)</td><td>No polluted area</td><td>XIII</td><td>Dense aquatic plants</td></tr>
<tr><td>No polluted area</td><td>XIV</td><td>Dense aquatic plants</td></tr>
<tr><td>No polluted area</td><td>XV</td><td>Dense aquatic plants</td></tr>
<tr><td rowspan="3">St. #6</td><td rowspan="3">Kom Ombo</td><td rowspan="3">West Bank</td><td>No polluted area</td><td>XVI</td><td>Dense aquatic plants</td></tr>
<tr><td>No polluted area</td><td>XVII</td><td>Dense aquatic plants</td></tr>
<tr><td>No polluted area</td><td>XVIII</td><td>Dense aquatic plants</td></tr>
</table>

Table 2. Physicochemical parameters values measured at the area between Aswan and Sebaiyia in the Nile during 2021

Site		St. 1			St. 2			St. 3			St. 4			St. 5			St. 6		
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII
Temp. ºC	Mean	22.8	24.2	23.1	23.3	26.9	23.9	23.5	23.5	24.2	24	23.7	24.3	22.6	22.8	22.8	23.7	23.4	23.8
	SD	2.8	3.4	2.7	3.3	3.4	3	2.7	2.6	2.7	2.8	2.7	2.7	3.3	3	2.8	2.8	3.3	2.9
	Min.	19.3	20.1	19.4	19.3	23.2	20	20	20.4	20.9	20.5	20.3	21	18.1	18.6	18.9	20	19.5	20
	Max.	25.8	28.4	25.5	27.2	30.6	27.3	26.4	26.7	27.6	27.2	26.9	27.7	26.1	25.4	25.4	26.8	27.4	27.1
Cond. µS cm-1	Mean	252	396.3	254	324	269	251	254	324	269	251	250	249	251	251	250	249	252	396
	SD	15.2	67.4	17.3	20.9	29	17.6	17.3	20.9	29	16.4	16.5	16.9	17.6	16.4	16.5	16.9	15.2	67.4
	Min.	236	326	239	293	261	234	239	293	261	235	235	235	234	235	235	235	236	326
	Max.	271	487	278	339	309	275	278	339	309	273	273	276	275	273	273	276	271	487
pH	Mean	8.3	8	8.2	8.2	7.9	8.3	8.2	8.2	8.3	8.4	8.1	8.3	8.2	8.3	8.2	8.2	8.2	8.3
	SD	0.5	0.2	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0	0.2	0.3	0.4	0.2	0.3	0.1	0.2
	Min.	7.9	7.7	8	8.2	7.6	8.2	8.2	8.1	8	8.2	8	8.1	8	8	8	8	8.1	8.2
	Max.	9	8.2	8.7	8.3	8.1	8.4	8.3	8.3	8.4	8.5	8.1	8.5	8.6	8.6	8.7	8.6	8.3	8.6
Dissolved oxygen mg L-1	Mean	7.1	3.5	6.9	6.9	9	9.2	7.6	8.1	8.2	8.4	8.2	8.6	6.3	6.7	6.5	6.7	8.4	8.7
	SD	3.6	3.4	3.3	2.5	1.1	1.8	2	1.4	0.9	1.1	1.6	1	3.4	4.1	2.9	3	1.1	1.8
	Min.	3.9	0.5	3.4	4.4	7.3	7.2	4.7	6.4	7	7.4	6.9	7.3	3.3	2.9	3.8	3.6	6.6	6.6
	Max.	11.3	7.3	9.9	9.4	9.8	11.3	8.9	9.5	9.1	9.9	10.5	9.7	9.8	11.9	9.1	10.1	9.4	10.8
Nitrite µg L^{-1}	Mean	3.4	8.8	5	6.1	14.6	6.3	4.9	5	5.9	6.1	5.6	6.1	3	3.5	3.3	3.9	5.8	5.8
	SD	1.3	3.9	1.6	2.9	3.3	3	2.7	2.5	2.5	2.8	2.6	2.8	1	0.8	0.7	0.8	2.7	2.5
