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Assessing the Biodiversity of Coastal Benthic Fauna Along the Eastern Side of the Gulf of Suez , Red Sea, Egypt

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ABSTRACT

This study investigated the benthic fauna in the eastern side of the Gulf of Suez and Suez Bay. The samples of macro-benthos living in the intertidal zone were collected from autumn 2019 to summer 2020. 57 different species were found with a density of 91,117 individuals per square meter. These macro-benthos belong to five main groups (phyla): bristle worms (polychaetes) were the most abundant with 18 species and 47,650 individuals/m^2, followed by mollusks (18 species, 22,299indiv./ m^2), crustaceans (14 species, 19,373indiv./ m^2), echinoderms (6 species, 945indiv./ m^2), and acorn worms (cephalochordates), with just 1 species and 850indiv./ m^2. Various water quality factors were examined in the current study to understand the environment where the macro-benthos under study live. This included measuring the acidity (pH), oxygen levels (DO), and the amount of organic material present (BOD and COD). The total dissolved solids (TDS) in the water was measured. Additionally, the grain size of the sediment on the bottom was analyzed and checked for the presence of heavy metals (copper, lead, zinc) in both the water and sediment.Higher concentrations of zinc were detected compared to lead and copper in the surface water, while the opposite was true for the sediments. Finally, the levels of total petroleum hydrocarbons (TPHs) and nutrients (ammonia, nitrite, nitrate, and phosphate) were measured in both the water and sediment samples. The results showed that most Gulf locations had high benthic organism diversity, indicating little contamination by heavy metals. However, the Suez Bay had lower diversity, likely due to organic matter and nutrient enrichment (eutrophication) from the nearby Suez City's wastewater. This highlights the negative effects of human activity on marine ecosystems.

INTRODUCTION

Macro-benthos play an exceedingly important role in aquatic ecosystems by mineralizing organic matter, promoting oxygen flux into the sediment, and facilitating its recycling **(Lind, 1979)**.

Despite being a rich and vibrant ecosystem, the intertidal zone, where land and sea meet, is under threat. Human activity is leading to increased development and use of coastal areas, causing damage to this delicate environment. This rapid loss of biodiversity jeopardizes the valuable resources and services this ecosystem provides **(Nordlund *et al*., 2014; Liao *et al*., 2023)**. Most of macro-benthos, immobile creatures on the ocean floor, are particularly sensitive to environmental changes due to their limited mobility. Shifts in water quality or human activity can cause changes in the species composition present, because of this sensitivity, scientists often use macro-benthos as indicators of marine ecosystem health **(Pearson & Rosenberg, 1978 ; Luo *et al*., 2017; Nazeer *et al*., 2021; Liu *et al.*, 2023).**

Water quality plays a key role in determining the health of species and habitats within the marine environment. Macro-benthic community structures, abundance, and distribution are strongly influenced by water quality **(APHA, AWWA, WEF, 1995; Odiete, 1999)**. The Shannon-Wiener index (H') is a widely used tool to evaluate the quality of aquatic ecosystems. Its simple calculation accurately reflects the stability of the benthic community structure **(Shannon & Weaver, 1963)**.

Steady economic growth in the Gulf of Suez and Suez Bay has fueled coastal development, but this has come at a cost, environmental damage and a decline in the health of tidal ecosystems. To address this, it urgently needs a long-term, continuous monitoring of the environmental quality in these areas.

El Komi and Emara (2007) investigated benthos within the western coast of the Gulf of Suez . Belal's research has focused on macro-benthic fauna in the Suez region. Their studies, spanning from 1995 to 2021, have investigated various aspects of these organisms, including the general ecology of macro-benthic invertebrates in the intertidal zone **(Belal, 1995)**, studying the polychaete worms (bristle worms), specifically in Suez Bay **(Belal, 2001)**, the establishment and description of a new serpulid worm (*Pomatoleios kraussii*) introduced through the Suez Canal **(Belal & Ghobashy, 2012)**, the distribution and diversity of macrobenthic invertebrates on both sides of the Suez Gulf **(Belal & Ghobashy, 2014**), using macrobenthic fauna as indicators of water and sediment quality **(Belal, 2019a)**, impacts of oil spills on macro-benthic invertebrate populations **(Belal, 2019b)**, a broader study incorporating both benthic fauna and microbial communities as environmental indicators **(Belal *et al*., 2020)**, as well as a study on heavy metals availability in sediments and their accumulation in two edible bivalves at the Suez Bay **(Nasr *et al*., 2021)**.

Suez Bay is exposed to several pollutants from Suez and Al-Nasser petroleum and oil production companies. Consequently, these refineries discharge large amounts of marine water polluted with oil (16 x 10^3 m^3 ⁄h) to the current space **(Said, 1992)**. Additionally, the area has been subjected to discharges from textile factories, fertilizer production facilities, and sanitary drainage systems. These activities contribute to the environmental burden, potentially impacting the water quality and the overall health of the ecosystem. It additionally contains four ports, specifically Port Tawfiq, Zaytiyat, Ataka and Adabiya, and the pollution caused by these ports to the marine environment.

