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The Effect of Industrial and Wastewater Effluents on the Diversity and Abundance of Macrobenthic Invertebrates in Upper Egypt's River Nile

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

[1]Zoology Department, Faculty of Science, Aswan University, Egypt
[2]National Institute of Oceanography and Fisheries, Cairo, 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

In 2021, the Nile River between Aswan and Sebaiyia (Egypt) was subjected to seasonal analyses of major biological parameters and the surrounding environmental conditions, such as temperature (ºC), conductivity (EC), pH, dissolved oxygen (DO), nitrite (NO_2), nitrate (NO_3), orthophosphate (PO_4), carbonate (CO_3), organic matter (O.M.), and chlorophyll-*a*. 32 taxa from 16 groups of macrobenthic invertebrates were identified; these included a crustacean, one Hirudineas, three oligochaetes, ten chironomid larvae, and fourteen molluscs. Furthermore, three unidentified species that belong to adult Corixidae, Ephemeroptera, and Zygoptera nymphs were discovered. Throughout the study period, the numerous groups of the Nile zoobenthos were represented by the combined contributions of molluscs, chironomid larvae, and oligochaetes. With 39.8 GFW m^{-2}, the average yearly number of macrobenthic invertebrates was 4560 ind.m^{-2}. According to the findings of the canonical corresponding analysis (CCA), many ecological parameters that were examined appeared to play a significant role in affecting the biomass and abundance of zoobenthos. Furthermore, the abundant macrophyte population at the western sites may be the cause of the biota differences between the east and west banks. Furthermore, the effects of industrial pollution were not directly present in those sample locations. Most significantly, the knowledge gathered from this study will be useful for managing the Nile, especially following the construction of Ethiopia's Renaissance Dam.

INTRODUCTION

Fish rely heavily on macrobenthic invertebrates as food, and plankton can have an impact on these organisms. Although they can produce more than zooplankton, they are among the most common and diverse elements of river biota **(Liang & Liu, 1995)**. Many annelids, insects, crustaceans, and molluscs are examples of macrobenthic invertebrates found in freshwater **(Merritt *et. al.*, 2008)**. These communities play important roles in the movement of energy and materials and integrate changes in the biological, chemical, and physical aspects of their habitat. As a result, they seemed to be quite significant when taking ecology and biodiversity evaluation into account **(Silva *et. al*., 2014)**. Since macrobenthic invertebrates, as opposed to planktonic organisms, form relatively stable communities in the sediments that integrate changes over long periods of time and reflect properties of both the sediments and the upper water layer, their composition has long been thought to be a good predictor of water quality **(Aboul-Ezz, 1984)**. Additionally, by offering a vast surface area for the growth of epiphytic algae and the colonization of organic materials, the macrophytes can offer both direct and indirect nutritional benefits. Macrophytes also offer a favorable substrate for the growth of *Chironomini* species **(Oliver, 1971)** providing shelter to many species from predators and water turbulence **(Lodge, 1988)**. Additionally, the Nile molluscs are typical populations of weed and depositional habitats according to **Fishar and Williams (2006)**. Numerous estimated biotic indicators that represent community composition and can account for the effects of water pollution on communities, are necessary for the biodiversity of aquatic ecosystems **(Hooper *et al.*, 2005; Nguyen *et al.*, 2014)**. Community structure and function are directly impacted by species composition and biotic interactions **(Guo *et al.*, 2010)**. In this regard, **Ward *et al.* (2001)** stated that better explanations and comprehensive descriptions of biotic communities require a set of complementary indices rather than using a single index.

The current study aimed to:

- Document the abundance of specific free-living organisms in in the water without macrophytes and compare them with epiphytic invertebrate samples sites.
- To determine the selectivity of natural food and fish-secure food materials from the free-living or epiphytic invertebrate sample locations, and examine the stomach contents of fish.
- Assess the relationship between the recorded taxa and the key physical and chemical parameters, 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 between 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

During the year 2021, sampling was done according to the seasons. According to the method of **APHA (2005)**, the CRISON Multimeter MM40+ was used to measure the pH, conductivity, and temperature of the water. An oxygen electrode was used to measure the amount of dissolved oxygen *in situ* (Jenway oxygen meter, model 1070 Jenway, UK). Van-Dorn Bottle water samplers were used to gather water samples. NO_2-N, NO_3-N, and PO_4-P water concentrations were measured using techniques outlined in **APHA (2005)**. 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 the organic materials in the silt. The back- titration method was used to determine the carbonates.

3. Collection and treatment of zoobenthos

Using an Ekman grab with a $234cm^2$ (1/43 m^{-2}) aperture, macrobenthic fauna was gathered. A metal sieve with a 0.4mm mesh size was used to remove the obtained samples from the muds. After manually shaking the sample, smaller organisms (such as chironomid larvae in their early instar) were extracted from the surface water. After being immediately sorted in the field, the bottom organisms were preserved using a 5% formalin solution. In the lab, the number of distinct species and genera was ascertained. Before weighing, the organisms were held on a filter paper for five minutes to remove any water that might have adhered to their bodies. This allowed for an estimation of the fresh weight of the various groups. Molluscs' shells were taken out in order to weigh their flesh. The attached invertebrates (epiphytic) were collected by sampling macrophytes and then washing them. To preserve the specimens of epiphytic invertebrates, a neutral formalin solution at 5% was used.

4. Statistical analysis

The environmental variables and benthic invertebrate groups were compared using Canonical Correspondence Analysis (CCA). Utilizing the XL STAT software (2018), it was conducted.