	Min.	2.2	6.1	3.3	4.1	10.2	3.8	2.7	3	3.9	4.3	3.8	3.9	2.3	2.9	2.4	3.1	3.8	3.6
	Max.	4.5	14.5	6.9	8.5	18.3	10.7	8.7	8.7	9.6	10.2	9.4	10.1	4.2	4.7	4.1	4.5	9.6	9.2
Nitrate µg L^{-1}	Mean	29.6	35.5	34.8	72.3	364	130	43.9	117	111	95.7	83	90.8	31.6	34.3	63.7	54.4	58.9	188
	SD	15.6	21.9	19.2	31.3	286	94.4	19.7	81.2	65.3	33.5	41.5	52.2	22	29.7	34	28.1	23.2	117
	Min.	14.9	15	14.4	27	96.6	57.8	24.6	40	33.9	56.4	32.4	35	9.9	13.4	18.5	31.6	24.8	45.3
	Max.	45.4	65.3	36.3	97.6	752	265	64.8	231	182	125	133	161	59	78.3	93.6	95	75.6	332
Ammonia µg L^{-1}	Mean	85.1	5205	128	98.9	64.6	90.3	52.3	42.6	40.6	52.1	50.2	39	89	81.9	76.4	66.1	68.1	75.2
	SD	66.1	3098	81.9	42.1	38.6	30.9	17.1	14	14.5	22.2	223	31.1	70.1	59.7	49.9	42.6	37.8	32.2
	Min.	27.4	2530	57.4	51.8	35.5	50.1	35.7	30.6	24.1	34.2	29.8	23.3	34.2	27.2	33.1	25.7	40.2	47.6
	Max.	179	9433	244	154	121	125	69.6	61.1	55.7	83.1	81.7	54.2	190	166	148	126	124	119
Ortho-Phosphate µg L^{-1}	Mean	26.6	39.7	29.2	30.8	27.6	31.6	31.4	30.5	30.5	29.5	29.7	28.9	26.8	28.8	29.8	30.1	26.2	33.5
	SD	7.9	7.3	5.9	6.1	5.6	12.5	4.5	4.6	4.2	5.1	2.7	4.3	6.5	8.1	7.8	8.4	8.2	5.6
	Min.	19.1	30.3	23.2	24.6	23.4	20.1	28.9	26.6	26.9	25.9	27.2	25.3	19.6	21.4	21.9	22.6	18.1	28.9
	Max.	37.3	47.9	36.7	39.1	35.8	45.3	38.1	37.1	35.8	37.1	33.3	34.9	33.5	39.5	39.3	40.7	37.6	40.8
Chl. mg L^{-1}	Mean	4.4	4.6	5.6	6.1	5.7	6.5	9.4	9.8	9.9	14.4	11.7	9.5	3.6	3.8	4.8	5.2	5.7	6
	SD	1.8	0.7	0.5	2.3	1.9	1.6	3	4.3	4.6	7.7	5.6	2.3	1.8	0.8	1.3	2.8	0.8	1.5
	Min.	2.1	3.6	5.2	3.5	3.9	4.8	5.1	5.1	6.7	7.9	7.4	6.7	1.9	3.1	3.1	2.5	5.1	4.7
	Max.	6.3	4.7	6.2	8.6	7.7	8.7	11.7	15.6	16.7	25.6	19.9	12.2	5.5	4.8	6.1	8.1	6.8	8.1
Orginic matter (%)	Mean	6.3	15	3.4	6.2	3.6	4.6	6.8	3.8	4.3	5.2	3.4	5	5.7	8.8	5	3.7	3.9	3.7
	SD	3.8	1.4	0.4	1.6	0.4	2.3	0.7	0.5	1.5	1.9	0.2	0.5	2.1	3.3	1.5	0.5	0.6	0.5
	Min.	3.9	12.8	3.1	4.4	3.2	3.1	5.9	3.5	3.3	3.6	3.2	4.4	3.8	4.1	3.9	3.3	3.2	3.3
	Max.	11.9	15.7	3.9	7.7	4.2	7.9	7.4	4.5	6.4	7.8	3.6	5.6	8.6	11.9	7.1	4.5	4.7	4.3
Carbonates (%)	Mean	5.8	6	3.5	4.5	4.4	4.5	8.7	4.9	16.1	6.4	5.9	9.8	5.8	15.1	6.3	3	5.1	3.9
	SD	3.3	0.3	0.2	1	0.5	2.1	4.6	0.6	7.5	2.7	1.4	1.4	0.8	7	1.4	0.5	1.5	0.5
	Min.	3.8	5.6	3.2	3.1	4	2.8	3.4	4.2	7.1	4.3	4.6	8.3	4.7	5	4.6	2.5	3.1	3.4
	Max.	10.7	6.2	3.7	5.4	5.1	7.6	12.7	5.7	25.3	10.4	7.9	10.3	6.4	20.3	8	3.7	6.7	4.4