This study aimed to evaluate the effects of anthropogenic activities (e.g., coastal development, pollution) on the macro-benthic community in the Suez region and the Gulf of Suez. The main objectives of this study were to describe the abundance and diversity of macro-benthic taxa, including species richness and evenness, in sediment samples collected from various sites in the Suez Bay region and the Gulf of Suez. Additionally, the study aimed to quantify the relationships between human activities, such as proximity to harbors and industrial sites, and the abundance and diversity of the macro-benthic community. Furthermore, it sought to determine how environmental parameters, such as water quality and sediment characteristics, influence the distribution and composition of the macro-benthic community, and to assess how these parameters might be affected by human activities.

MATERIALS AND METHODS

Area of study

The Gulf of Suez, a rift basin trending northwest-to-south-southeast, stretches roughly 250 kilometers southward from the Suez port (29°56′N) to Shadwan Island (27°36′N). Its width varies between 20 and 40 kilometers, with a consistent average depth of 45 meters along its main axis **(El-Sabh & Beltagy, 1983)**. Notably, the depth increases dramatically near its mouth, reaching around 250 meters **(Shukri, 1945)**. The southern end seamlessly connects the Red Sea with the gulfs of Suez and Aqaba. The northern section, known as the Suez Bay, experiences a counter-clockwise water circulation pattern **(Meshal, 1970)** (Fig. 1). Unfortunately, this region faces significant pollution challenges due to the discharge of sewage and industrial waste from the Suez City's activities, including oil refineries, chemical plants, power stations, and harbors **(Hamed, 1992)**. On the eastern side of the Gulf of Suez, 5 stations were chosen for the study, and the 6th one was chosen for comparison. It is located west of the gulf in the Suez Bay behind the National Institute of Oceanography and Fisheries (NIOF).

Fig. 1. Map of the Gulf of Suez to show the stations of sampling

Sampling and analysis

Macro-benthic fauna's samples were taken from the intertidal zone, and the study period extended from Autumn 2019 to Summer 2020. The study covered several stations representing the entire research area, including: I- NIOF; II- Eion Mosa; III- Ras Sudr; IV- Abu Zanimah ; V- Petro-Bil ; VI- Al Tur, which represent the whole area of the study. At each station, the sediments were collected using a hand core covering an area of 0.023m^2 or 1 - 44m^2 of bottom with a maximum penetration of 20cm. In beaches made of rocks, a wooden frame of 20 X 20cm was used. Attached organisms to the rocks were picked manually from various rocks within the quadrate. In surface sediments, the abundance of macro-benthos was represented by the number of individuals per square meter (indivi./m^2).

In the sea, the sediments containing the organisms were sieved (through a 0.5mm mesh), and the bottom organisms were kept in plastic containers with 10% formalin in saltwater; the packages were numbered with the names of the various stations, and they were immediately transferred to the laboratory.

Sediment samples for various analyses, including soil analysis, heavy metal measurement, and hydrocarbon determination, were collected in special bags and promptly transported to the laboratory. Surface water samples were also collected for the measurement of nutrients (NO_2, NO_3, NH_4, PO_4), biochemical oxygen demand (BOD), chemical oxygen demand (COD), and heavy metals (Cu, Pb, Zn). These surface water samples were gathered in dark bottles to measure total hydrocarbons (TPHCs). Additionally, parameters such as pH, dissolved oxygen (DO), and total dissolved solids (TDS) were measured.

Laboratory procedure

The benthic fauna were identified in the laboratory using stereoscopic and compound microscopes. The abundance of macro-benthic invertebrates was calculated per individual per square meter, and the macro-benthic invertebrates were maintained in 70% ethyl alcohol. By Winkler's methodology **(APHA, 1995)**, dissolved oxygen (DO) was measured. As for nutrient salts, ammonia (NH_4), nitrite (NO_2), ,itrate (NO_3) and phosphate (PO_4) were analyzed using the strategy of **APHA (1995)**. In surface waters, heavy metals were previously extracted with APDC-MIBK and determined according to the special quality strategies of **APHA (1989)**. Minerals of interest were measured using a flame atomic absorption spectrophotometer (AAS: Perkin Elmer A Analyzer 100) at NIOF, Suez. The results were expressed in µg/L.While in the sediments, the methodology of **Oregioni and Aston (1984)** was applied to measure the amount of heavy metals. The solutions were then aspirated in an atomic absorption spectrophotometer (AAS) for mineral determination. The obtained results were then expressed in µg/g.

