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Monitoring the Effect of Seasonal Variation on Macro-Benthic Invertebrates' Fauna in Timsah Lake and Western Lagoon, Ismailia, Egypt

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ABSTRACT

Macroinvertebrates (MBI) serve as a food source for various animals in both aquatic and terrestrial environments. Consequently, they are important indicators of ecosystem health and functionality. This paper investigated the macroinvertebrate fauna of Lake Timsah and the western lagoon seasonally, exploring variations in community distribution and physicochemical parameters to correlate these factors with macroinvertebrate abundance and seasonal changes. A total of 43 species were collected, belonging to six groups. The most abundant group was Arthropoda, comprising 48.23% of the total MBI, with an annual average of 22,412 individuals per square meter (ind./m²). Mollusca contributed 38.25% of the total MBI, averaging 17,776 ind./m² annually. Annelida and Chordata had annual averages of 4,544 and 1,491 ind./m², respectively. From June 2022 to May 2023, approximately 24 water samples were taken from both the lake and the western lagoon on a seasonal basis. Higher levels of dissolved oxygen were observed in the tested samples during spring compared to other seasons, ranging from 11.2 to 6.96mg/ L. The pH levels varied from 7 to 9.5, with the maximum mean value (9.5) recorded in autumn, while the average salinity in summer was 30.5‰. The MBI displayed spatial distribution variations across the study sites, with Timsah Lake exhibiting the highest number of species and individuals (41 species, 40,275 ind.) compared to the western lagoon (20 species, 6,198 ind.). The highest seasonal density at Timsah Lake occurred in summer (12,579 ind./m²), while the western lagoon recorded its highest density in winter (11,862 ind./m²). Principal component analysis (PCA) revealed a strong positive correlation with the most prevalent MBIs, particularly Bivalvia and Crustacea, across all seasons. Canonical correspondence analysis (CCA) indicated that the physicochemical parameters tested in Lake Timsah during summer, autumn, and spring had a strong positive association with MBIs, including Polychaeta, Cnidaria, and Crustacea.

INTRODUCTION

A sieve or mesh with pore sizes ranging from 0.2 to 0.5 mm, commonly used in stream sampling equipment, can capture a wide variety of spineless animals known as macroinvertebrates. According to **Winterbourn (1999)**, various macroinvertebrate species found in streams include worms such as segmented roundworms, eelworms, and flatworms; mollusks viz. snails and bivalves; crustaceans, including shrimp, crayfish, and similar groups; mites; and, most importantly, insects. Many factors determine where and how invertebrates that inhabit streams are distributed. The most important factors include temperature with altitude and season effects **(Sullivan *et al*., 2004; Sporka *et al.*, 2006; Joshi *et al*., 2007)**, and current speed **(Donohue *et al*., 2006; Hussain, 2011)**. Moreover, vegetation **(Subramanian & Sivaramakrishnan, 2005)** and substratum **(LeCraw & Mackreth, 2010)** play an integral part.

Most invertebrates play a crucial role in stream ecosystems. They feed on periphyton, which helps control blooms, assist in the decomposition of organic matter, and facilitate nutrient cycling. Additionally, they serve as prey for predators such as fish **(Hynes, 1970; Jimoh *et al.*, 2011; Uwem *et al.*, 2011)**.

The biomass and community structure of macroinvertebrates can be impacted by environmental changes such as sediment quality, habitat features, and water temperature **(Veiga *et al.*, 2016; Wang *et al.*, 2021)**. Therefore, macroinvertebrates are commonly used as a practical biological marker to monitor and assess the state of habitats found in rivers, lakes, and seas **(Wang *et al*., 2021)**.

Timsah Lake is located in the middle section of the Suez Canal, which is roughly 16 square kilometers in size and ranges in depth from 3 to 16 meters. Swimming is prohibited in the lake. The lake is recognized as one of the most efficient lakes in proximity to the Suez Canal, as signed by **Madkour *et al*. (2006)**. On its western side, the lake is connected to a little, shallow lagoon. Additionally, it is a narrow road that contributes significantly to Ismailia City's revenue as the primary destination for tourists and fishermen. However, over the past few years, Lake Timsah has seen major environmental changes brought on by a variety of anthropogenic activities such as **Saad El-Din *et al*. (2013)**. Unfortunately, the ecosystem surrounding Timsah Lake has been critically polluted for the past thirty years. Toxic metals, petroleum pollutants, and insecticides have all been found in the soil, water, and edible aquatic creatures **(Gabr & Gab-Alla, 2008)**. According to **Cendrero *et al*. (2020)**, anthropogenic activities, at all levels, have a greater impact on the environment than natural processes.

According to **Abd El Samie *et al*. (2008)**, Timsah Lake—particularly its northern and eastern regions—experiences high discharge levels due to various events occurring nearby. As a result, the lake's water quality is noticeably more polluted than that of the adjacent Suez Canal. Despite exposure to pollutants or environmental changes, such as shifts in water quality, most invertebrates tend to remain in their habitats. However, pollution can lead to a less complex community composition, favoring more tolerant species, while still maintaining high numbers of a single species. This may result in an increase in species variety and abundance, along with a reduction in individual size. Assessing the diversity and functions of various species groupings can provide insights into the health of the benthic macrofaunal community, making them effective indicators of environmental health **(Dar *et al.*, 2018)**.

Research on the macro-invertebrates of Lake Timsah is limited in comparison to other lakes in Egypt. The majority of studies have focused on particular macro-benthic fauna groups despite the lake being just one of many sites along the Suez Canal. Several studies have focused on monitoring the diversity and distribution of zooplankton **(Abo-Zaid, 1990; El-Sherbiny *et al*., 2011; El-Damhougy *et al*., 2019)**, fouling organisms **(Emara & Belal, 2004)**, specific bivalve molluscan species **(Mohammad *et al*., 2009, 2014)**, and benthic polychaetes **(Belal & Ghobashy, 2012)**.

Several studies have focused on the Western Lagoon, which serves as the western gateway to Timsah Lake and is a primary source of pollution for the lake. The most recent comprehensive study by **Belal *et al.* (2016)** examined macro-benthic diversity and density under various conditions in Timsah Lake (at three stations) and the Western Lagoon (at ten stations) between the fall of 2014 and the summer of 2015. Given the significance of Lake Timsah and the Western Lagoon for tourism, recreational activities, and fishing, it is crucial to assess the current state of the lake. The primary objective of this study was to identify the macro-benthic fauna of Timsah Lake and the Western Lagoon and to investigate the relationship between seasonal variations, physicochemical changes, and the distribution of macroinvertebrate fauna in both locations. This assessment was necessary to obtain up-to-date data on the dynamics of the invertebrate community in the lake.

MATERIALS AND METHODS

1. Site of collection

Timsah Lake, with a surface area of 15km², a variable depth ranging from 3 to 16 meters, and a water volume between 90 and 106 million cubic meters, is located 80km south of Port Said at the midpoint of the Suez Canal. It lies between latitudes 30° 33' and 30° 35' N and longitudes 30° 16' and 30° 19' E (Fig. 1). The two locations selected for this study, Timsah Lake (30.56° N, 32.29° E) and Western Lagoon (30.57° N, 32.26° E), represent different physical conditions and faunal diversity within the lake.

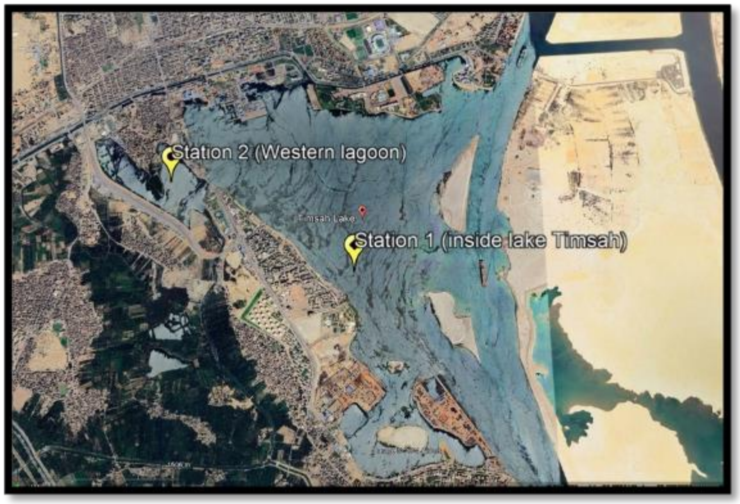

Fig. 1. Timsah Lake map displaying the two collection sites: Western Lagoon (station 2) and the lake itself (station 1)

2. Obtaining and analyzing samples

Seasonally, water samples were taken from the lake's interior (about 30cm below the surface) between June 2022 and May 2023. For the other physico-chemical examination, samples were gathered in a Ruttner water sampler bottle and kept at 4^0C in the dark.

3. Physicochemical parameters

To ascertain the physicochemical characteristics, *in situ* measurements of surface water temperature, pH, and dissolved oxygen (DO) were conducted using a Hydro Lab version 4. Seasonal assessments of nutrient salts in lake water samples were performed with a JENWAY spectrophotometer following the conventional procedures outlined in **APHA (2005)**. These assessments measured dissolved phosphorus, ammonia, nitrates, and nitrites.