RESULTS

1. Water quality

In winter, spring, summer, and fall, Site V (St.2) recorded the greatest water temperature readings (23.2, 30.6, 28.7, and 25.1°C, respectively); in winter, Site XIII (St. 5) recorded the lowest value (18.1°C). Due to the disposal of sail-drain effluent, site II (St.1) reported the greatest EC values of 375, 326, 487, and 397$\mu S\ cm^{-1}$ in the winter, spring, summer, and fall, respectively. In spring, Site V (St.2) recorded the lowest pH value of 7.6, while Site I (St.1) reported the highest value of 9.0. In winter, spring, summer, and fall, Site II (St.1) recorded the lowest DO values, which were 7.3, 5.3, 0.5, and 0.8mg L^{-1}, respectively. However, at location XIV (St.5), the highest DO value of 11.9 mg L^{-1} was recorded throughout winter. In winter, spring, summer, and fall, Site V (St.2) recorded the highest NO_2 concentrations, 10.2, 14.7, 18.3, and 15.1µg L^{-1}, respectively.

On the other hand, the lowest NO_2 values of 2.1µg L^{-1} was measured at Site XIII (St.5) during summer. The highest NO_3 values of 212.3, 393.6, 96.6, and 752.1µg L^{-1} were measured in winter, spring, summer, and autumn, respectively at Site V (St. 2). The highest PO_4 values of 30.3, 39.2, 41.2, and 47.9µg L^{-1} were recorded at Site II (St.1) in winter, spring, summer, and autumn, respectively. The highest chlorophyll-*a* values of 11.7, 12.2, 7.9, and 25.6mg L^{-1} were recorded at Site X (St.4) in winter, spring, summer, and autumn, respectively. The highest values of OM were 15.9, 12.8, 15.4, and 15.7% at Gezira Site II (St. 1) during winter, spring, summer, and autumn, respectively. The highest value of carbonate content (25.3%) was recorded at Site IX (St. 3) during autumn (Table 2). The natural bottom sediments in the River Nile are composed of clayey silty sand. The sand fractions formed the main size of the sediments (range: 79.8 – 99.9%), while the silt fraction of varied between 0.1 to 17.9% and the clay ones ranged between 0.0 and 2.9% (Table 3).

2. Zoobenthos

The macrobenthic invertebrates in the Nile consisted mainly of three main groups: molluscs (14 species), aquatic insects (13 species), and oligochaetes (3). According to relative abundance, they accounted for about 50.8, 31.8 and 15.8% of the total zoobenthos, respectively. In addition, two other groups including the Crustacea (1 species) and the Hirudinea (1 species) were recorded as rare forms, together accounting for about 1.6% of the total benthos (Table 4). High values of the Nile macrobenthic invertebrates standing crop were recorded at the sampling sites that located upstream of the wastewater discharge points with mean values fluctuating between 3498 ind.m^{-2} with biomass of 41.6 GFW.m^{-2} at east Site IV (st.2) and 14498 ind.m^{-2} with biomass of 55.0 GFW.m^{-2} at west Site XV(St.5). On the other hand, sharp lower values (range: 2442 ind.m^{-2} with 14.8 GFW M^{-2}-2879 ind.m^{-2} with 21.9 GFW m^{-2}) were detected at the points of discharge (range: 2732 ind.m^{-2} with 16.9 GFW m^{-2}- 4296 ind.m^{-2} with 62.4 GFW m^{-2}) and in the downstream sites (Fig. 2). Regarding their seasonal variations, the macrobenthic invertebrates living at the various sites along the Nile showed a rapid increase in winter and spring, particularly at the sites of Kom Ombo (range: 2992-7702 ind.m^{-2}) and Aswan (range: 4972-14696 ind.m^{-2}), as shown in Fig. (3).

The molluscs (Fig. 4) recorded in the sector of the Nile between Aswan and Sebaiyia during the present study comprised 14 species. Of these, 11 species of gastropods, namely *Valvata nilotica* Jickeli, *Bellamya unicolor* Olivier, *Gabbiella senoarients* Kuster, *Melanoides tuberculata* Muller, *Cleoptara bulimoides* Olivier, *Theodoxus niloticus* Reeve, *Lymnaea anatalensis* Krauss, *Gyraulus ehrenbergi* Beck, *Biomphalaria Alexandria* Ehrenberg, *Bulinus truncates* Audouin and *Physa acuta*

Draparnaud and 3 species of bivalve, namely *Spharium hartmannni* Jickeli, *Pisidium pirothi* Jickeli, *Corbiculla consobrina* Cailiaud. In terms of their seasonal variation, two abundance peaks were recorded in spring (avg. 2325 ind.m^{-2} with a 9.9 GFW m^{-2}) and summer (avg. 3188 ind.m^{-2} with 11.6 GFW m^{-2}) (Fig. 5) and in particular at Site XV (St.5) which had the highest values of 12364 with 35.1 GFW m^{-2} and 25960 ind.m^{-2} with 40.1 GFW m^{-2}, respectively, due to the development of high densities of *V. nilotica*, which accounted for 41.2% (average 949 molluscs m^{-2}) of the total molluscs; while *G. ehrenbergi* and *M. tuberculata* contributed about 28.5 % (average 663 snails m^{-2}) and 8.2% (average 189 molluscs m^{-2}), respectively, of the total molluscs.