Researchers analyzed the grain size of sediment samples using a dry method based on the Wentworth scale **(Folk, 1974)**. They meticulously separated the particles into seven size classes, ranging from coarse gravel (Ø -1) all the way down to fine mud (Ø5), with each class representing a specific size range on the Phi scale. To simplify analysis, these seven fractions were then grouped into three broader categories: coarse sediment (CSG), consisting of the largest particles (gravel and very coarse sand), medium sediment (MSG) containing medium-sized particles (coarse and medium sand), and fine sediment (FSG) encompassing the smallest particles (fine sand, very fine sand, and mud). The organic matter (TOM) contents were determined and calculated as loss on ignition at 550°C for two hours according to **Dean (1974)** and according to the following formula:

$$\text{TOM\%} == \frac{wt.of\ sample - wt.\ of\ ash}{wt.of\ sample} x\ 100$$

Statistical analysis

To measure species diversity, the evenness, diversity and richness index were calculated using the individual data matrix. Indices of richness were calculated by applying the equation of **Margalef (1958)**. Moreover, the community dominance index (CDI) was calculated using the index determined by **McNaughton (1968)**, and the index of diversity and evenness or equitability of distribution was estimated based on the idea of **Shannon-Wiener (1963)**. Pearson’s simple correlation and canonical corresponding analysis (CCA) were applied to analyze the relationships between environmental factors and different biological variables using XLSTAT Version 2014.5.03. Multivariate analyses were used to identify environmental parameters that affect benthic fauna community structure. Prior to multivariate analyses, species abundances were log (x+1) transformed. The biological similarity matrices were constructed using the Bray-Curtis index. The seasonal variability of benthic fauna assemblages was formally examined using per-mutational multivariate analysis of variance (PERMANOVA).

Then, the principal coordinate analysis (PCO) coupled with cluster analysis was performed. These analyses were performed using PRIMER 6 (6.1.16).

RESULTS

1. Physico-chemical parameters

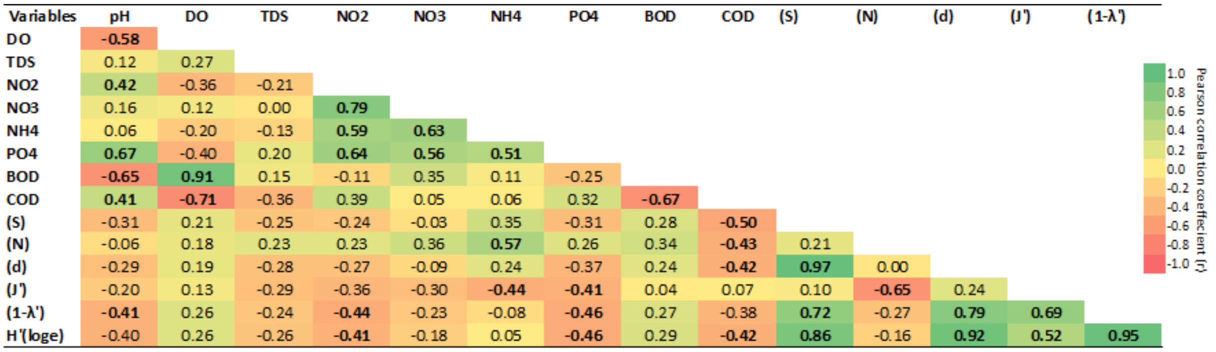
As shown in Table (1) the highest water pH was recorded at station XI (8.39 ±0.17), while the lowest one was observed at station II (8.28±0.09). Dissolved oxygen (DO) in the area of study ranged from 6.75 ±1.08mgO_2/L estimated at station IV to 6.05± 1.05mgO_2/L at station II. Total dissolved solids (TDS) of the surface water fluctuated between 36.13± 1.01 at station I and 34.93± 0.25 recorded at station VI.

2. Nutrients

Nitrite (NO2), nitrate (NO3), and ammonia (NH4) are the most important forms of nutrients in seawater of the inorganic nitrogen. The maximum nitrite in surface water (3.09± 0.9µmol/l) was manifested at station I, while the minimum one was found at station II (2.27± 0.53µmol/ l). The results showed that nitrate content attained its maximum concentration (4.40± 1.03µmol/ l) at station I, while the minimum nitrate value of 3.44± 0.52µmol/ l occurred at station VI. The dissolved ammonium in surface water in the studied area varied between 3.27± 0.71µmol/ l, as recorded in station I, and 1.80± 0.50µmol/ l at station V (Table 1). As described in Table (1) the concentration of the reactive phosphate (PO_4) varied between the lowest value of 1.66± 0.44µmol/ l at station III and the highest concentration of 2.20± 0.39µmol/ l at station I. Current results show that station I recorded the highest concentrations of nitrite, nitrate, ammonia, and phosphate in the investigated area.

3. Biological oxygen demand (BOD) and chemical oxygen demand (COD)

Biological oxygen demand (BOD) recorded its highest value at station I, and the lowest one was found at station VI (3.93 ±0.65 and 3.2 ±0.48, respectively). Chemical oxygen demand (COD) attained its maximum concentration at station III (4.89±1.04), while the minimum was found at station I (3.64 ±0.62) (Table 1). BOD/COD: The relationship between BOD and COD showed that the highest value was recorded at the first station (1.11 ±0.3), while the lowest value was observed at the third and fifth stations (0.74±0.31for each) (Table 1). Pearson correlation revealed that Shannon was significantly negatively correlated with NO2, PO4 and COD) and stressed the importance of pH, NO2, NH4, PO4 and COD in governing benthic fauna biomass and diversity (Fig. 2).