4. Macro-benthic fauna identification

The macro-benthic fauna was collected using a Van Veen grab, which has a seabed opening area of 0.0288m². To anesthetize the organisms, each sample was submerged in a 10% formalin solution after being kept for four hours in a shallow white glass panel containing 7% magnesium chloride in the lab. Species identification was conducted using stereo and compound microscopes. Polychaete species were identified based on the works of **Müller (1771, 1776)**, **Blainville (1818)**, **Delle Chiaje (1827, 1828)**, **Örsted (1843)**, **Philippi (1844)**, **Mörch (1863)**, **Malmgren (1867)**, **Verrill (1873)** and **Horst**

(1924). Arthropod species were identified according to **da Costa (1778)**, **Fabricius (1787)**, **Weber (1795)**, **Fabricius (1798)**, **Herbst (1801)**, **Milne (1834, 1831)**, **de Haan (1835)** and **Costa (1853)**. Molluscan species were identified following **Linnaeus (1758)**, **Born (1778)**, **Gmelin (1791)**, **Olivier (1804)**, **Brocchi (1821)**, **Reeve (1845)**, **Valenciennes (1846)**, **Philippi (1846)** and **Krauss (1848)**. Holothurian species were identified through their dermal ossicles based on the studies of **Delle Chiaje (1824)** and **Selenka (1867)**.

5. Statistical analyses

5.1. Diversity indices

Using Past Program version 5, diversity indices, such as species richness, Shannon–Wiener, Simpson and evenness, were applied to data at specific sites.

a. Shannon–Wiener index (H′)

Following **Weber (1973)**, the Shannon–Wiener index of species diversity was applied using the following formula:

$$H' \sum (ni/N) \text{ lin2 } (ni/N)$$

Where, ni is the number of individuals of species, and the total number of individuals is denoted by N.

Medium pollution is indicated by a diversity index between 0 and 3, while pure water is indicated by a diversity value more than 3 **(Wilhm, 1972)**.

b. Species richness index or Margalef's diversity index (d)

Margalef's diversity index (d), often known as the species richness index was calculated as follows:

$$d = n\text{-}1 / \log N$$

A straightforward ratio between the total number of individuals (N) and the total number of species (n) was used to express it **(Margalef, 1958)**.

c. Evenness index (J)

Since S is the total number of species in each sample and H′max is the number of maximal theatric diversity, the evenness index (J) was calculated using the Shannon index:

$$J = H'/\ln(s)$$ **(Shannon & Wiener, 1963)**.

d. Simpson index

The dominance index, as described by **Simpson (1949)**, is calculated using the total squares of the species' proportions within a community. It is expressed with the formula:
$$C = \Sigma (ni / N)^2$$
In this formula, C is the dominance index; ni is the important value for each species, and N is the total importance value.

5.2. Correlation coefficient

Office Excel 2007 was used to conduct correlation coefficient analysis, illustrating the relationships between environmental factors and the dominant groups and species. Additionally, principal component analysis (PCA) was performed using the XL Stat Program 2019 to analyze the relationships between biological and environmental factors.

RESULTS

1. Physico-chemical parameters

Fig. (2) shows the average values of the chosen parameters over the lake and the Western Lagoon. In both summer and winter, Timsah Lake’s water temperatures in summer and winter (32.8 and 23.1°C, respectively) were greater than those recorded in the Western Lagoon (26.5 and 16.2°C, respectively); the hydrogen ion concentration (pH) varied due to seasons, ranging from 7 to 9.5. Conversely, there were no differences in the pH between the two investigated sites, except in summer during which it was slightly high alkaline in the Western Lagoon (8.1). Low water temperatures in the Western Lagoon ranged from 26.5°C in summer to 16.2°C in winter. In the Western Lagoon, dissolved oxygen exhibited substantial fluxing and depletion rates; it rose to 6.96mg/ l in spring after falling to 4.3mg/ l in autumn. The water coming from the Western Lagoon had a significant impact on DO at Timsah Lake, as it ranged from 5.32mg/ l in summer to 11.2mg/ l in spring. At any season the salinity of Lake Timsah was significantly higher than that of the Western Lagoon, sometimes was double or four times the salinity of the Western Lagoon. Phosphates values were higher in the Western Lagoon during summer and autumn than those recorded in Timsah Lake, while no differences were recorded in the rest of seasons. Notably, Timsah Lake and Western Lagoon had the highest ammonia averages (6.92 and 4.14µg/ l, respectively) in winter. Timsah Lake had its highest nitrates concentration in winter (14.1µg/ l), whereas the Western Lagoon recorded the highest value in autumn (14.9µg/ l). Moreover, Timsah Lake had the greatest average nitrites contents in the fall (4.54µg/ l), while the Western Lagoon had the highest value in the winter (1.59µg/ l). Furthermore, the Western Lagoon (3.96µg/ l) had the highest averages of dissolved phosphates over the autumn season and Timsah Lake (3.25lmol/ l) in winter (Fig. 2).

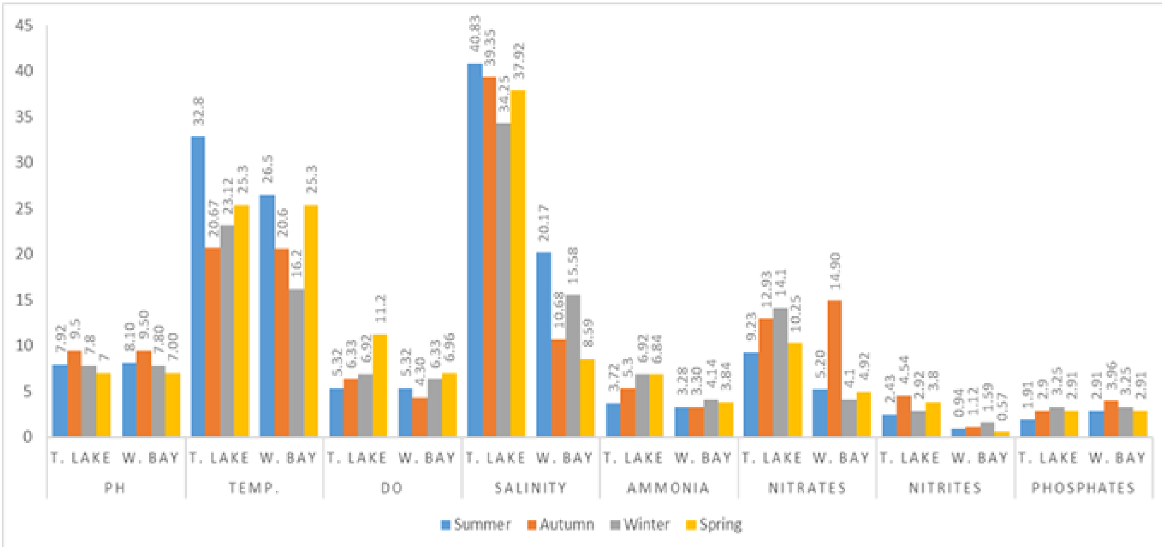

Fig. 2. Seasonal changes in the various stations' physico-chemical characteristics

2. Distribution patterns of macro-benthic fauna in the Western Lagoon and Timsah Lake

The 43 species that made up the macrobenthic invertebrates (MBI) were divided into six groups: the phylums Annelida (12 species and six families), Arthropoda (10 species and ten families), Mollusca (15 species and twelve families), Echinodermata (4 species and two families), Cnidaria (1 species and one family), and Chordate (tunicates) (1 species and one family). With an annual average of 22412 Org./m^2, the Arthropoda category was the most numerous, accounting for 48.23% of the total MBI. Mollusca, with an average of 17776 Org. /m^2, accounted for 38.25% of the total MBI. With an annual average of 4544 and 1491 Org. /m^2, respectively, Annelida and Chordata provided 9.78 and 3.21% of the total MBI. Cnidaria and Echinodermata recorded the lowest average density of the entire MBI, contributing 0.05 and 0.49% with an annual average of 23 and 277 Org./m^2, respectively (Table 1& Fig. 3).