The aquatic insects recorded in the Nile sector from Aswan to Sebaiyia (Fig. 6) included four orders, namely Diptera (chironomid larvae and their pupae), nymphs of Odonata (Zygoptera), nymphs of Ephemeroptera and Hemiptera (adult Corixidae). For their seasonal variation, they showed their maximum persistence in winter and spring, particularly at sites XIII (St. 5), and XVII, XVI, and XVIII (St. 6) with averages of 4400, and 4796, 8712, and 2200 ind.m^{-2}, respectively (Fig. 7). Otherwise, the densities were at their lowest values in summer and autumn, which was associated with the increased water temperature. In generally, Diptera (mainly larvae of Chironomidae) were dominant, followed by nymphs of Zygoptera. Their biomass was generally, linearly proportional to their numbers.

Oligochaetes (Fig. 8) are represented by three species belonging to the Tubificidae family, namely *Branchiura sowerbyi* Beddard, *Limnodrilus udekemianus* Claparede, and *L. hoffmeisteri* Claparede. Regarding their seasonal variation, two peaks of abundance were identified. The first took place in winter (average. 895 ind.m^{-2} with 8.8 GFW m^{-2}), particularly at the sites (Sts. I & II) in Aswan. This is mainly due to the increased density of *L. udekemianus* and *B. sowerbyi*. The second peak occurred in spring (average. 999 ind.m^{-2} with 5.3 GFW m^{-2}), at the downstream sites (II (St.1) and III (St.1)). This peak consisted mostly of *L. udekemianus* and *L. hoffmeisteri*. Further increasing density oligochaetes was also recorded at the downstream Site VIII (St.3) (Fig. 9) due to the increased numbers of the a for- mentioned species.

Crustacea (*Cardina nilotica* Roux) was mainly confined at most sites during autumn. The highest value of 968 ind.m^{-2} with 11.6 GFW m^{-2} was recorded at Site I (St.1) during spring.

Hirudinea (*Helobdella conifer*) appeared rarely or missed during the different seasons at most sites, except the highest density of 660 ind.m^{-2} with 6.7 GFWm^{-2} that was recorded at Site XIV (St. 5) in spring.

In the present study, the macrobenthic invertebrates found in the stomach contents of four fish species (*Alestes baremoze*; *Labeo niloticus*; *Mormyrus kannume* and *Oreochromis niloticus*) collected from the River Nile comprised of three animal groups (represented in eight species and other immature stages), in addition to some macroalgal species (Table 5).

3. Free and epiphytic invertebrates

Concerning the macrobenthic invertebrates (Table 6) chironomid larvae, five molluscs, Trichoptera larvae, and three oligochaetes were recorded with substrate composed mainly of clayey silty sand. On the other hand, fifteen species (nine molluscs, two chironomid larvae, one odonate, one corixidian, one ephemeropterans, and one hirudinean were associated with different aquatic submerged plants.

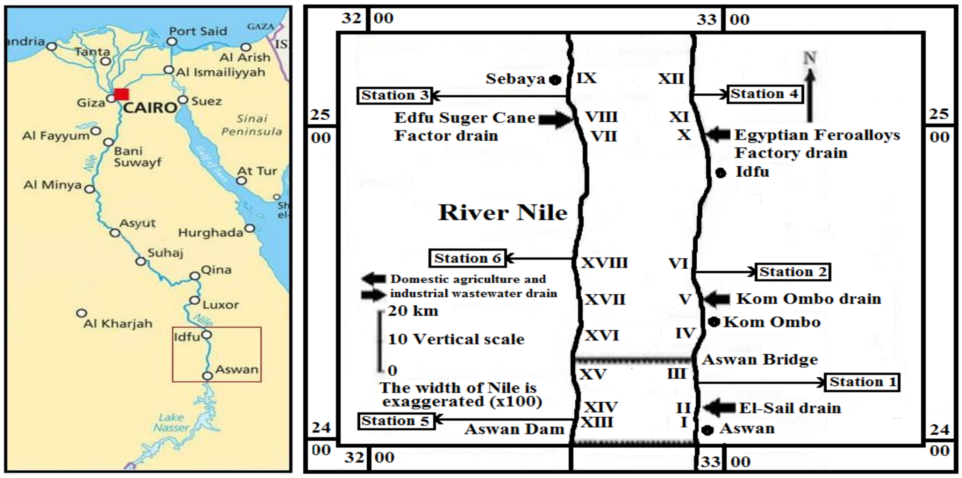

Fig. 1. Sampling sites in the River Nile water between Aswan and Sebaiyia during 2021

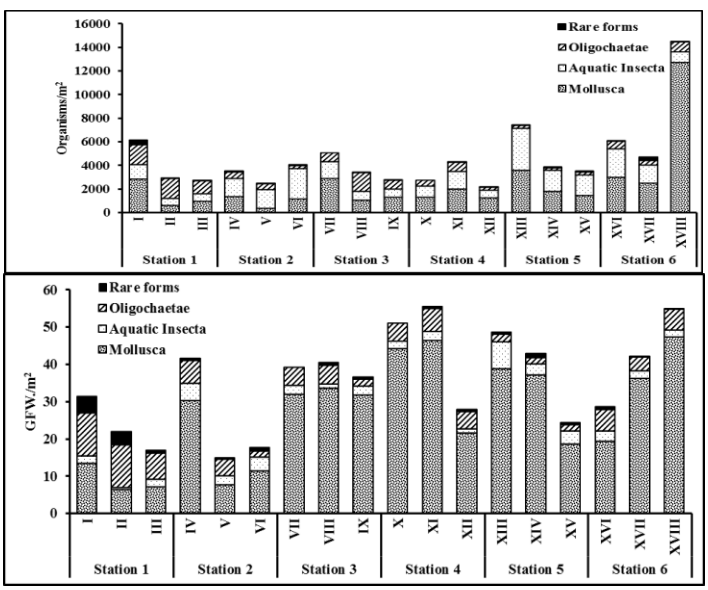

Fig. 2. Annual average numbers and biomass of macrobenthic invertebrates (orgs.m^{-2}) and GFW. m^{-2}) recorded in the Nile water between Aswan and Sebaiyia during 2021