Table 3. Zooplankton species recorded in the River Nile between Aswan and Sebaiyia during 2021 and their presence contribution (%)

Species	%	Species	%
Rotifers:		*Lepadella ovalis*	1.6
Keratella cochlearis	10.2	*Lepadella patella*	0.4
K. tropica	8.1	*Polyarthra vulgaris* Carlin	1.6
Lecane bulla	3	*Euchlanis dilatata* Ehrenbeng	1.4
L. luna	2.4	*Asplanchna priodonta* Gosse	1.4
L. depressa	1.5	*Hexarthramira* Hudson	0.4
Lecane lunaris	1.1	**Copepoda**	
Lecane elachis	0.1	*Thermocyclops hyalinus*	3.2
Trichocerca longiseta	1.8	*Thermodiaptomus gablebi*	3.1
Trichocerca collaris	1.7	*Mesocyclops leuckarti*	2.1
Trichocerca similis	0.8	**Cladocera**	
Trichocerca pusilla	0.5	*Bosmina longirostris*	5.9
Anuraeopsis fissa	2.5	*Daphnia longispina*	3.8
Brachionus calyciflorus	1.4	*Ceriodaphnia cornuta*	3.2
Brachionus angularis	1.4	*Bosmina longirostris*	2.9
Brachionus patulu	0.4	*Daphnia longispina*	2.5
Conochilus hippocrepis Schrank	2.2	**Platyhelminthes**	1.3
Cephalodella catellina Huller	2.1		

Table 4. Zooplankton of stomach contents in different fish species collected from the River Nile between Aswan and Sebaiyia

Zooplankton	
Rotifera:	**Cladocera:**
Brachionus calyciflorus	*Bosmina longirostris*
Brachionus angularis	*Ceriodaphnia cornuta*
Euchlanis dilatata	*Daphnia barbata*
Keratella cochlearis	*Daphnia longispina*
Keratella tropica	*Diaphanosoma excisum*
Lecane bulla	
Lecane depressa	**Copepoda:**
Lecane elachis	Nauplius larvae
Lecane luna	Copepodit stages
Lecane lunaris	*Thermocyclops neglectus*
Polyarthera vulgaris	*Mesocyclops leuckarti*
Trichocerca pusilla	
Trichocerca similis	
Trichocerca longiseta	
Trichocer cacollaris	

Table 5. Distribution of zooplankton species according to their biotopes between Aswan and Sebaiyia