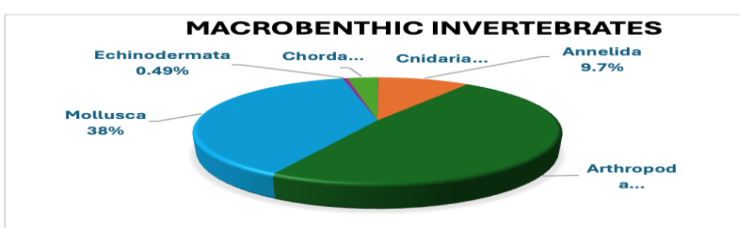

Fig. 3. The percentage (%) of macro-benthic invertebrate groupings

Table 1. List of the recorded species of MBI during this study

Phylum	Class	Family	Species
Cnidaria	Scyphozoa	Cassiopeidae	*Cassiopea* sp. **(Péron and Lesueur, 1809)**
Annelida	Polychaeta	Sabellida	*Dasychone lucullana* **Delle Chiaje (1828)**
		cirratulidae	*Chaetozone setosa* **Malmgren (1867)**
			Cirratulus cirratus **Müller (1776)**
		Terebellidae	*Amphitrite* sp. **Müller (1771)**
		Opheliidae	*Ophelina* sp. **Örsted (1843)**
		Serpulidae	*Spirobranchus* sp. **Blainville (1818)**
			Hydroides elegans **Haswell (1883)**
			Hydroides dianthes **Verrill (1873)**
			Hydroides dirampha **Mörch (1863)**
		Nereididae	*Vermilopsis infundibulum* **Philippi (1844)**
			Nereis (Neanthes) caudata **sensu Delle Chiaje (1827)**
			Nereis (Nereis)heteromorpha **Horst (1924)**
Arthropoda	Thecostraca	Balanidae	*Balanus* sp. **da Costa (1778)**
	Malacostraca	Maeridae	*Elasmopus rapax* **Costa (1853)**
		Sphaeromatidae	*Spheroma serratum* **Fabricius (1787)**
		Xanthidae	*Leptodius exaratus* **Milne (1834)**
		Majidae	*Schizophrys aspera* **Milne (1831)**
		Galenidae	*Halimede Tyche* **Herbst (1801)**
		Euryplacidae	*Eucrate crenata* **de Haan (1835)**
		Squillidae	*squilla* sp. **Fabricius (1787)**
		Portunidae	*Portunus* sp. **Weber (1795)**
		Penaeidae	*Penaeus* sp. **Fabricius (1798)**
Mollusca	Gastropoda	Turbinidae	*Turbo radiatus* **Gmelin (1791)**
		Ampullariidae	*Lanistes carinatus* **Olivier (1804)**
		Fasciolariidae	*Fusinus verrucosus* **Gmelin (1791)**
		Muricidae	*Rapana venosa* **Valenciennes (1858)**
		Planaxidae	*Planaxis sulcatus* **Born (1778)**
		Trochidae	*Trochus eritherus* **Brocchi (1821)**
		Patellidae	*Patella* sp. **Linnaeus (1758)**
	Bivalvia	Veneridae	*Paphia undulata* **Born (1778)**
			Venerupis aurea **Gmelin (1791)**
			Ruditapes decussata **Linnaeus (1758)**
		Mactroidea	*Mactra olorina* **philippi (1846)**
		Cardiidae	*Cerastoderma lamarkii* **Reeve (1845)**
		Mytilidae	*Modiolus auriculatus* **Krauss (1848)**
			Brachydontes variabilis **Krauss (1848)**
		Pectinidae	*chlamys squamosa* **Gmelin (1791)**
Echinodermata	Holothuroidea	Astropectinidae	*Astropectin* sp. **Gray (1840)**
		Holothuriidae	*Holothuria nobilis* **Selenka (1867)**
			Holothuria poli **Delle Chiaje (1824)**
			Holothuria princeps **Selenka (1867)**
Chordata	Ascidiacea	Cionidae	*Ciona* sp. **Fleming (1822)**

3. Geographical range of the identified MBI species

In the sites under study, the spatial distribution of MBI differed significantly. Timsah Lake had higher number (41) of species than the Western Lagoon (20). Remarkably, Timsah Lake had the greatest number of MBI individuals (40275 ind./m2), while the Western Lagoon had the lowest number (6198 ind./m2) (Table 2).

Table 2. Spatial distribution of the recorded MBI individuals

Species	Inside Timsah Lake (site 1)	Western Lagoon (site 2)
Dasychone lucullana	50	0
Chaetozone setosa	83	25
***Amphitrite* sp.**	240	9
***Ophelina* sp.**	325	0
***Spirobranchus* sp.**	118	0
Hydroides elegans	921	0
Hydroides dianthes	289	0
Hydroides dirampha	133	0
***Vermilopsis* sp.**	1675	0
Cirratulus cirratus	397	0
Nereis (Neanthes) caudata	179	0
Nereis (Nereis) heteromorpha	100	0
Thias* sp. *(Turbo radiatus)	818	0
Lanistes carinatus	530	707
Fusinus verrucosus	35	0
Rapana venosa	61	0
Planaxis sulcatus	225	0
Trochus eritherus	293	0
***Patella* sp.**	61	78
Paphia undulata	1414	96
Venerupis aurea	2764	760
Ruditapes decussata	0	1259
Mactra olorina	679	0
Cerastoderma lamarkii	1366	640
Modiolus auriculatus	2194	0
Brachydontes variabilis	7484	933
chlamys squamosa	15	0
***Balanus* sp.**	3922	689
Elasmopus rapax	1012	0
Spheroma serratum	11221	0
Leptodius exaratus	250	101
Schizophrys aspera	32	0
Halimede Tyche	74	34
Eucrate crenata	18	9

***squilla* sp.**	64	29
***Portunus* sp.**	66	43
***Penaeus* sp.**	115	97
***Cassiopia* sp.**	15	8
***Astropectin* sp.**	40	29
Holothuria nobilis	98	0
Holothuria poli	0	59
Holothuria princeps	1	0
***ciona* sp.**	898	593
Total MBI	**40275**	**6198**
Species number	**41**	**20**

4. Seasonal variation of total macrobenthic invertebrates (MBI)

Summer witnessed the highest average density of total MBI (7132 Org./m^2), whereas spring had the lowest average (4769 Org./m^2) (Table 3 & Fig. 4). According to MBI, Timsah Lake displayed the highest seasonal density in the summer (12579 Org./m^2), while the Western Lagoon showed the highest in the winter (1862 Org./m^2). Timsah Lake had the highest average yearly density (10068 Org./m^2) according to MBI, while the Western Lagoon recorded the lowest figure (1549 Org./m^2).

Table 3. Distribution and seasonal variation of total macrobenthic invertebrates (Org./m^2) in fields of study

Season / Location	Summer	Autumn	Winter	Spring	Average
1) Inside Timsah Lake	12579	8598	10896	8202	**10068**
2) Western Lagoon	1686	1313	1862	1337	**1549**
Average	**7132**	**4955**	**6379**	**4769**	**5809**

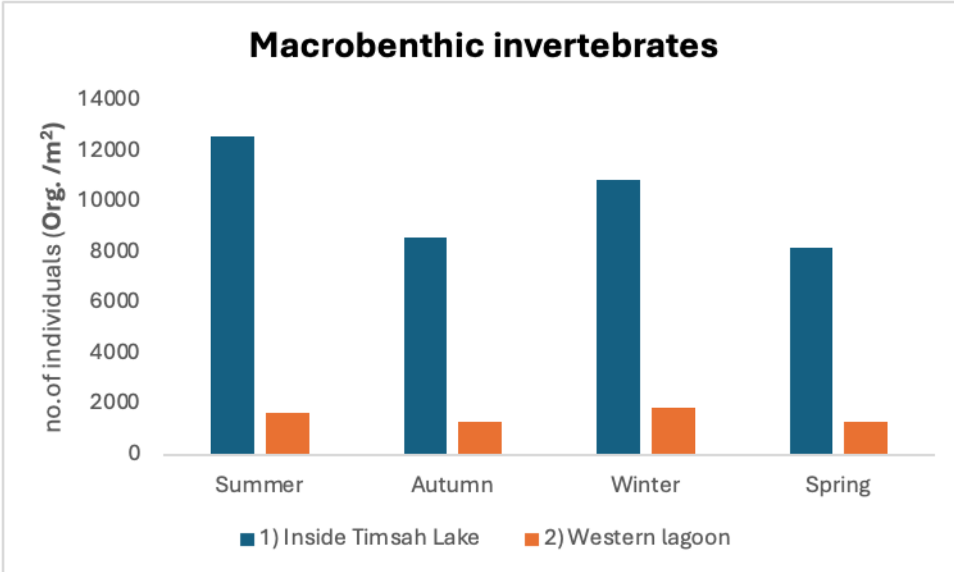

Fig. 4. Macrobenthic invertebrates (ind. /m^2) in the two study areas of Timsah Lake

5. Biological quality indicators, spatial variation, and descriptive analysis

Diversity indices were calculated based on the species, total number, seasons, and collecting sites of macrobenthic invertebrates. Site 1 (Timsah Lake) had the greatest richness index (Dominance) value (0.19) during summer, followed by sites 1 and 2 (Western Lagoon) in spring (0.175 and 0.176, respectively). Site 1 had the lowest value for the evenness index (0.125) in winter. During summer, Site 1 also recorded its lowest evenness index (0.27), while the maximum values were found at Site 2, with scores of 0.597 in summer and 0.594 in fall. Site 2 had the lowest evenness indices of 0.86 in spring and 0.6 in winter. For the Shannon diversity index, Site 1 recorded the highest value (2.55) in winter, while Site 2 depicted the lowest value (1.8) in spring. In winter, Site 1 achieved the highest Simpson index value (0.87), whereas it had the lowest value (0.8) in summer. According to data in Table (4), the equitability index was at its highest value at Site 2 in spring (0.93) and the lowest was recorded at Site 1 in summer (0.6).