Variables	pH	DO	TDS	NO2	NO3	NH4	PO4	BOD	COD	(S)	(N)	(d)	(J')	(1-λ')
DO	**-0.58**													
TDS	0.12	0.27												
NO2	**0.42**	-0.36	-0.21											
NO3	0.16	0.12	0.00	**0.79**										
NH4	0.06	-0.20	-0.13	**0.59**	**0.63**									
PO4	**0.67**	-0.40	0.20	**0.64**	**0.56**	**0.51**								
BOD	**-0.65**	**0.91**	0.15	-0.11	0.35	0.11	-0.25							
COD	**0.41**	**-0.71**	-0.36	0.39	0.05	0.06	0.32	**-0.67**						
(S)	-0.31	0.21	-0.25	-0.24	-0.03	0.35	-0.31	0.28	**-0.50**					
(N)	-0.06	0.18	0.23	0.23	0.36	**0.57**	0.26	0.34	**-0.43**	0.21				
(d)	-0.29	0.19	-0.28	-0.27	-0.09	0.24	-0.37	0.24	**-0.42**	**0.97**	0.00			
(J')	-0.20	0.13	-0.29	-0.36	-0.30	**-0.44**	**-0.41**	0.04	0.07	0.10	**-0.65**	0.24		
(1-λ')	**-0.41**	0.26	-0.24	**-0.44**	-0.23	-0.08	**-0.46**	0.27	-0.38	**0.72**	-0.27	**0.79**	**0.69**	
H'(loge)	-0.40	0.26	-0.26	**-0.41**	-0.18	0.05	**-0.46**	0.29	**-0.42**	**0.86**	-0.16	**0.92**	**0.52**	**0.95**

Fig. 2. Heatmap of Pearson correlation coeffiecient matrix between diversity indices and some environmental parameters (Values in bold are significant; *P*> 0.05)

Table1. Means ± SD of physico-chemical parameters and nutrients (µ mol/L) at the different stations in the investigated area from autumn 2019 to summer 2020

Table (1)	**Means ± SD**	**Means ± SD**	**Means ± SD**	**Means ± SD**	**Means ± SD**	**Means ± SD**
Stations	**NIOF**	**Eion Mosa**	**Ras Sudr**	**Abu Zanimah**	**Petro-Bil**	**Al Tur**
PH	**8.36 ± 0.055**	**8.28±0.09**	**8.29±0.19**	**8.37 ±0.16**	**8.34 ±0.15**	**8.39 ±0.17**
DO (mgO$_2$/L)	**6.68 ±0.65**	**6.05±1.05**	**6.3±0.59**	**6.75 ±1.08**	**6.55 ±0.64**	**6.23 ±0.50**
TDS (g/L)	**36.13 ±1.01**	**35.6±0.22**	**35.33±0.74**	**35.88 ±0.56**	**35.3 ±0.24**	**34.93 ±0.25**
NO$_2$	**3.09 ±0.9**	**2.27±0.53**	**2.37±0.69**	**2.66 ±0.49**	**2.82 ±1.11**	**2.32 ±0.63**
NO$_3$	**4.40 ±1.03**	**3.48±0.38**	**3.79±0.67**	**3.99 ±0.34**	**3.86 ±0.70**	**3.44 ±0.52**
NH$_4$	**3.27±0.71**	**2.79±0.85**	**2.40±0.71**	**2.41 ±0.49**	**1.80 ±0.50**	**2.39 ±0.70**
PO$_4$	**2.20 ±0.39**	**1.82±0.34**	**1.66±0.44**	**1.89 ±0.37**	**1.86 ±0.30**	**1.69 ±0.41**
BOD	**3.93 ±0.65**	**3.23±0.83**	**3.35±0.81**	**3.7 ±1.14**	**3.5 ±0.74**	**3.2 ±0.48**
COD	**3.64 ±0.62**	**4.32±0.79**	**4.89±1.04**	**3.74±0.85**	**4.89 ±0.69**	**3.80±0.36**
BOD/COD	**1.11 ±0.3**	**0.78±0.28**	**0.74±0.31**	**1.06 ±0.44**	**0.74 ±0.22**	**0.86 ±0.19**

PH	**0.055**	**8.28±0.09**	**8.29±0.19**	**8.37 ±0.16**	**8.34 ±0.15**	**8.39 ±0.17**
DO (mgO$_2$/L)	**6.68 ±0.65**	**6.05±1.05**	**6.3±0.59**	**6.75 ±1.08**	**6.55 ±0.64**	**6.23 ±0.50**
TDS (g/L)	**36.13 ±1.01**	**35.6±0.22**	**35.33±0.74**	**35.88 ±0.56**	**35.3 ±0.24**	**34.93 ±0.25**
NO$_2$	**3.09 ±0.9**	**2.27±0.53**	**2.37±0.69**	**2.66 ±0.49**	**2.82 ±1.11**	**2.32 ±0.63**
NO$_3$	**4.40 ±1.03**	**3.48±0.38**	**3.79±0.67**	**3.99 ±0.34**	**3.86 ±0.70**	**3.44 ±0.52**
NH$_4$	**3.27±0.71**	**2.79±0.85**	**2.40±0.71**	**2.41 ±0.49**	**1.80 ±0.50**	**2.39 ±0.70**
PO$_4$	**2.20 ±0.39**	**1.82±0.34**	**1.66±0.44**	**1.89 ±0.37**	**1.86 ±0.30**	**1.69 ±0.41**
BOD	**3.93 ±0.65**	**3.23±0.83**	**3.35±0.81**	**3.7 ±1.14**	**3.5 ±0.74**	**3.2 ±0.48**
COD	**3.64 ±0.62**	**4.32±0.79**	**4.89±1.04**	**3.74±0.85**	**4.89 ±0.69**	**3.80±0.36**
BOD/COD	**1.11 ±0.3**	**0.78±0.28**	**0.74±0.31**	**1.06 ±0.44**	**0.74 ±0.22**	**0.86 ±0.19**