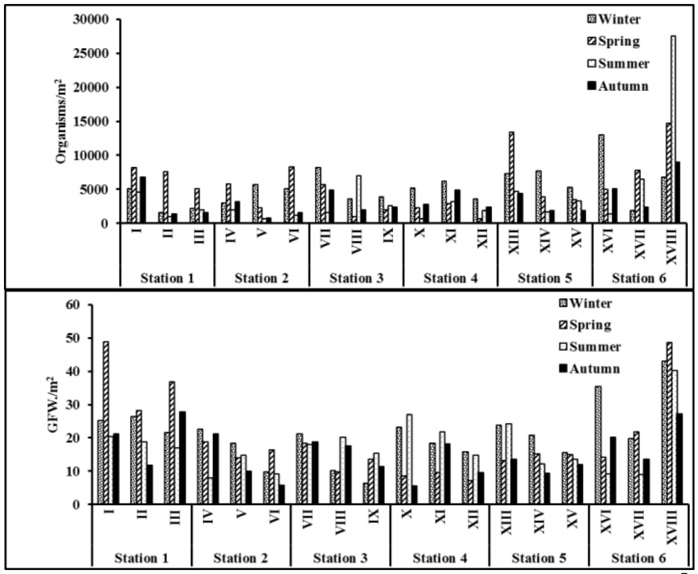

Fig. 3. Seasonal variations of macrobenthic invertebrates (orgs.m^{-2}) and GFW m^{-2}) recorded in the Nile water between Aswan and Sebaiyia during 2021

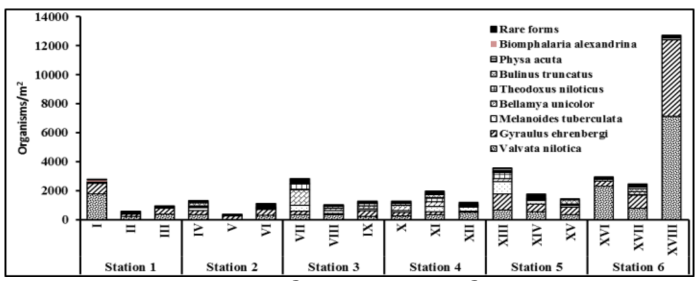

Fig. 4. Distribution of mollusca (org.m^{-2}) & GFW.m^{-2}) recorded in the River Nile water between Aswan and Sebaiyia during 2021

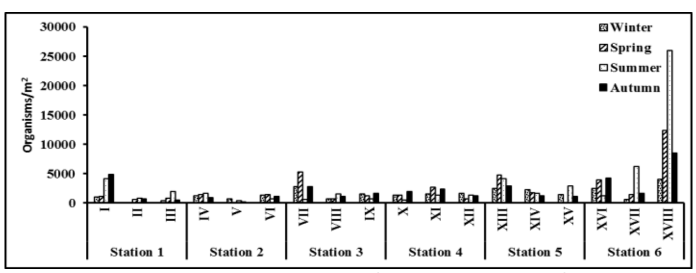

Fig. 5. Seasonal variations of mollusca (org.m^{-2} and GFW m^{-2}) recorded in the River Nile water between Aswan and Sebaiyia during 2021

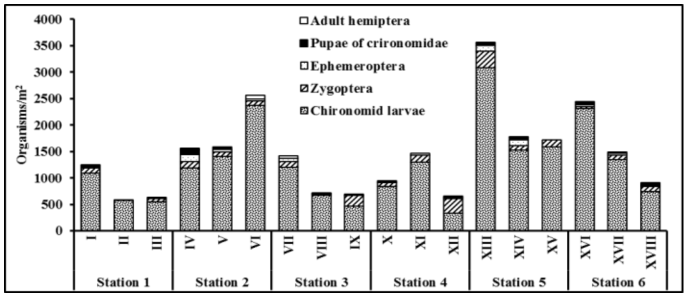

Fig. 6. Distribution of Aquatic Instect (insects m^{-2} and GFW m^{-2}) recorded in the River Nile water between Aswan and Sebaiyia during 2021

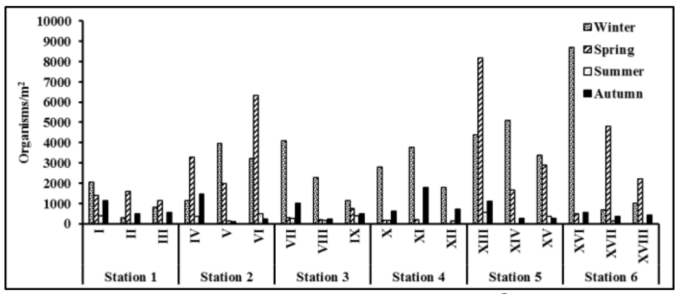

Fig. 7. Seasonal variations of Aquatic Instect (insects m^{-2} and GFW m^{-2}) recorded in the River Nile water between Aswan and Sebaiyia during 2021

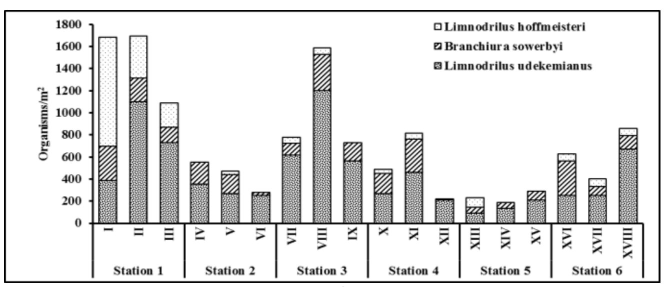

Fig. 8. Distribution of Oligochaetae (orgs.m^{-2}) recorded in the River Nile water between Aswan and Sebaiyia during 2021.