Table 4. Macrobenthic invertebrates' data-based diversity indices between locations

Diversity indices	site 1 Summer	site 1 Autumn	site 1 Winter	site 1 Spring	site 2 Summer	site 2 Autumn	site 2 Winter	site 2 Spring
Taxa_S	39	27	29	19	14	15	14	7
Individuals	12579	8598	10896	8202	1686	1313	1862	1337
Dominance_D	0.1911	0.1275	0.1256	0.1754	0.1465	0.136	0.1447	0.1765
Simpson_1-D	0.8089	0.8725	0.8744	0.8246	0.8535	0.864	0.8553	0.8235
Shannon_H	2.367	2.438	2.548	2.13	2.124	2.188	2.134	1.802
Evenness_e^H/S	0.2736	0.4242	0.4407	0.443	0.5978	0.5943	0.6034	0.8662
Equitability_J	0.6462	0.7398	0.7567	0.7235	0.805	0.8078	0.8086	0.9262

6. **The principal component analysis (PCA) between studied sites and Macrobenthic invertebrates (MBI)**

Principal component analysis (PCA) was employed to compare macrobenthic invertebrates across the study sites and different seasons (Fig. 5). The most prevalent macrobenthic invertebrates, particularly Bivalvia and Crustacea, showed a substantial positive correlation (indicating they are aligned) with the two collection sites: Site 1 (Lake Timsah) and Site 2 (Western Lagoon) across all seasons. In contrast, there was a strong negative correlation with Polychaeta, Gastropoda, Echinodermata, and Chordata, which were located on the opposite side of the analysis.

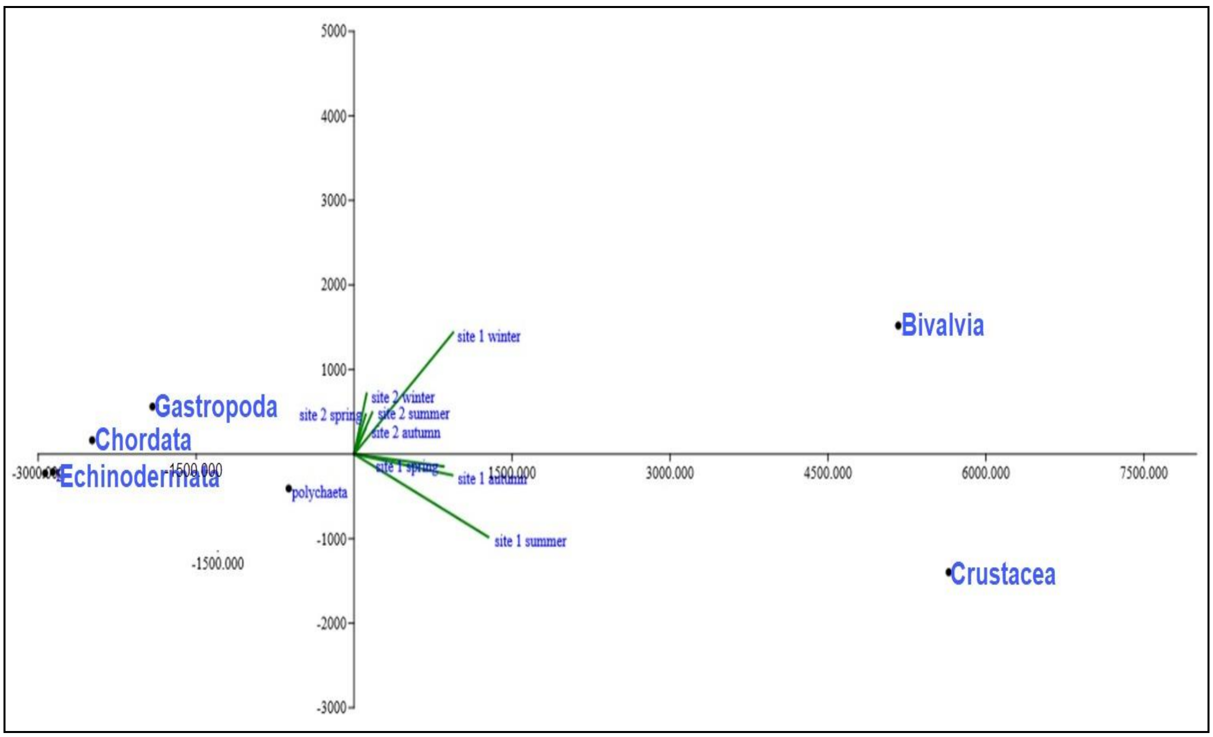

Fig. 5. The principal component analysis (PCA) diagram between macrobenthic invertebrates and sites during seasons

7. **The canonical correspondence (CCA) between studied sites, physico-chemical parameters and macrobenthic invertebrates (MBI)**

Canonical correspondence analysis (CCA) was conducted to examine the relationships between the studied sites across different seasons, macrobenthic invertebrates, and physicochemical characteristics (Fig. 6). At Site 1 (within Lake

Timsah), macrobenthic invertebrates such as Polychaeta, Cnidaria, and Crustacea exhibited a strong positive correlation with water temperature, nitrite, pH, dissolved oxygen, ammonia, and salinity during the summer, fall, and spring seasons. In contrast, there was a strong inverse relationship with Bivalvia, Gastropoda, Echinodermata, and Chordata, which were located on the opposite side of the analysis.

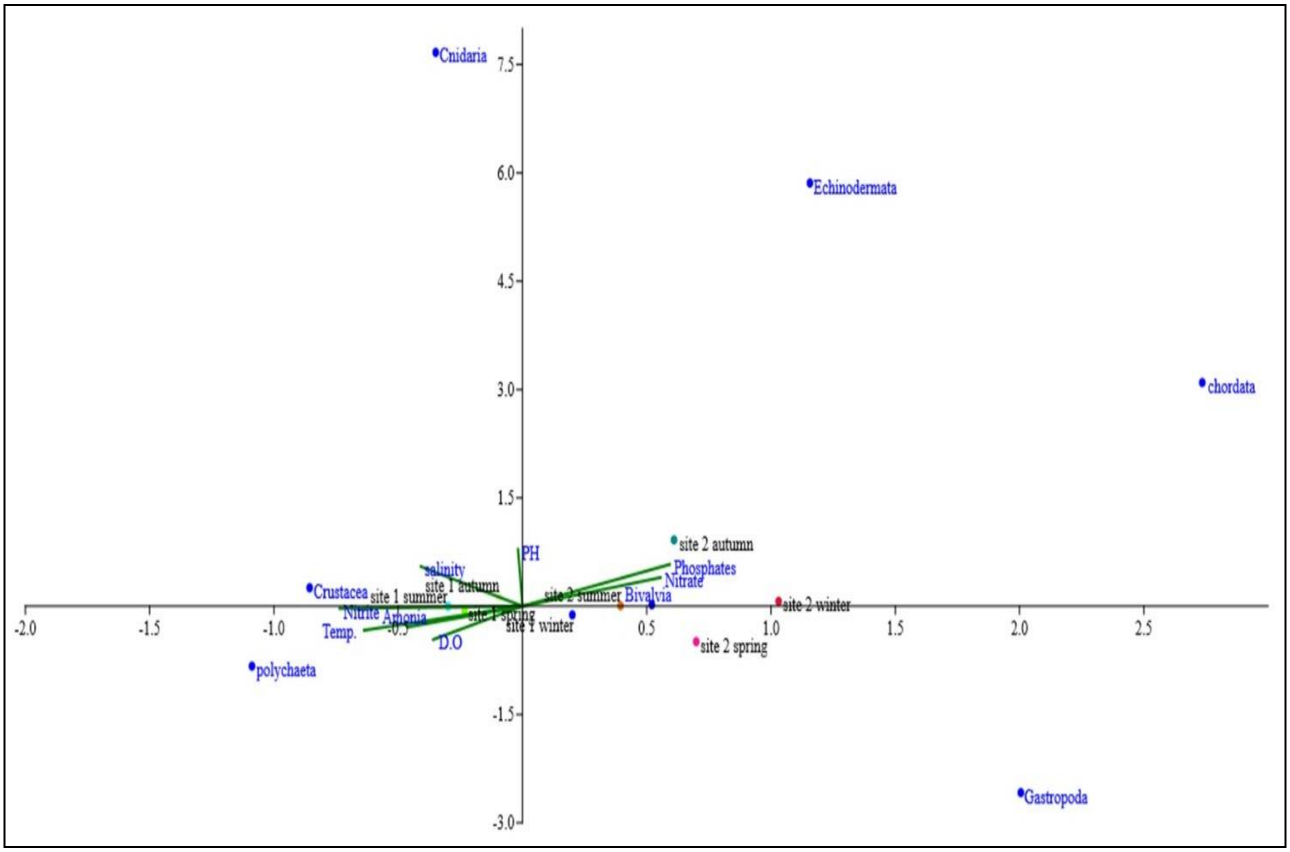

Fig. 6. The canonical correspondence analysis (CCA) diagram between macrobenthic invertebrates, physico-chemical parameters and sites during seasons

8. Similarity clustering index for macrobenthic invertebrates

Cluster analysis revealed the similarity clustering index across stations based on the distribution of macro-benthic invertebrates in the sites under study throughout the various seasons (Table 5 & Fig. 7). In spring and winter, site 1 showed the most resemblance (74.29%). Furthermore, site 1 showed high similarity in both the spring and summer seasons according to cluster analysis, which could be explained by its proximity to other sites. The lowest similarity index, however, was found between Site 1 in summer and Site 2 in autumn.