4-Determining the levels of some heavy metals in surface water and sediments

From Fig. (3a) it was observed that, means of heavy metals in seawater follows the order: Zn > Pb >Cu > Zinc (Zn). On the other hand, in surface water, the means of heavy metals showed high concentrations in Zn (13.181µg/ L), followed by Pb (3.143µg/ L), while Cu was estimated with the lowest values (0.848µg/ L). Station VI recorded the highest mean value of Cu (1.405µg/ L), while station I was estimated with the lowest one (0.455µg/ L). Pb recorded its highest value at station VI (3.76µg/ L), while its lowest value was estimated at station I (2.65µg/ L). Additionally, Zn manifested the maximum value at station VI and the minimum at station I (13.985 and 12.47µg/ L, respectively). It is worth noting that, the sixth station was in contrast to the first station in terms of metal concentrations in the water. While, the sixth station recorded the highest concentrations of all metals, the first station recorded the lowest concentrations of them in the water.

Fig. (3b) showed that, Cu manifested its highest concentration in sediments (3.419µg/ g), followed by Pb with a value of 2.551µg/ g, while Zn attained the lowest value in the sediments (2.129µg/g) of the studied area. Station V recorded the highest mean value of Cu in sediments (4µg/ g), while station I was estimated with the lowest one (2.928µg/ g). Pb recorded its highest value at station VI (3.158µg/ g), while its lowest value was assessed at station II (2.208µg/ g). Zn attained its maximum value at station V (2.971µg/ g), while its lowest was recorded at station III (1.411µg/ g). Consequently, the concentration of heavy metals in the sediments were arranged in the following sequence: Cu >Pb > Zn .

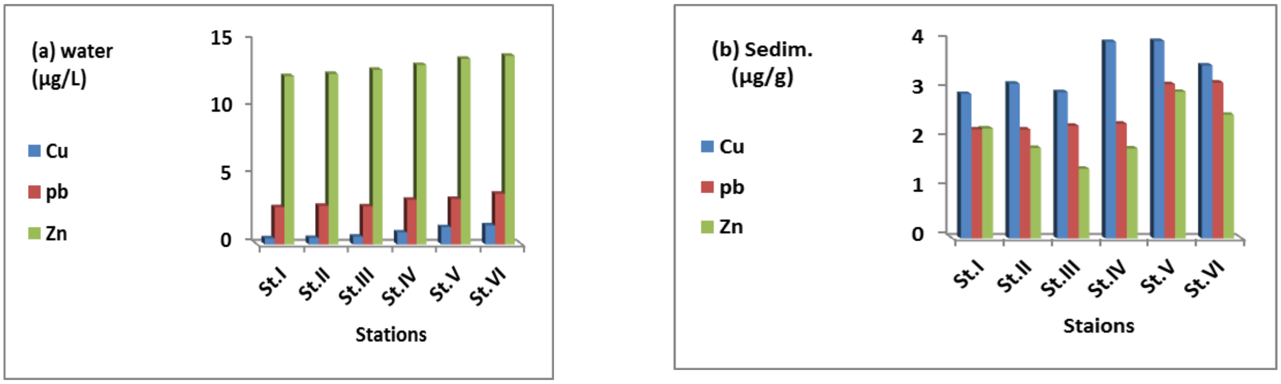


Fig. 3a, b. Means of heavy metals in surface water (µg/L) & sediments (µg/g) at the different stations in the studied area

5- Determination the total petroleum hydrocarbons (TPHs) in surface water and sediments

Fig. (4a, b) shows the average concentrations of (TPHs) in water and sediments in the study area. From the data presented, it is clear that station V (Petro-Bil) manifested the highest average concentration of TPHs in winter, recording 149.2µg/ L with an average of 92.35µg/ L, followed by station VI (Al-Tur) which estimated a means of 57. 666µg/ L. Whereas, station I (NIOF) recorded the lowest average (19.168µg/ L) of TPHs in water in the study area. Regarding the sediments, Fig. (4b) shows that the highest concentration of TPHs was at stations III and V, where they recorded 34.160 and 33.582µg/ g, respectively. On the other hand, station II recorded the lowest value (8.07µg/ g).