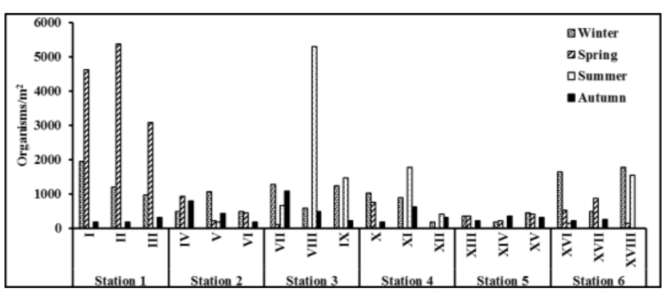

Fig. 9. Seasonal variations of Oligochaetae (orgs.m^{-2} & GFW m^{-2}) recorded in the River Nile water between Aswan and Sebaiyia during 2021

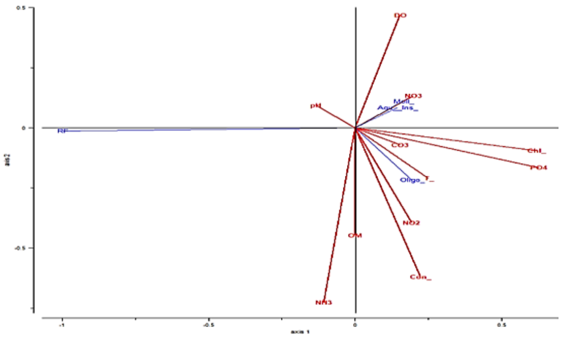

Fig. 10. The CCA applied on samples of groups of macrobenthic invertebrates with 11 physicochemical parameters at the Nile between Aswan and Sebaiyia during 2021. Cods: Moll., mollusca; Aquat-ins., Aquatic insects; Oligo., Oligochaetae

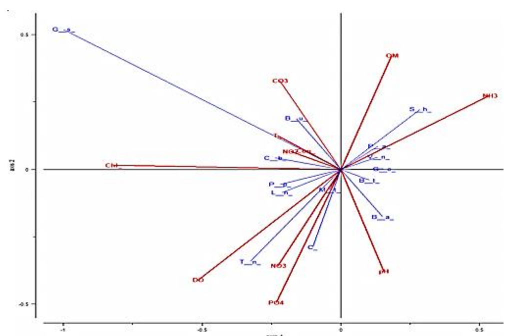

Fig. 11. The CCA applied on samples of genera of mollusca with 11 physicochemical parameter at the Nile between Aswan and Sebaiyia during 2021.Cods: *V-n, Valvata nilotica,; B-u, Bellamya unicolor*; G-s, *Gabbiella senoarients*; M-t, *Melanoides tuberculate;* C-b, *Cleoptara bulimoides; T-n, Theodoxus niloticus;* L- a, *Lymnaea anatalensis*; G- e, *Gyraulus ehrenbergi; B-a, Biomphalaria Alexandria; B-t; Bulinus truncates;* p- a, *Physa acuta;* P- h, *Spharium hartmannni; P –p, Pisidium pirothi; C- c, Corbiculla consobrina*

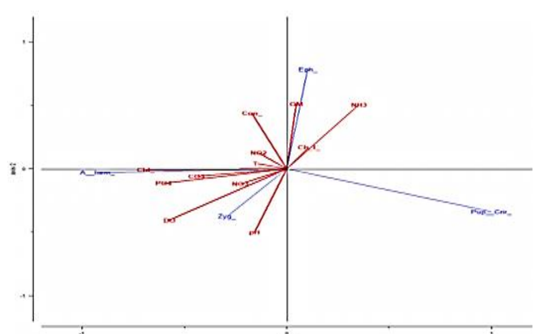

Fig. 12. The CCA applied on samples of genera of aquatic insects with 11 physicochemical parameters at the Nile between Aswan and Sebaiyia during 2021.Cods: Chir., Chironomid larvae; Eph., Ephemeroptera; Zyg., Zygoptera; A-hem, Adult hemiptera

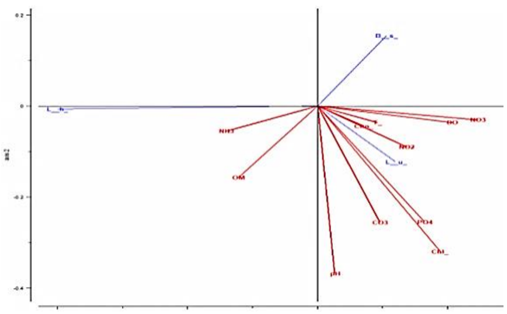

Fig. 13. The CCA applied on samples of genera of Oligochaetae with 11 physicochemical parameters at the Nile between Aswan and Sebaiyia during 2021. Cods: *L-u, Limnodrilus*