Table 5. Similarity clustering index (%) across the two studied stations based on the distribution of macro-benthic invertebrates throughout the four seasons

Season / Site	site 1 summer	site 1 autumn	site 1 winter	site 1 spring	site 2 summer	site 2 autumn	site 2 winter	site 2 spring
site 1 summer	100.00%	54.67%	71.30%	71.53%	18.28%	12.09%	13.09%	13.12%
site 1 autumn	54.67%	100.00%	61.72%	63.38%	23.40%	19.98%	24.24%	20.98%
site 1 winter	71.30%	61.72%	100.00%	74.29%	19.09%	14.53%	20.33%	16.53%
site 1 spring	71.53%	63.38%	74.29%	100.00%	17.44%	14.21%	15.60%	17.02%
site 2 summer	18.28%	23.40%	19.09%	17.44%	100.00%	61.22%	60.15%	69.34%
site 2 autumn	12.09%	19.98%	14.53%	14.21%	61.22%	100.00%	61.86%	59.25%
site 2 winter	13.09%	24.24%	20.33%	15.60%	60.15%	61.86%	100.00%	68.02%
site 2 spring	13.12%	20.98%	16.53%	17.02%	69.34%	59.25%	68.02%	100.00%

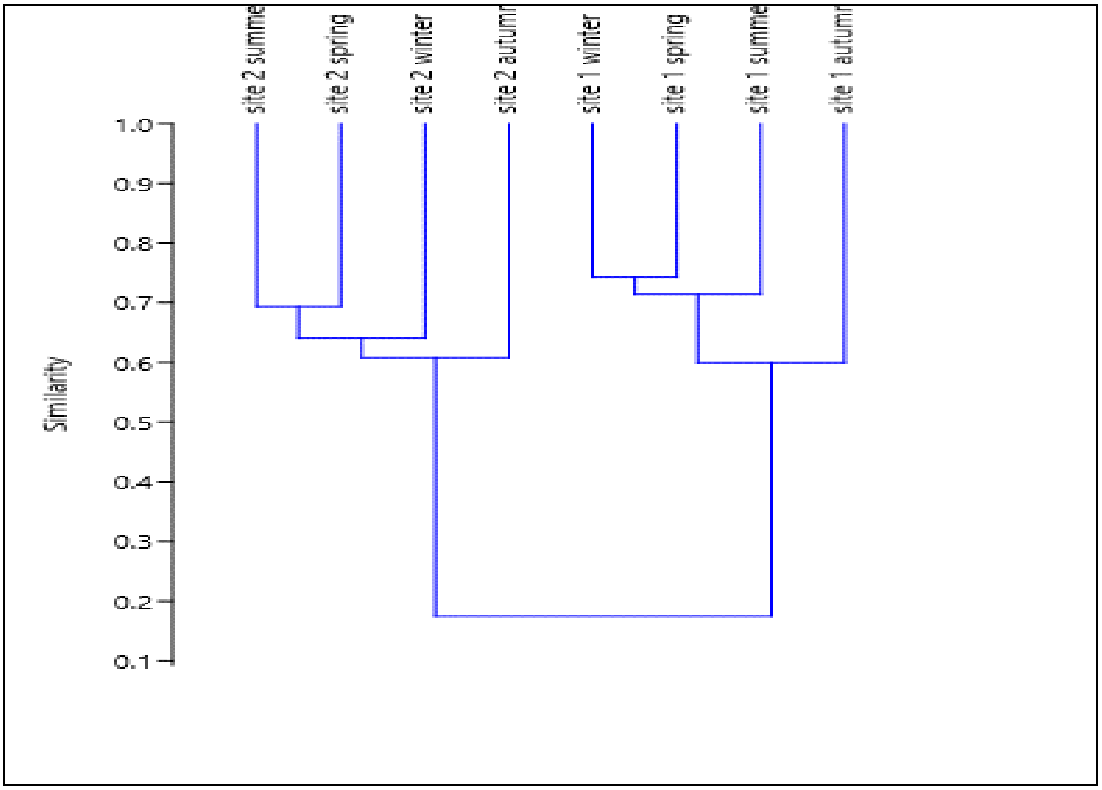

Fig. 7. Similarity clustering index between sites sampled based on data of macrobenthic invertebrates

DISCUSSION

Evaluating the variety and quantity of studying invertebrates is a crucial method for gaining insight into overall health and oversee the condition and operational state of specific ecosystems **(Kumar *et al.*, 2023)**. The biodiversity of macroinvertebrates in Timsah Lake and the Western Lagoon, as well as how they react to the aquatic environment throughout the year, were made clear in this study. The kind of substrate that macroinvertebrate populations live on and physical disruption have a big impact on them **(Liu *et al*., 2022)**. Prior research has shown that the aquatic setting is affected by many natural factors, with water temperature playing a crucial role in impacting the physical and chemical characteristics of water bodies and the organisms living in them **(Yan *et al.*, 2017)**. Temperature and pH are critical factors for aquatic ecosystems because they affect both organisms and the chemical and physical properties of water **(WHO, 2003)**. In this study, the physicochemical characteristics of water in Lake Timsah and the Western Lagoon were assessed to evaluate water quality. The water temperature showed an appropriate seasonal variation, consistent with the findings of **El-Enany (2009)**, who noted that changes in water temperature align with air temperature fluctuations. In the Western Lagoon, temperature displayed a wide range, and the shallow depth combined with high turbidity levels could lead to the loss of sensitive benthic species. Furthermore, thermal stress may result in systemic hypoxemia, as noted by **Belal *et al*. (2016)**.

Timsah Lake and the Western Lagoon had pH values ranging from 7 to 9.5; Timsah Lake had the lowest pH value and the Western Lagoon had the highest. According to **Hassanin (2006)**, the Western Lagoon station's poor productivity of macrobenthic invertebrates can be explained by relatively lower pH values, which may indicate the lake's lowered production as a result of the polluted water dumped into the lake.

The highest salinity value recorded during the summer season was 40‰, likely due to the high evaporation rate of water. In contrast, the lowest salinity value was observed in spring in the Western Lagoon, where it measured 8.59‰, attributable to freshwater discharge from agricultural drainage and sewage. **Bahgat (2011)** noted that the salinity range in Timsah Lake (40 to 34‰) was significantly higher than that of the Western Lagoon (20 to 8.59‰). This difference is primarily due to the continuous inflow of various drains, including the Abu Gamous Drain and the El-Mahsama Drain, as mentioned by **Saad El-Din *et al.* (2013)**. According to **Gray *et al*. (2002)**, aspects of metabolism are impacted at dissolved oxygen levels between 4 and 2mg L^{-1}, while growth is impacted from 6.0 to 4.5mg L^{-1}. Dissolved oxygen levels below 6mg L^{-1} are appropriate for stress in the majority of species. According to the **USEPA (1999)**, Timsah Lake and the Western Lagoon typically have oxygen levels between 5 and 10mg/ L, indicating healthy water quality. However, in autumn, the Western Lagoon recorded its lowest oxygen level of 4.3mg/ L. This low dissolved oxygen content in autumn was likely due to a high rate of organic matter decomposition, suggesting significant pollution in the water **(Mocuba, 2010)**. Ammonium is a crucial type of inorganic nitrogen. **Meade (1985)** established that the maximum tolerable level is 0.1mg/ l of NH3-N. In this study, Timsah Lake exhibited the highest average value (5.69 µg/l) while the Western Lagoon showed the lowest average value (3.64µg/ l). A notable difference in ammonia levels was observed, with the lowest recorded level of 3.3µg/ L occurring in autumn in the Western Lagoon. This decrease is likely due to phytoplankton uptake of NH_4. However, the rise in NH_4 levels could be attributed to the conversion of NO_3 into NH_4 through denitrification, a process supported by **Seitzniger (1988)**. Because of the enormous volume of drainage water entering the lake and the decrease in nitrite uptake by phytoplankton, the nitrite levels were higher in autumn than in the other seasons. Small fluctuations in nitrite levels were seen during the remaining seasons, possibly due to the conversion of NO_2 to ammonia in anaerobic settings. The increase in NH_4 was detected alongside lower nitrite levels, which can be attributed to this phenomenon **(Wetzel, 2001)**. The elevated mean NO_3 levels in autumn (13.9µg/ l) could be ascribed to the breakdown of organic material and significant volumes of drainage water. However, the decrease in values in summer (7.2µg/ l) was mainly caused by absorption by phytoplankton and aquatic plants, an explanation which is supported by **Al-Yamani (2006)**, **Abdo (2010)** and **El-Sherbiny (2011)**.