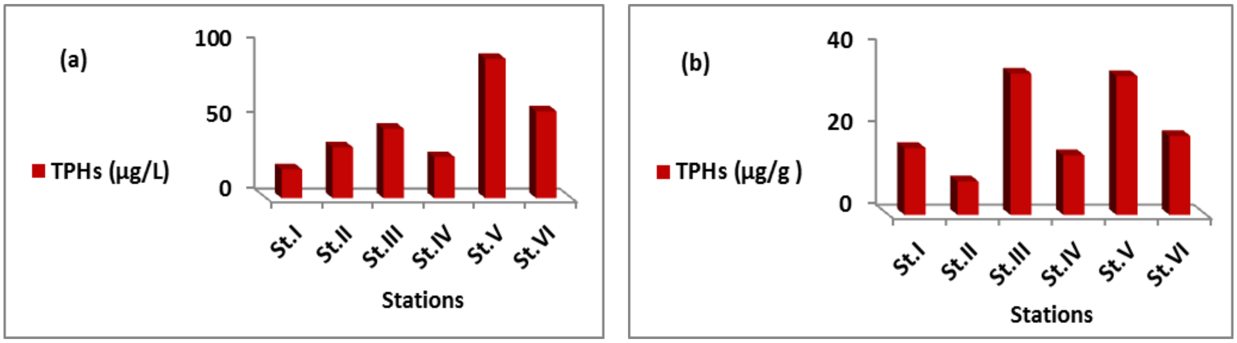


Fig. 4a, b. Means of total petroleum hydrocarbons (TPHs) in water (µg/L) & sediment (µg/g) in the investigated area

6. Grain size analyses

As shown in Fig. (5), the sediment texture fluctuated between the medium sand group (MSG), which had the highest percentage at 48.45%, followed by the coarse sand group (CSG) at 33.33%, and the fine sand group (FSG) at 18.29%. The coarse gravel made up 12.78% of the sediment, while the mud fraction was 1.71%. Sand recorded the highest average content across the samples, at 85.58%. Among the stations, station I exhibited the highest percentage of gravel at 24.68% and the highest mud fraction at 3.86%, but the lowest sand fraction was recorded at 71.46%. Station II had the highest sand fraction at 94.67% and the lowest gravel percentage at 3.45%. Station III had the lowest mud fraction at 0.33%.

7. Total organic matter (TOM)

TOM percentage recorded its highest value at stations I and II (37.06 and 36.107%, respectively). Station V recorded the lowest percentage of TOM (32.77%) (Fig. 5).

8. Distribution patterns of macro-benthic fauna in the western Gulf of Suez and Suez Bay

8.1. Community structure

A total of 57 species of macro-benthic fauna belonging to five phyla were identified. The diversity and density of macro faunal values were 57 and 91117ind./ m^2, respectively. Polychetes were the most dominant group, accounting for 31% of the total species and 52.3% of the total abundance, followed by mollusks, crustaceans, echinoderms, and cephalochordates.

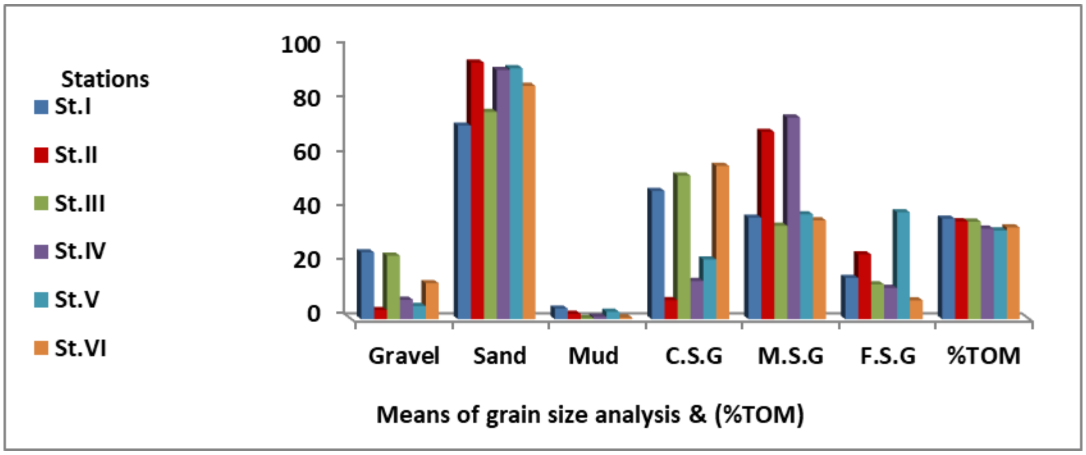


Fig. 5. Means of grain size analyses (%) and total organic matter (%TOM) at the different stations in the investigated area from autumn 2019 to summer 2020

The polychaetes were composed of 18 species (10 errantes and 8 sedentaries). Moreover, the molluscs were represented by 18 species, including 15 gastropods and 3 bivalves. The crustaceans contained 14 species from which 1 cirripedia, 8 decapods; 2 Isopods and 3 amphipods. Echinodermata manifested by 6 species and cephalochordates were represented by one species (Table 2). Polychaetes formed both the highest diversity and density (18 species and 47650 individuals/m^2).The highest density of polychaetes was mainly due to the serpulid (*Spirobranchus kraussii*) which formed 27575indiv./ m^2 and was estimated with 30.26% of the total benthic fauna in the investigated area. As polychaetes, molluscs recorded the highest species number and the second density (18 species and 22299indvi./ m^2). These highest density clearly was due to the dominance of one species (*Brachidontes pharaonis*) that was delineated by 15490indiv./ m^2 and constituted 17% of the full population within the area. While, crustaceans came in the third place in terms of diversity and density, with 14 species and 19737indiv./ m^2. Then, echinodermata represented the fourth place, recording 6 species and 945indiv./ m^2. Whereas, cephalochordates were represented by 1 species and 850indiv./ m^2.