Table 1. Description of the sampling regime

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

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. Grain size analysis (%) and substrate texture in the River Nile water between Aswan and Sebaiyia during 2021

	Site	**Sand %**	**Silt %**	**Clay %**	**Substrate texture**		Site	**Sand %**	**Silt %**	**Clay %**	**Substrate texture**
Station 1	I	98.5	1.2	0.3	Sand	**Station 4**	X	99.9	0.1	0	Sand
	II	97.3	2.4	0.3	Sand		XI	86.1	12.8	1.1	Silty sand
	III	99.1	0.9	0	Sand		XII	79.8	17.9	2.3	Silty sand
	Avg.	98.30	1.50	0.20			Avg.	88.60	10.27	1.13	
Station 2	IV	96.7	3.1	0.2	Sand	**Station 5**	XIII	94.7	3.4	1.9	Sand
	V	99.9	0.1	0	Sand		XIV	99.9	0.1	0	Sand
	VI	81.5	15.6	2.9	Silty sand		XV	87.8	11.9	0.3	Silty sand
	Avg.	92.70	6.27	1.03			Avg.	94.13	5.13	0.73	
Station 3	VII	94.7	4.8	0.5	Sand	**Station 6**	XVI	96.5	2.9	0.6	Sand
	VIII	96.3	3.1	0.6	Sand		XVII	83.5	15.6	0.9	Silty sand
	IX	85.6	13.3	1.1	Silty sand		XVII	96.9	2.9	0.2	Sand
	Avg.	92.20	7.07	0.73			Avg.	92.30	7.13	0.57	Sand

Table 4. Macrobenthic invertebrate species recorded in the River Nile water between Aswan and Sebaiyia during 2021 and their presence contribution (%)

Species	%	Species	%	Species	%
Valvata nilotica	20.8	*Lymnaea natalensis*	0.3	*Chironomus* sp.	0.5
Gyraulus ehrenbergi	14.5	*Pisidium pirothi*	0.3	*Cricotopus* sp	0.4
Melanoides tuberculata	4.1	*Corbicula consobrina*	0.2	Zygoptera	2.4
Bellamya unicolor	3.6	*Procladius* sp.	8.7	Ephemeroptera	0.9
Theodoxus niloticus	2.1	*Clinotanypus* sp	5.5	Pupae of Chironomidae	0.6
Bulinus truncatus	1.8	*Ablabesmyia* sp	4.2	Adult Hemiptera	0.5
Physa acuta	0.9	*Dicrotendipes modestus*	2.9	*Limnodrilus udekemianus*	9.7
Biomphalaria alexandrina	0.7	*Tanytarsus* sp.	1.6	*Limnodrilus hoffmeisteri*	2.6
Cleoptara bulimoides	0.6	*Polypedilum* sp.	1.5	*Branchiura sowerbyi*	3.5
Sphearium hartmanni	0.5	*Cryptochironomus* sp.	1.3	*Helobdella conifera*	0.7
Gabbiella senoariensis	0.4	*Microtendipes* sp.	0.8	Crustacea	0.9

Table 5. Benthic communities of stomach contents in different fish species collected from the River Nile between Aswan and Sebaiyia

Mollusca	**Instect**
Bulinus truncates	*Cardina nilotica*
Gyraulus ehrenbergi	Chironomid larvae
Physa acuta	**Oligochaeta**
Psidium pirothi	*Branchiura sowerbyi*
	Limnodirlus udekemianus

Table 6. Distribution of macrobenthic invertebrate species according to their biotopes between Aswan and Sebiayia

Invertebrate taxa	Macrophyte taxa	Substrate texture
Procladius sp.		Clayey silty sand
Clinotanypus sp.		Clayey silty sand
Ablabesmyia sp.		Clayey silty sand
Tanytarsus sp.		Clayey silty sand
Polypedilum sp.		Clayey silty sand
Cryptochironomus sp.		Clayey silty sand
Microtendipes sp.		Clayey silty sand
Chironomus sp.		Clayey silty sand
Cricotopus sp.	*C. dermersum & P. crispus*	
Dicrotendipes modestus	*M. spicatum & C. dermersum*	
Pseudagrion niloticum	*M. spicatum & C. dermersum*	
Nymphs of Ephemeroptera	*M. spicatum & C. dermersum*	
Adult of Micronect splicuta	*M. spicatum & C. dermersum*	
Cardina nilotica		Clayey silty sand
Branchiura swerbyi		Clayey silty sand
Limnodrilus udekemianus		Clayey silty sand
Limnodrilus hoffmeisteri		Clayey silty sand
Helobdella conifera	*M. spicatum & P. crispus*	Clayey silty sand
Valvata nilotica	*P. perfoliatus & Najas horrida*	Clayey silty sand
Bellamya unicolor	*C. dermersum & P. perfoliatus*	Clayey silty sand
Gabbiella senaariensis	*C. dermersum*	
Melanoides tuberculata		Clayey silty sand
Cleopatra bulimoides		Clayey silty sand

Theodoxus niloticus	*M. spicatum & C. dermersum*	
Lymnaea natalensis	*M. spicatum & P. crispus*	
Gyraulus ehrenbergi	*C. dermersum & P. crispus*	Clayey silty sand
Biomphalaria alexandrina	*C. dermersum & P. crispus*	
Bulinus truncatus	*P. crispus*	
Physa acuta	*C. dermersum & P. perfoliatus*	
Sphearium hartmanni		Clayey silty sand
Pisidium pirothi		Clayey silty sand
Corbicula consobrina		Clayey silty sand