Riley and Chester (1971) stated the crucial role of phosphorus in regulating aquatic organisms' development and reproduction. Phytoplankton generally prefers inorganic phosphorus over organic phosphorus, even though many organisms rely on both forms for survival. This study revealed that the values of reactive phosphate were significantly increased during autumn, and according to this study, reactive phosphate levels increased dramatically in the fall and winter, which may have been caused by drainage water that was enriched with phosphorous compounds. However, based on the rising consumption by phytoplankton, the mentioned parameter shows a large drop during the summer and spring seasons, with average values of 2.4 and 2.9µg/ l, respectively. **Khalil *et al*. (2014)** suggested that the breakdown of organic residues may be the cause of the summer's reduced total phosphorous concentration.

Spatial distribution of MBI was greatly varied at the study sites. Timsah Lake showed the most variable species dominance with 41 species, while the minimum with 20 species was recorded in the Western Lagoon. The highest number of MBI individuals (40275 ind./m^2) was recorded inside Timsah Lake and the lowest number (6198 ind.) was recorded in the Western Lagoon. These findings agree with the findings of **Belal *et al*. (2016)**, who stated that the majority of stations near the drainage outlets in the Western Lagoon had either very few or no recorded species present in Timsah Lake, due to significant fluctuations in certain local conditions across different seasons. **Belal *et al*. (2016)** also mentioned that Timsah lake had greater diversities than the Western Lagoon because of the strong flow of water toward the lake and the presence of the Suez Canal, which reduces the impact of the muddy, oxygen-deprived, and low oxygen level sediments. According to the current results the highest density of MBI in Timsah Lake was recorded during the summer season than the winter season, while the highest density in the Western Lagoon was recorded in winter season. According to **Veiga *et al*. (2016)** and **Chen *et al*. (2018)**, macroinvertebrates being ectothermic animals display varying ideal temperatures for growth. In an appropriate temperature range, breeding and growth rates typically rise, while lower temperatures can lead to inhibited or halted growth **(Wang *et al*., 2021)**. The winter's high value may be due to samples being collected in the last month of the season, making the temperature ideal for breeding and growth.

Biodiversity is essential to aquatic ecosystems due to the diverse roles that different species play within the community. Consequently, a reduction in species abundance is determined as a decline in biodiversity, particularly in polluted environments, leading to habitat destruction. Recent findings from biological monitoring indicate the presence of 42 aquatic macroinvertebrate species across 36 genera and 8 classes (including Scyphozoa, Polychaeta, Thecostraca, Malacostraca, Bivalvia, Gastropoda, Holothuroidea, and Ascidiacea).

Arthropods were the most common group, with a density of 22,412 individuals per square meter. The highest average was recorded in Timsah Lake, reaching 4,193 individuals per square meter. Aquatic arthropods, particularly the genus *Spheroma*, comprised 48.23% of the total fauna. According to **Abdelhamid and El-Ayouty (1991)**, the isopod *S. serratum* is known for its high tolerance to dry conditions and its ability to thrive in brackish water. **Gad El-Hak and Saad El-Din (2017)** suggested that the abundant presence of these species in Timsah Lake is likely due to the availability of ample food and nutrients, as well as the absence of competing species and predators.

Furthermore, the presence of families such as Neritidae, Viviparidae, Unionidae, Caenidae, and Atyidae during the summer months indicates good to excellent water quality, as noted by **Bendary and Hegab (2024)**.

S. serratum was the species with the highest number of individuals among all specimens collected in both areas of the lake. **Abdelhamid and El-Ayouty (1991)** stated that *Spheroma serratum* is highly tolerant to dry conditions and can also endure brackish water. According to **Saad El-Din and Gad El-Hak (2017)**, the high densities of *S. serratum* in the most polluted stations during the current study were attributed to the abundance of food and nutrients, as well as the absence of competitors and predators in those stations.

Throughout all seasons, the two collection sites—Lake Timsah and the Western Lagoon—exhibited a strong positive correlation (pointing in the same direction) with the most prevalent macrobenthic invertebrates, particularly Bivalvia and Crustacea. On the other hand, it had a strong inverse relationship with the opposite-side Polychaeta, Gastropods, Echinodermata, and Chordata. **Grall and Chauvaud (2002)** and **Savage *et***

***al*. (2002)** postulated that moderate organic enrichment leads to an enhancement in species richness, abundance, and biomass within the macro-benthic community structure. Nevertheless, an abundance of organic matter decreases the variety of species present, while raising the populations and quantities of a small number of adaptable species and their connected biomass. Using canonical correspondence analysis (CCA) demonstrated that seasonal changes in physico-chemical factors impact the presence of macroinvertebrates in the lake due to recreational activities in summer and disposal of untreated wastes from vessels and boats, as well as raw sewage and agricultural waste in specific areas as mentioned by **Kaiser *et al.* (2009)** and **Bahgat (2011)**. The results also revealed, through the use of the similarity clustering index, that the highest similarity was observed in Timsah Lake, reaching 74.29% during the spring and winter seasons. In contrast, Site 1 in summer and Site 2 in autumn exhibited the lowest similarity index.

CONCLUSION

To sum up, the results showed that the changes in the physico-chemical properties of Lake Timsah throughout the seasons can result in various macrobenthic fauna communities. Multivariate statistical analysis showed that in both Timsah Lake and the Western Lagoon, physical parameters had significant impacts on community distribution. Therefore, continually monitoring Lake Timsah's water is crucial to guaranteeing its safety for economic and touristic activities in lake.

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Declarations

Conflict of interest- I declare that the authors have no competing interests as defined by Applied Water Science, or other interests that might be perceived to influence the results and/or discussion reported in this paper.

REFERENCES

Abd EL Samie, S.G.; Hamza, M.S. and Hassan, H.B. (2008). 9th International Conference of Nuclear Sciences and Applications. 11–14 Feb 2008 Sharm El-Shiekh Sinai Egypt.

Abdelhamid, A.M. and El-Ayoty, S.A. (1991). Effect of catfish (Clarias lazera) composition of ingestion rearing water contaminated with lead or aluminum compounds. Arch. Anim. Nutr., Berlin, 41: 757 – 763.

Abdo, M.H.; Sabae, S.Z.; Haroon, B.M.; Refaat, B.M. and Mohammed, A.S. (2010). Physico-chemical characteristics, microbial assessment and antibiotic susceptibility of pathogenic bacteria of Ismailia canal water, river Nile, Egyptian Journal of Aquatic Science 6(5):234-50.

Abo-Zaid, G.M. (1990). Distribution of zooplankton in Lake Timsah with special reference to Copepoda, M. Sc. thesis, Fac. Sci. Suez Canal Univ. 96 pp.

Al-Yamani, F.; Subba Rao, D.V.; Mharzi, A.; Ismail, W. and Al-Rifaie, K. (2006). Primary production off Kuwait, an Arid zone environment, Arabian Gulf. International Journal of Oceans and Oceanography 1(1): 67-85.

APHA (2005). In Standard Methods for the Examination of Water and Wastewater. 21. American Public Health Association, Washington p. 1450.

Bahgat, M. (2011). Diversity of bacterial communities in contrasting aquatic environments: Lake Timsah. Egyptian Microbiology Insights (4):11–9.

Belal, A.A.M. and Ghobashy, A.F.A. (2012). Distribution of newly recorded benthic polychaetes in Timsah Lake, Suez Canal, Egypt. Egyptian Journal of Aquatic Biology& Fishers Research 38(3), pp. 171–184.

Belal, A.A.M.; El-Sawy, M.A. and Dar, M.A. (2016). The effect of water quality on the distribution of macro-benthic fauna in Western Lagoon and Timsah Lake, Egypt 1. Egyptian Journal of Aquatic Research 42, 437–448.

Bendary, R.E. and Hegab, M.H. (2024). Applying Diversity and Pollution Biotic Indices Based on Macroinvertebrates to Assess Water Quality of the Ismailia Canal, Egypt. Egyptian Journal of Aquatic Biology & Fisheries Zoology Department, Faculty of Science, Ain Shams University, Cairo, Egypt.ISSN 1110 – 6131Vol. 28(1): 1277 – 1291.

Born, I. Von. (1778). Index rerum naturalium Musei Cæsarei Vindobonensis. Pars I.ma. Testacea. Verzeichniß der natürlichen Seltenheiten des k. k. Naturalien Cabinets zu Wien. Erster Theil. Schalthiere. [1-40], 1-458, [1-82]. Vindobonae [Vienna]; (Kraus) page(s): 251-252.

Cendrero, A.; Luis, M. Forte; Juan Remondo and Juan A. Cuesta-Albertos (2020). Anthropocene Geomorphic Change. Climate orHuman Activities?. Earth's Future: Volume 8, Issue 5.