Canonical correspondence analysis (CCA) showed a relationship between the dominant species of benthic invertebrates and the concentrations of heavy metals, hydrocarbons, sediment grain size and organic matter in the sediments (in winter and summer) at different stations (Fig. 6).

8.2. Descriptive analysis, spatial variation and biological quality parameters

The distribution pattern of the benthic fauna in the eastern shore of the Gulf of Suez, (5 stations) and the sixth one (west of the Gulf in the Suez Bay behind the (NIOF) were as follow:

The NIOF station (station 1) recorded the highest density (46548indiv./ m^2). However, it recorded the second least diversity in the number of species, as only 25 species were recorded. The highest number of individuals at this station is owing to the dominance of the serpulid polychaetes (*Spirobranchus kraussii*) which formed 20625indiv. /m^2 and was estimated with 44.31% of the total benthic fauna at this station. The highest number of individuals at station I is primarily due to the dominance of the bivalve *Brachidontes pharaonis* and the crustaceans *Amphibalanus amphitrite* and *Sphaeroma serratum*, with densities of 9,200, 3,600, and 6,600 individuals per square meter, respectively. Consequently, station I exhibited the highest dominance (CDI = 64.07%) and the lowest values for both evenness (E = 0.54) and diversity ($\bar{H}$ = 1.75). This low diversity and evenness were attributed to the uneven distribution of individuals among the species, as detailed in Tables (2, 3).

In contrast to station I, station III (Ras Sudr) recorded a substantial density of 7,526 individuals per square meter but achieved the highest evenness (E = 0.89) and diversity ($\bar{H}$ = 3.17), resulting in the lowest dominance (CDI = 18.60%). This is because individuals were more evenly distributed among species, with no single species dominating. On the other hand, station V (Petro-Bel) had the lowest density of individuals at 13 per square meter, which corresponded with the lowest diversity, recording only 13 species and the lowest species richness (SR = 1.55). Lastly, station VI ranked the third in terms of individual density with 13,582 individuals per square meter but achieved the highest species diversity, with 41 species and the highest species richness (SR = 4.20), as summarized in Tables (2, 3).

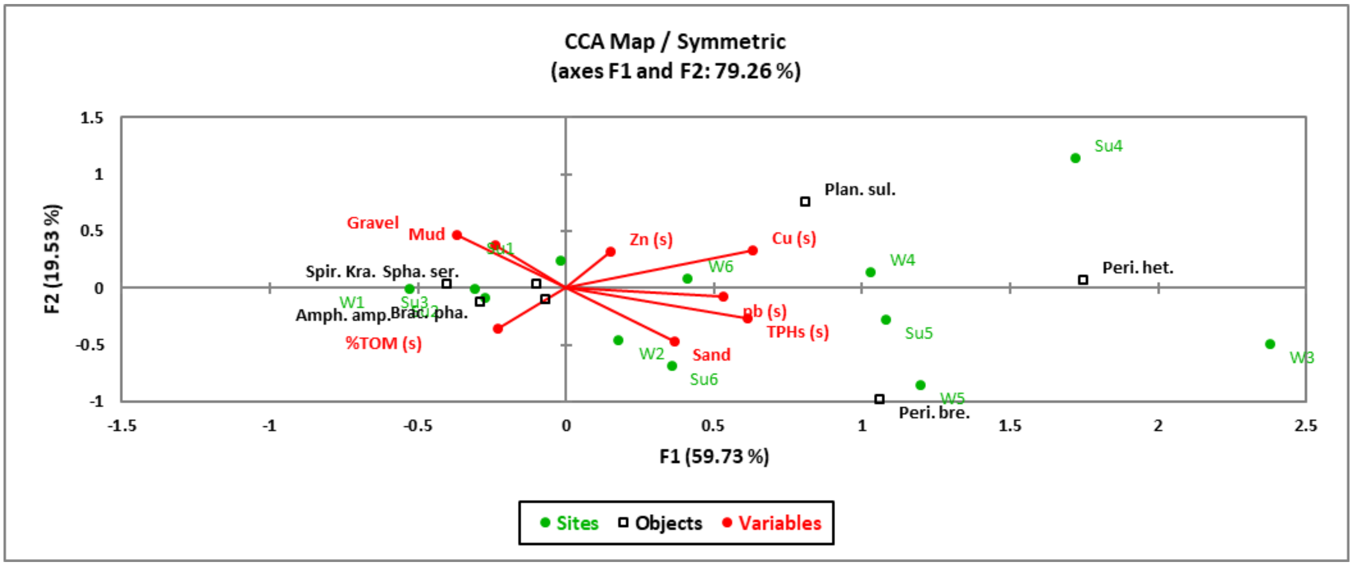


Fig. 6. Biplot of CCA composition for dominant species of benthic macrofauna and different variables in sediments of the study area