DISCUSSION

The Nile system has been known to harbor zoobenthos viz. mollusca, aquatic instect, annelida, crustacea, and hirudinea **(El-Shimy & Obiud-Allah, 1992; El-Shabrawy & Rizk, 2005; Fishar & Williams, 2006; El-Otify & Iskaros, 2018)**. Physical, chemical, and biological environmental conditions, all have a significant impact on the characteristics and abundance of macrobenthic invertebrates in rivers **(Angradi *et al.*, 2006; Jiang *et. al.*, 2010)**. In order to control habitat complexity, food availability, and protection from predators and flow disruption, the substrate state is also crucial. Accordingly, the amount of organic matter that accumulates on the riverbed can be influenced by the types of substrates **(Hepp *et al*., 2012)**. **Ali and Soltan (1996)** identified five species of aquatic plant blets (Table 5) that were found at the surveyed sites: *C. demersum*, *N. horrida*, *M. spicatum*, *P. crispus*, and *P. perfoliatus*. One Odonate, one Corixidian, one Ephemopetrn, one Hirudinean, two chironomid larvae, nine molluscs, and fifteen species have been linked to those macrophytes. However, on a substrate that was mostly made of loamy silty sand, eight chironomid larvae, five molluscs, one trichopteran, three oligochaetes, and one crab were observed (Table 2).

In addition, the main bottom sediment components; sand (avg. 93.1%), silt (avg. 6.2%), and clay (avg. 0.7%) along with submergent macrophytes, represented favorable conditions for the presence of several macrobenthic invertebrate taxa, as demonstrated by the Aswan and Kom Ombo sites on the western bank. According to **Difonzo and Campbell (1988)**, the kind of microhabitat (aquatic plants, bottom sediments, or water columns) affects the relative quantity and makeup of invertebrates. This suggests that many invertebrates were able to develop and colonize macrophytes because they offered superior microhabitats with unique features. Most significantly, the canonical corresponding analysis (CCA) revealed the following link between several water parameters and microbenthic invertebrates: In 2021, samples from macrobenthic invertebrate groups along the Nile between Aswan and Sebaiyia were subjected to the CCA.

This led to the presentation of the observed distribution according to environmental variables (Fig. 10). Oligochaetae had a negative correlation with pH and a positive correlation with EC, NO_2, temperature, CO_3, PO_4, and chlorophyll *a*. DO and NO_3 showed a positive correlation with mollusca and aquatic instect, but NH_3 and organic matter showed a negative correlation. The explanatory factors accounted for 38.4% of the variation in the weighted averages of the mollusca assemblages, according to the 2021 CCA, which was applied to samples of mollusca genera along the Nile between Aswan and Sebaiyia. The observed distribution based on environmental variables was thus displayed (Fig. 11).

Biomphalaria alexandrina and *Bulinus truncates* had a positive relationship with pH. *Sphearium hartmanni*, *Physa acuta*, and *Valvata nilotica* showed favorable correlations with OM and NH_3. Temperature, CO_3, NO_2, and chlorophyll-*a*, all showed positive correlations with *Bellamya unicolor*, *Cleoptara bulimoides*, and *Gabbiella senoariensis*. Positive correlations were found between NO_3, PO_4, DO, and *Lymnaea natalensis*, *Pisidium pirothi*, *Corbiculla*, *Melanoides tuberculata*, and *Theodoxus niloticus*. The explanatory variables explained 52.78% of the variance in the weighted averages of the aquatic insect assemblage, according to the 2021 CCA, which was applied to samples of aquatic insect taxa along the Nile between Aswan and Sebaiyia. Consequently, Fig. (12) shows the observed distribution based on environmental variables. EC, NO_2, and temperature had a negative correlation with chironomid larvae and their pupae. There was a favorable correlation between NH_3, organic matter, and chlorophyll *a* and Ephemeroptera. Adult Hemiptera and Zygoptera showed favorable correlations with DO, pH, NO_3, PO_4, and CO_3. The explanatory variables accounted for 95.07% of the variance in the weighted averages of the Oligochaetae assemblages, according to the 2021 application of the CCA to samples of Oligochaetae taxa along the Nile between Aswan and Sebaiyia (Fig. 13). This led to the presentation of the observed distribution according to environmental variables. A positive correlation was detected between *L. udekemianus* and temperature, pH, EC, DO, NO_2, NO_3, PO_4, and CO_3. *B. sowerbyi* showed a negative correlation with NH_3 and organic matter, but *L. hoffmeisteri* showed a positive correlation with both.

At every site examined, the overall population densities of these biota and their main groups were higher on the west bank of the Nile (ranging from 2145 ind. m^{-2} to 14498 ind. m^{-2}) than on the east side (ranging from 2442 to 6138 ind. m^{-2}). The high density of macrophytes in the west bank locations is thought to be the cause of the observed disparities between the east and west banks. Additionally, the effects of industrial waste were not directly present in these sample locations. Thus, compared to the east bank, the west bank locations under study, which were not exposed to industrial trash directly, contained twice as much or more.

According to these findings, the frequency of Nile zoobenthos accumulations was constrained by the effluent from factories on the east bank of the channel. This suggested that wastewater induces adverse conditions by altering the water's physical and chemical characteristics, which subsequently impact zoobenthos population density and community structure. **Ibrahim (2009)** found that the variety of zoobenthos found in

African rivers was a definite sign of contamination in a locality brought on by the release of industrial effluents.