Chen, J.; Hu, D.; Zhang, C. and Ding, Z. (2018). Temporal and spatial changes of macrobenthos community in the regions frequently occurring black water aggregation in Lake Taihu. Sci. Rep. p. 5712.

Costa, A. (1853). Relazione sulla memoria del Dottor Achille Costa, di Ricerche su' Crostacei Amfipodi del Regno di Napoli. Rendiconti della Societa Reale Borbonica, Accademia delle Scienze, new series. 2, 167-178.

Da Costa, E.M. (1778). Historia naturalistestaceorum Britanniæ, or, the British conchology; containing the descriptions and other particulars of natural history of the shells of Great Britain and Ireland: illustrated with figures. In English and French. - Historia naturalis testaceorum Britanniæ, ou, la conchologie Britannique; contenant les descriptions & autres particularités d'histoirenaturelle des coquilles de la Grande Bretagne & de l'Irlande: avec figures en taille douce. En anglois & françois. i-xii, 1-254, i-vii, [1], Pl. I-XVII. London. (Millan, White, Emsley & Robson), available online at https://www.biodiversitylibrary.org/page/13116783 page(s): 210-211.

Dar, M.A.; Belal, A.A. and Madkour, A.G. (2018). The differential abilities of some molluscs to accumulate heavy metals within their shells in the Timsah and the Great Bitter lakes, Suez Canal, Egypt. Egyptian Journal of Aquatic ResearchThis link is disabled 44(4), pp. 291–298.

De Haan, W. (1833–1850). Crustacea. In: von Siebold, P.F., Fauna Japonica sive Descriptio Animalium, quae in Itinere per Japoniam, Jussu et Auspiciis Superiorum, qui Summum in India Batava Imperium Tenent, Suspecto, Annis 1823-1830 Collegit, Notis, Observationibus et Adumbrationibus Illustravit. i–xxxi, ix–xvi, 1–243, pls. A–J, L–Q, 1–55. Lugduni-Batavorum. [Dates of publication per Holthuis, 1953: 1833 (ix–xvi, De Haan's "Praemissa" & "Expositio"; 1–24, pls. 1–8, A, B, circ. 2), 1835 (25–64, pls. 9–15, 17, C, D), 1837 (65–72, pls. 16, 18–24, E, F), 1839 (73–108, pls. 25–32, G, H), 1841 (109–164, pls. 33–37, 39–42, 47), 1844 (pls. 38, 43–46, 48, 51–55, I–N), 1849 (165–196, 197–243, pls. 49, 50 O–Q), 1849 (i–xxxi, De Haan's "Praefatio"), 1850 (vii–xvii, Von Siebold's "Commentatio")).

Donohue, I.; McGarrigle, M.L. and Mills, P. (2006). Linking catchment characteristics and water chemistry with the ecological status of Irish rivers. Water Res. 40:91-98.

EL Damhougy, K.A.; El-Naggar, H.A.; Aly-Eldeen, M.A. and Abdella, M.H. (2019). Zooplankton groups in Lake Timsah, Suez Canal, Egypt. Egyptian Journal of Aquatic Biology& Fishers Zoology Department, Faculty of Science, Ain Shams University, Cairo, Egypt. ISSN 1110-6131, Vol.23(2): 303 – 316.

El-Enany, H.R. (2009). Ecological studies on planktonic and epiphytic microinvertebrates in Lake Nasser, Egypt. PhD thesis, Zoology Department, Faculty Science, Benha University.

El-Sherbiny, M.M.; Al-Aidaroos, M.A. and Gab-Alla, A. (2011). Seasonal composition and population density of zooplankton in Lake Timsah, Suez Canal, Egypt. Oceanologia 53(3):837–859.

Emara, A.M. and Belal, A.A. (2004) Marine fouling in Suez Canal, Egypt. J. Aquat. Res., 30 (A), 189–206.

Fabricius, J.C. (1787). Mantissa Insectorum Sistens Eorum Species Nuper Detectas Adjectis Characteribus Genericis Differentiis Specificis, Emendationibus, Observationibus. Tome I. Hafniae: Christ. Gottl. Proft. xvi + 348 pp.

Fabricius, J.C. (1798). Supplementum Entomologiae Systematicae. Hafniae: Proft et Storck: 1-572: 404.

Fleming, J. (1822). The philosophy of zoology: or a general view of the structure, functions and classification of animals. Edinburgh Vol. 2: 1-618: 512.

Gabr, H.R. and Gab-alla, A. (2008). Effect of transplantation on heavy metal concentrations in commercial clams of Lake Timsah, Suez Canal, Egypt. Oceanologia 50 (1): 83-93.

Gmelin, J. F. (1791). Vermes. In: Gmelin J.F. (Ed.) Caroli a Linnaei Systema Naturae per Regna Tria Naturae, Ed. 13. Tome 1(6). G.E. Beer, Lipsiae [Leipzig]. pp. 3021-3910. Systema Naturae. Linneaeus (ed.). Ed. 13. 1: pars. 6., available online at http://www.biodiversitylibrary.org/item/83098#5 page(s): 3289.

Grall, J. and Chauvaud, L. (2002). Marine eutrophication and benthos: the need for new approaches and concepts. Glob. Change Biol. 8: 813–830.

Gray, J.E. (1840). XXXII. A synopsis of the genera and species of the class Hypostoma (Asterias, Linnaeus). Annals of the Magazine of Natural History 6: 275-290.

Gray, J.S.; Wu, R.S. and Or, Y.Y. (2002). Effects of hypoxia and organic enrichment on thecoastal marine environment. Marine ecology- progress series. 238: 249-279.

Hassanin, M.F. (2006). Microbiological diversity studies on certain locations of the River Nile. M.Sc. Thesis, Botany Department, Faculty of Science, Al Azhar University.

Horst, R. (1924). Polychaeta errantia of the SibogaExpedition. Pt. 3. Nereidae and Hesionidae. Siboga-Expeditie Uitkomsten op Zoologisch, Bonatisch, Oceanographisch en Geologischgebied verzameld in Nederlandsch Oost-Indië 1899-1900, 24(1c): 145-198. page(s): 151-152, plate XXX figs. 6-7.

Hussain, Q.A. (2011). An Ecological Study of Doodhganga and its Drainage Basin—A Lotic System of Kashmir. PhD. Thesis, P. G. Department of Environmental Science, University of Kashmir, Srinagar.

Hynes, H.B.N. (1970). The Ecology of Running Waters. Liverpool University Press, England p. 555.

Jimoh, A.A.; Clarke, E.O.; Whenu, O.O. and Adeoye, H.B. (2011). Food and feeding habits of the African river prawn (Macrobrachium vollenhovenii, Herklots, 1857) in Epe Lagoon, Southwest Nigeria. Int. J. Fish. Aquacul. 3(1):10-15.

Joshi, P.C.; Negi, R.K. and Negi, T. (2007). Seasonal variations in benthic macroinvertebrates and their correlation with the environmental variables in a freshwater stream in Garhwal Region (India). Life Sci. J. 4(4):85-89.

Kaiser, M.F.; Amin, A.S. and Aboulela, H.A. (2009). Environmental hazards in the El-Timsah Lake, Suez Canal District, Egypt, Advances in Geoscience and Remote Sensing, Gary Jedlovec (Ed.).

Khalil, M.A.; Beltagy, E.A.; ELShouny, W.; EL-naga, E.H.A.; ELshenawy, M.A. and kelany, M.S. (2014). Seasonal Bacteriological and Physico-Chemical

Analysis of Lake Timsah, Ismailia, Egypt. Life Science Journal 2014; 11(10) http://www.lifesciencesite.com.

Krauss, F. (1848) Die Südafrikanischen Mollusken. Ein Beitrag zur Kenntniss der Mollusken des Kap- und Natallandes und zurGeographischen Verbreitung derselben mitBeschreibung und Abbildung der neuenArten. Ebner and Seubert, Stuttgart, 140 pp., 6 pls.

Kumar, R.; Horwitz, P. and Finlayson, C.M. (2023). Wetlands as social–ecological systems: Bridging nature and society. In Ramsar Wetlands pp. 525-553. Elsevier.

LeCraw, R. and Mackreth, R. (2010). Sources of small-scale variation in the invertebrate communities of headwater streams. Freshwater Biol. 55:1219-1233.

Linnaeus, C. (1758) Systema Naturae per regna tria naturae, secundum classes, ordines, genera, species, cum characteribus,differentiis, synonymis, locis. Editio decima, reformata, Laurentius Salvius, Holmiae, 824pp.

Liu, Y.; Tian, Y.; Gao, Y.; Cui, D.; Zhang, W.; Jiao, Z.; Yao, F.; Zhang, Z. and Yang, H. (2022). The impacts of different anthropogenic disturbances on macroinvertebrate community structure and functional traits of glacier-fed streams in the Tianshan Mountains Water, 14:1298.

Madkour, F.; Amer, A.M. and El-Sherbiny, M.M. (2006). Assessment of Eutrophication In Lake Timsah,Suez Canal, Egypt. Egyptian Journal of Aquatic Research ISSN: 1687-4285vol. 32, special issue: 259-272.