Invertebrates	E	P	E, P	Invertebrates	E	P	E, P
Rotifera:				*Lepadella patella*	E	0	E
Anuraeopsis fissa	E	P	E+P	*Polyarthera vulgaris*	E	0	E
Asplanchna priodonta	E	P	E+P	*Trichocerca pusilla*	0	p	p
Brachionus calyciflorus	E	P	E+P	*Trichocerca similis*	E	P	E+P
Brachionus angularis	E	P	E+P	*Trichocerca longiseta*	E	P	E+P
Brachionus patulus	E	P	E+P	*Trichocerca collaris*	E	P	E+P
Cephalodella catallina	E	0	E	**Copepoda:**			
Conochilus hippocrepis	E	0	E	Naulius larvae	E	P	E+P
Euchlanis dilatate	E	0	E	*Thermodiaptomus galebi*	0	P	P
Hexarthera mira	E	0	E	*Thermocyclops neglectus*	E	P	E+P
Keratella cochlearis	E	P	E+P	*Mesocyclops leuckarti*	0	P	P
Keratella tropica	E	P	E+P	**Cladocera:**			
Lecane bulla	E	0	E	*Bosmina longirostris*	E	P	E+P
Lecane depressa	E	0	E	*Ceriodaphnia cornuta*	0	P	P
Lecane elachis	E	P	E+P	*Chydorus sphaericus*	E	P	E+P
Lecane luna	E	0	E	*Daphnia longispina*	0	P	P
Lecane lunaris	E	0	E	*Diaphanosoma excisum*	0	P	P
Lepadella ovalis	E	P	E+P				

E: Epiphytic invertebrates and PI: Planktonic invertebrates

DISCUSSION

Rotifers, copepods, cladocerans, and platyhelminthes are among the zooplankton groups that dominated the zooplankton community during the study period. These invertebrates appeared to be susceptible to environmental influences in the Nile ecosystem, and they have been regularly observed in the Nile River **(El-Otify & Iskaros, 2015, 2018; Fishar *et al.*, 2019; Obuid-Allah *et al.*, 2020)**.

Furthermore, the main qualitative and quantitative regulation of these communities was determined by their response to inputs of industrial wastewater, intraspecific competition, alterations in water-physical chemical parameters, and the impact of substrate conditions. Alongside these changes, there were seasonal variations in the abundance and community structure of the various aquatic biota components.

Most significantly, the canonical corresponding analysis (CCA) revealed the following association between several water factors and zooplankton invertebrates: In 2021, the CCA was done on samples of zooplankton invertebrate groups in the River Nile between Aswan and Sebaiyia. Consequently, the observed distribution depending on environmental variables was shown in Fig. (7). Rotifera showed a positive correlation with temperature, NO_3, NO_2, and PO_4. Copepoda showed a positive correlation with conductivity, organic matter, and NH_3. There was a positive correlation between Cladocera and CO_3. The CCA of Rotifera group samples in the River Nile between Aswan and Sebaiyia in 2021 showed that the explanatory variables explained 37.16% of the variation in the averages of the Rotifera. Fig. (8) displays the observed distribution based on environmental variables. *Euchlanis* and *Polyarthra* were positively correlated with temperature, NO_2, PO_4, and Chl. *a*. NH_3 and organic materials were positively correlated with *Hexarthra* and *Lepadella* species. *Monostyla* species were positively correlated with pH, CO_3, NO_3, and dissolved oxygen.

The explanatory variables accounted for 54.54% of the variance in the weighted averages of the Copepoda assemblage, according to the CCA conducted on samples of Copepoda genera in the River Nile between Aswan and Sebaiyia in 2021. Consequently, the observed distribution based on environmental variables is shown in Fig. (9). *Thermodiaptomus* was strongly linked with NH_3, organic matter and conductivity. *Thermocyclops* was positively associated with CO_3. Mesocyclops was positively associated with Chl. *a*, temperature, NO_2, NO_3, pH and DO. The explanatory variables accounted for 87.02% of the variance in the weighted averages of the Cladocera assemblage, according to the CCA conducted on samples of Cladocera genera in the River Nile between Aswan and Sebaiyia in 2021. Consequently, the observed distribution according to environmental variables is shown in Fig. (10). *Diaphanosoma* was positively correlated with NH_3 and pH, while *Bosmina longirostris*, *Daphnia longispina*, and *Ceriodaphnia* were positively correlated with CO_3. *Chydorus* was positively correlated with NO_2, NO_3, PO_4, Chl. *a*, and conductivity.