In reference to seasonal fluctuations, the abundance of aquatic insects (average 2821 insects m^{-2} and 3.7g fresh weight m^{-2}) and molluscs (average 2325 ind. m^{-2} and 9.9g fresh. wet m^{-2}) was the primary cause of the winter (average 5294 ind. m^{-2} with 18.9g fresh weight m^{-2}) and spring (average 5525 ind. m^{-2} with 19.7g fresh weight m^{-2}) peak sizes of macrobenthic invertebrates that inhabited the Nile sector between Aswan and Sebaiyia. Furthermore, most of the benthic population that lived in the Nile sector during most seasons was composed of molluscs (average 2319 ind. m^{-2} with 31.2g fresh weight m^{-2}).

As a result of the high submerged plant population, sites in western Aswan, especially Site VI, had an average of 12,716 people per year m^{-2} and 47.4g fresh weight m^{-2} of biomass **(El-Otify & Iskaros, 2018)**. The higher populations of *V. nilotica* and *G. ehrenbergi* were primarily responsible for these peaks. As the water temperature decreased in fall and winter, mollusca populations gradually decreased (Figs. 4, 5).

At an average of 1447 insects per year and a biomass of 2.7g fresh weight m^{-2}, aquatic insects were the second most significant organisms in the benthic community in the Nile sector between Aswan and Sebaiyia. With a range of 1562 insects m^{-2} with 4.8g fresh weight m^{-2} to 3564 insects m^{-2} with 7.2 g fresh weight m^{-2}, their maximum distribution was discovered at Kom Ombo sites. The highest resistance was observed in winter (average 2821 insects m^{-2} and 3.7g fresh weight m^{-2}) and spring (average 2083 insects m^{-2} and 3.3g fresh weight m^{-2}) as opposed to the lowest densities, which coincided with higher water temperatures in summer (average 206 insects m^{-2} and 1.9g fresh weight m^{-2}) and autumn (average 654 insects m^{-2} and 1.7g fresh weight m^{-2}). Thus, it is anticipated that the spring and summer temperature increases will quicken the rate at which aquatic insects develop and eventually result in pupation or nymphs, which will bring them to adulthood. Adult Corixidae nymphs peaked in fall, while Zygoptera peaked in summer. Lake Nasser **(Iskaros, 1988 & 1993; Iskaros *et al.*, 2021; Abdelmageed *et al.*, 2024)**, Aswan Reservoir **(Iskaros and El-Otify, 2013)**, and the Nile **(EL-Otify and Iskaros, 2018)** have also recorded similar findings (Figs. 6, 7).

With an average of 719 ind. m^{-2} each year and 5.0g fresh weight m^{-2}, oligochaetes were the third most significant bottom dweller among the benthic organisms that inhabited the Nile. The oligochaetes, however, demonstrated a significant rise and discrepancy in the discharge points in this study, including site II (St.1) (avg. 1691 ind.m^{-2} with 11.6 GFW m^{-2}), site I (St.1) (avg. 1683 ind.m^{-2} with 11.5 GFW m^{-2}), and site VIII (St. 3) (avg. 1584 ind.m^{-2} with 5.1 GFW m^{-2}). Similarly, **Varnosfaderany *et al.* (2010)** found that oligochaetes were highly prevalent in areas contaminated by industrial water. This finding could be explained by the fact that tubificids were notably abundant at organically polluted sites during the investigation, which was conducted because the decomposition of organic matter can allow for the spectacular growth of tubificids. Two maxima in frequency were observed; the first occurred at sites in Aswan during winter (average 895 ind. m^{-2} with 8.8g fresh weight m^{-2}). This is mostly because of the higher density of *B. sowerbyi* and *L. udekemianus*. At downstream sites III and V, the second event took place in spring, with an average of 999 ind. m^{-2} and 5.3g fresh weight m^{-2}.

Phytoplankton is important in the natural habitat because it is the primary food source for aquatic organisms, including herbivorous zooplankton and macrobenthic invertebrates that feed on detritus **(Iskaros, 1993)**. This peak was primarily composed of *L. udekemianus* and *L. hoffmeisteri*. Another increasing number was recorded at site XVI downstream, ascribed to the increased density of the above species, *H. conifera* and *C. nilotica*, which were scarcely observed in the various seasons and locations.

The final link in the food chain is the crop of fish from any body of water. *Oreochromis* (Tilapia) *niloticus* Linn, which lives in a Nile canal close to Cairo, had more diatoms and animal-based food (zooplankton and chironomid larvae) in its stomach. As the fish gets bigger, the proportion of the latter food item rises **(Khallaf & Alne-naei, 1986; Delince, 2013)**. Particularly following the construction of the Renaissance Dam in Ethiopia, the findings of this study will offer a helpful hint for monitoring the impact of wastewater discharges on the ecology and limnology.

CONCLUSION

During the present investigation, the macrobenthic invertebrates in the Nile sector between Aswan and Sebaiyia contained three primary groups, namely molluscs, aquatic insects and oligochaetae. They made up roughly 50.8, 31.8, and 15.8% of all zoobenthos, respectively, based on their relative abundance. Moreover, other rare animals were also seen, such as Decapoda and Hirudinea, which together made up 1.6%.

There were 4560 ind.m^{-2} and 39.8 GFW m^{-2} of macrobenthic invertebrates on average every year. Due to the large macrophyte population at the west bank sites, it is speculated that the observed disparities between the east and west banks may be their cause. Furthermore, these sample locations were not in close proximity to the effects of industrial waste.

Availability of data and materials
This article contains all the data created or examined during our research.

Competing interests
No conflicting financial interests or personal relationships that might seem to have influenced the work described in this article are known to the authors.

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