Margalef, R. (1958). Information theory in ecology. Gen.Syst. 3:36–71.

Meade, J.W. (1985). Allowable Ammonia for Fish Culture. The Progressive Fish-Culturist: Vol. 47, Issue 3: 135-201.

Milne Edwards, H. (1832). Observations sur les Crustacés du genre Mithrax. *Magasin de Zoologie.* 2(7): 1-16, pls. 1-5.

Milne Edwards, H. (1834-1840). Histoire Naturelle des Crustacés, Comprenant l´Anatomie, la Physiologie et la Classification de ces Animaux. Encyclopédique Roret, Paris; vol I (1834): i-xxxv + 1-468, vol. II (1837): 1-532, vol. III (1840): 1-638, pls. 1–42. Paris, Roret. 2: Text pp. 1–532; Atlas, pp. 1–32, pls. 1–42.

Mohammad, S.H.; Belal, A.A. and El-Agroudy, N.A. (2009). A study on cerastoderma glaucum (Bruguie` re, 1789) As a biomonitor aspect of oil pollution in Lake Timsah, Suez Canal, Egypt. Egyptian Soc. Environ. Sci. 4 (1):21–30. CATRINA.

Mohammed, S.H.; Belal A.A. and Hassan, S.S. (2014). Growth, age and reproduction of the commercially clams Venerupis aurea and Ruditapes decussatus in Timsah Lake, Suez Canal, Egypt. Indian J. Geo Mar. Sci. 43(4):589–600.

Mourad, F.A. (1996). M. Sc. thesis, Suez Canal Univ., Ismailia, Egypt.

Mucoba, J.J. (2010). Dissolved oxygen and biochemical oxygen demand in the waters close to the Quelimane sewage discharge. Master thesis inChemical Oceanography NOMA. University ofBergen Norway.

Müller, O.F. (1771). Von Würmern des süssen und salzigen Wassers. 1-200. H. Mumme and Faber. Copenhagen., available online at https://www.biodiversitylibrary.org/page/14389400 page(s):188.

Müller, O.F. (1776) Zoologicae Danicae Prodromus, seu Animalium Daniae et Norvegiae indigenarum characteres, nomina etsynonyma imprimis popularium. Hallageriis. Havniae [Copenhagen], i-xxxii, 1–282.

Péron, F. and Lesueur, C.A. (1810). Tableau des caractères génériques et spécifiques de toutes les espèces de méduses connues jusqu'à ce jour. Annales du Muséum national d'histoire naturelle de Paris. 14: 325-366, p.356.

Philippi, R.A. (1844). Enumeratio molluscorum Siciliae cum viventium tum in tellure tertiaria fossilium, quae in itinere suo observavit. Vol. 2 Halle [Halis Saxorum]: Eduard Anton. iv + 303 pp., pls 13-28.

Philippi, R.A. (1845-1847). Abbildungen und Beschreibungen neuer oder wenig gekannter Conchylien. Zweiter Band. 2. Cassel: Fischer. 1-231, pls. 1-48. (publ. dates: (1): 1-32 [Sep 1845]; (2): 33-63 [Oct 1845]; (3): 65-87 [Feb 1846]; (4): 89-121 [Aug 1846]; (5): 123-152 [Oct 1846]; (6): 153-182 [Feb 1847]; (7): 183-212 [Mar 1847]; (8): 213-231 [Apr 1847]):72, pl. 2 fig. 2.

Reeve, L.A. (1844-1845). Monograph of the genus Mitra. In: Conchologia Iconica, or, illustrations of the shells of molluscousanimals, vol. 2, pl. 1-39 and unpaginated text. L. Reeve & Co., London. [stated dates: pl. 1-7, August 1844; pl. 8-15, September 1844; pl. 16-19, October 1844; pl. 20-23, November 1844; pl. 24-27, December 1844; pl. 28-29, January 1845; pl. 30 imprinted March 1844, presumably March 1845; pl. 31-39, March 1845].

Riley, J.P. and Chester, R. (1971). Introduction to marine chemistry. Academic Press, London and New York p. 465.

Saad El-Din, M.; Gaber, A.; Koch, M.; Ahmed, R.S. and Bahgat, I. (2013). Remote sensing application for water quality assessment in Lake Timsah, Suez Canal, Egypt. J. Remote Sens. Technol. 1 (3):61–74.

Saad El-Din, M.I. and Gad EL-Hak, H.N. (2017). Impact of heavy metals concentration on spring abundance of aquatic macro-invertebrates inhabiting in Lake Timsah, Egypt. Journal of Water Security, Vol. 3:1-6.

Savage, C.; Elmgren, R. and Larsson, U. (2002). Effects of sewage-derived nutrients on an estuarine macrobenthic community. Mar.Ecol.Prog. Ser. 243:67–82.

Seitzniger, S.P. (1988). Denitrification in freshwater and coastal marine ecosystem: Ecological and Geochemical significance. Limnology Oceanography. 33:702-24.

Selenka, E. (1867). Beiträge zur Anatomie und Systematik der Holothurien. Zeitschrift für wissenschaftliche Zoologie. 17(2): 291-374, pls. XVII-XX.

Shannon, G.E. and Wiener, W.W. (1963). The Mathematical Theory of Communities-Urbana. University of Illinois Press, Illinois, p. 117.

Simpson, E.H. (1949). Measurement of diversity. Nature 163:688 Sipaúba-Tavares LH, Millan RN, Santeiro RM (2010) Characterization of a plankton community in a fish farm. Acta Limnol Bras 22(1):60–69.

Sporka, F.; Vlek, H.E.; Bulankova, E. and Krno, I. (2006). Influence of seasonal variation on bioassessment of streams using macroinvertebrates. Hydrobiologia 566:543-555.

Subramanian, K.A.; Sivaramakrishnan, K.G. and Gadgil, M. (2005). Impact of riparian land use on stream insects of Kudremukh National Park, Karnataka state, India. J. Insect Sci. 5:49-59.

Sullivan, S.M.P.; Watzin, M.C. and Hession, W.C. (2004). Understanding stream geomorphic state in relation to ecological integrity: evidence using habitat assessments and macroinvertebrates. Environ. Manage 34(5):669-683.

UNEP (1996). Assessment of the State of Eutrophication in the Mediterranean Sea Map Technical Series No. 106. UNEP, Athens, p. 214.

UNESCO (1988). Eutrophication in the Mediterranean Sea Receiving Capacity and Monitoring of Long-term Effects, Athens (Greece), p. 200.

USEPA (1999). National recommended water quality criteria - correction - United State Environmental Protection Agency (EPA) 822- Z-99-001.

Uwem, G.U.; Ekanem P.A. and Eni, G. (2011). Food and feeding habits of Ophiocephalus obscura (African snakehead) in the Cross River estuary, Cross River State, Nigeria. Int. J. Fish. Aquacult 3(13):231-238.

Valenciennes, A. (1858). Note sur une suite intéressante de coquilles rapportées des mers du Japon, et de la Manche de Tartarie, par M. le Dr Barthe. Compte Rendu des Séances de l'Académie des Sciences. 46: 759-762, page(s): 761.

Veiga, P.; Torres, A.C.; Aneiros, F.; Sousa-Pinto, I.; Troncoso, J.S. and Rubal, M. (2016). Consistent patterns of variation in macrobenthic assemblages and environmental variables over multiple spatial scales using taxonomic and functional approaches. Mar. Environ. Res, 120, pp. 191-201.

Wang, Y.; Liu, J.; Li, B.; Liu, W.; Zuo, Y.; Kong, D. and Zhu, J. (2021). Relationships between characteristics of macrobenthic assemblages and environmental variables in the Heihe River Basin, China.Aqua-Water Infrastruct. Ecosyst. Soc, 70 (5), pp. 710-730.

Weber, C.I. (1973). Biological field and laboratory methods for measuring the quality of surface water and effluents. Environmental monitoring series, Office of Res. Devi. Useda, Cincinnati, Ohio.

Weber, F. (1795). Nomenclator entomologicus secundum Entomologiam systematicum ill. Fabricii adjectis speciebus recens detectis et varietatibus. i-viii, 1-171. Chilonii et Hamburgii.

Wetzel, R.G. (2001). Limnology Lake and Reservoir Ecosystems. Academic Press, San Diego, p.1006.

WHO (2003). World Health Organization. Guidelines for safe recreational water environments. Volume 1, coastal and fresh waters. Geneva, Switzerland.

Wilhm, J. (1972). Graphic and mathematical analysis of biotic communities in polluted streams. Ann Rev Entomol 17:223–252.

Winterbourn, M.J. (1999). Insect faunas of acidic coal mine drainages in Westland, New Zealand, New Zealand Entomologist, 21: 65-72.

Yan, J.; Xu, Y.; Sui, J.; Li, X.; Wang, H. and Zhang, B. (2017). Long-term variation of the macrobenthic community and its relationship with environmental factors in the Yangtze River estuary and its adjacent area. Mar. Pollut. Bull., 123 (1-2), pp. 339-348.