Ceratophyllum demersum, *Najas horrida*, *Myriophyllum spicatum*, *Potamogeton crispus*, and *P. perfoliatus* were the five species found in the aquatic plant belts observed at the survey sites (Ali & Soltan, 1996). Twenty-two rotifer species that favor macrophytes, one plankton-forming species, and twelve species were discovered in both biotopes in the zooplankton population (Table 3). **Pennak (1978)** stated that *Keratella* spp., *Asplanchna* spp., and *Hexaarthra* spp. are common in plankton, moreover *Trichocerca* spp., *Lepadella* spp., *Lecane* spp., *Cephalodella* spp., and *Brachionus* spp. are primarily littoral forms. Furthermore, according to **Hanna (1965) and Green (2001, 2003)**, the prevalence of rotifers on aquatic plants can be caused by their primary body traits, such as their small size and short toes, which help them evade predators and feed on epiphytic microorganisms.

Two copepod species and two Cladocera species have been found in the deeper water zone of littoral plant-free vegetation and the shallow water zone of littoral vegetation. The distinct microhabitat provided by the submerged macrophytes such as an oxygen-rich environment with an abundance of food, explains this. Additionally, copepods were more frequently detected in the water column than in the littoral zone of macrophytes than the other groups. This is because copepods are good swimmers and eat planktonic algae, including calanoids. **Hann (1995)** and **Ali *et al.* (2007)** observed that macrophytes provide superior microhabitats with distinctive traits that enhance the establishment and maintenance of a few invertebrates, and our results agree with their findings.

Thirty-two zooplankton species, comprising 23 Rotifera species, 3 Copepoda species, 5 Cladocera species, and 1 Turbellaria species, were identified in the Nile sector between Aswan and Sebaiyia. They contributed roughly 48.0, 32.4, 18.3, and 13% of the total zooplankton, respectively. The highest zooplankton densities (range: 46689–53720 orgs. m^{-3}) were seen in the western bank locations. These values reached their lowest point in the eastern side locations (range: 16527 - 21199 orgs. m^{-3}). The average annual counts of all zooplankton in the entire Nile sectors during the study were 31392 orgs. m^{-3}.

The temporal trend of zooplankton found in the current study showed that their maximal persistence (avg. 54993 orgs. m^{-3}) coincided with phytoplankton prospering in the spring. However, throughout the summer-fall season, the low zooplankton abundance (avg. 28733 orgs. m^{-3} & 23953 orgs. m^{-3}, respectively) was accompanied by a relatively high-water flow rate (Fig. 3). This might be regarded as an additional abiotic element impacting the growth of zooplankton (**Dumont, 2009**).

With an average of 15070 orgs. m-3, Rotifera members made up the majority of the zooplankton population living in the Nile sector between Aswan and Sebaiyia. They were most persistent in the spring (avg. 27736 orgs. m^{-3}) (Fig. 4). The higher populations of *Keratella* species, *Lecane* species, *Trichocerca* species, *Anuraeopsis fissa* Gosse, *Conochilus hippocrepis* Schrank, and *Cephalodella catellina* Muller which together accounted for almost 72.5% of all rotifers were responsible for this surge. These findings are consistent with earlier findings about seasonal variability in the Nile rotifers (**Mokhtar, 2003; Amer, 2007; Iskaros *et al.*, 2008; Khalifa & Bendary, 2016; El-Otify & Iskaros, 2018; Fishar *et al.*, 2019)**. Their ability to reproduce across a wide temperature range, as in Lake Nasser **(Iskaros *et al.*, 2008)**, their short generation time in comparison with larger crustacean zooplankton, their simple parthenogenetic reproduction, which, under favorable conditions, results in high production rates **(Andrew & Fizsimons, 1992)** and the way that eutrophication conditions affect the composition of zooplankton are some of the reasons why rotifers predominate in rivers.

The second most prevalent group among the zooplankton population living in the Nile sector between Aswan and Sebaiyia was Copepoda (avg. 10179 orgs. m^{-3}). The spring (avg. 16677 orgs. m^{-3}) and summer (avg. 10246 orgs. m^{-3}) seasons are when copepod populations are at their highest (Fig. 5). These peaks are accompanied by higher densities of nauplii larvae, copepodite stages, and less adult forms. This could be explained by the fact that high temperatures hasten copepod formation when nutrient concentrations are high **(El-Bassat, 2002; Fishar *et al.*, 2019)**. The current findings roughly correspond with the findings from the seasonal trend of Copepoda in Lake Nasser **(Zaghloul, 1985; Abdel-Mageed, 1992, 1995; Iskaros, 1993; Mokhtar, 2003)** and the River Nile **(Hussein *et al.*, 1999; Iskaros *et al.*, 2008; El-Otify & Iskaros, 2018)**.

With an average of 5733 orgs. m^{-3} per year, Cladocera ranked third among the zooplankton community that inhabited the Nile sector between Aswan and Sebaiyia. With the exception of *Ceriodaphnia cornuta*, which peaked in the summer and fall, the majority of cladoceran species saw their highest densities in the spring (avg. 9558 orgs. m^{-3}) (Fig. 6). According to **El-Bassat (2002)**, temperature has a significant impact on Cladocera distribution, with the majority of them favoring colder seasons. Furthermore, most Cladocera studies conducted in Egypt show that the species generally grows and thrives during the spring **(Obuid-allah, 1987, 1990; Iskaros, 1993; Abdelmageed, 1995, 2004; Mahmoud, 1995; El-Shabrawy, 1996; El-Shabrawy & Dumont, 2003; Iskaros *et al.*, 2008; El-Otify & Iskaros, 2015)**.

There were twice as many of the examined locations in the west bank that were not directly exposed to industrial waste as there were in the east bank. These findings suggested that the Nile zooplankton assemblages' abundance was limited by the wastewater released by factories on the eastern bank of the river. This showed that wastewater produces adverse conditions by changing the physical and chemical properties of the water, which in turn affects the density of zooplankton populations and the structure of their communities. Thus, these circumstances may be considered limiting factors that impact herbivore feeding rates, population dynamics, and production processes, ultimately leading to a decline in the Nile system's population.

Furthermore, chemicals found in wastewater may be harmful to aquatic plants and animals, causing an unbalanced food chain in the aquatic ecosystem. Accordingly, **Ibrahim (2009)** concluded that the diversity of zooplankton in African rivers was a certain sign of pollution in a localized form brought on by the discharge of industrial effluents.

The stomach contents of several fish species obtained from the Nile and classified into three groups of the Animal Kingdom (Table 86) contained a total of 24 species, along with additional immature stages that represented the zooplankton community. This is consistent with research on the Nile by **Hegab (2010)** and **Mola and Ahmed (2015)**.

Regarding the balance between the functional categories of the biota and the variations in the discharge of industrial effluents into the Nile water, ecological considerations are the most significant in determining the composition of the biological communities. Future studies should therefore focus on a greater number of locations along the Nile's mainstream.

CONCLUSION

With comparatively few copepods and cladocerans, rotifers (such as *Keratella* spp., *Lecane* spp., *Trichocerca* spp., and *Brachionus* spp.) usually dominate the zooplankton in rivers. Since it is a secondary producer in the aquatic food chain, zooplankton is significant. The west bank locations had the highest zooplankton densities, the density fell to the lowest at the east side sites. The current study's observed zooplankton temporal trend showed that they peaked in the spring in conjunction with a phytoplankton bloom. However, the summer-autumn season's low zooplankton abundance is accompanied by a comparatively highwater flow rate, which might also be considered an additional abiotic factor affecting zooplankton development. The wastewater discharged from factories on the east side of the Nile limits the frequency of Nile zooplankton accumulations. Therefore, we recommend that the industrial discharges in the east bank of the Nile should be stopped.

Availability of data and materials

This published article contains all the data created or examined throughout our investigation.

Competing Interests

The authors state that none of the work discussed in this article appears to have been impacted by any conflicting financial interests or personal ties.

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