Table 2. Communities of macro-benthic fauna (organisms /m ²) at the different stations of investigated area from autumn 2019 to summer 2020

Station	St. I	St. II	St. III	St. IV	St. V	St.VI	Total	Average
sp.								
Polychaeta								
A-Sedentaria forms								
Spirobranchus kraussii	**20625**	**3100**	**750**	**—**	**—**	**3100**	**27575**	**6893.75**
Nainereis setosa	**404**	**—**	**174**	**130**	**174**	**130**	**1012**	**168.67**
Clymenella torquata	**—**	**130**	**520**	**—**	**—**	**—**	**650**	**108.33**
Chaetozone setosa	**304**	**—**	**174**	**—**	**—**	**261**	**739**	**123.17**
Cirratulus cirratus	**608**	**347**	**434**	**—**	**130**	**217**	**1736**	**289.33**
Ophelina acuminata	**—**	**—**	**130**	**652**	**—**	**—**	**782**	**130.33**
Pista cristata	**—**	**—**	**130**	**130**	**—**	**—**	**260**	**43.33**
Euclymen zonalis	**—**	**260**	**—**	**304**	**—**	**260**	**824**	**137.33**
B-Errantia forms	**—**	**—**	**—**	**—**	**—**	**—**	**—**	**—**
Perinereis nuntia brevicirrus	**821**	**695**	**304**	**304**	**737**	**521**	**3382**	**563.67**
Perinereis nuntia vallata	**—**	**261**	**—**	**174**	**—**	**—**	**435**	**72.5**
Perinereis nuntia heterodonta	**434**	**174**	**347**	**738**	**260**	**608**	**2561**	**426.83**
Perinereis cultrifera typica	**130**	**652**	**217**	**—**	**—**	**694**	**1693**	**282.17**
Perinereis cultrifera floridana	**391**	**445**	**261**	**—**	**—**	**217**	**1314**	**219**
Perinereis cultrifera perspicillata	**—**	**348**	**—**	**130**	**—**	**—**	**478**	**79.67**
Lepidonotus squamatus	**477**	**434**	**260**	**—**	**—**	**434**	**1605**	**267.5**
Trypanosyllis zebra	**0**	**521**	**304**	**—**	**—**	**261**	**1086**	**181**
Eunice antennata	**0**	**260**	**304**	**260**	**—**	**—**	**824**	**137.33**
Glycinde multidens	**130**	**—**	**130**	**130**	**—**	**304**	**694**	**115.67**
Mollusca	**—**	**—**	**—**	**—**	**—**	**—**	**—**	**—**
A-Gastropoda	**—**	**—**	**—**	**—**	**—**	**—**	**—**	**—**
Patella sp.	**—**	**40**	**15**	**—**	**25**	**40**	**120**	**20**
Planaxis sulcatus	**2210**	**80**	**125**	**655**	**250**	**1080**	**4400**	**733.33**
Semiricinula konkanensis	**—**	**—**	**—**	**15**	**15**	**35**	**65**	**10.83**
Cellana eucosmia	**25**	**30**	**65**	**60**	**—**	**—**	**180**	**30**
Fusus marmoratus	**—**	**—**	**—**	**10**	**—**	**—**	**10**	**1.67**

Cerithium scabridium	**—**	**—**	**—**	**40**	**—**	**25**	**65**	**10.83**
Clypeomorus sp.	**—**	**60**	**160**	**110**	**130**	**160**	**620**	**103.33**
Trocus erythraeus	**219**	**—**	**—**	**—**	**—**	**—**	**219**	**36.5**
Nerita albicilla	**—**	**35**	**55**	**90**	**90**	**130**	**400**	**66.67**
Volema pyrum	**50**	**—**	**—**	**—**	**—**	**—**	**50**	**8.33**
Monodonta canilifera	**—**	**25**	**65**	**40**	**—**	**60**	**190**	**31.67**
Thais savignyi	**—**	**—**	**10**	**25**	**65**	**50**	**150**	**25**
Acanthoplura hadoni	**40**	**—**	**—**	**—**	**—**	**—**	**40**	**6.67**
Chiton olivaceus	**—**	**15**	**—**	**25**	**—**	**55**	**95**	**15.83**
Onchidium peronii	**50**	**45**	**—**	**—**	**—**	**—**	**95**	**15.83**
B-Bivalvia	**—**	**—**	**—**	**—**	**—**	**—**	**—**	**—**
Brachidontes pharaonis	**9200**	**2550**	**650**	**750**	**410**	**1930**	**15490**	**2581.67**
Gafrarium pectinatum	**40**	**—**	**—**	**—**	**—**	**15**	**55**	**9.17**
Circe (circenita)calipyga	**—**	**—**	**10**	**15**	**—**	**30**	**55**	**9.17**
Arthropoda	**—**	**—**	**—**	**—**	**—**	**—**	**—**	**—**
Crustacea	**—**	**—**	**—**	**—**	**—**	**—**	**—**	**—**
A-Cirripedia	**—**	**—**	**—**	**—**	**—**	**—**	**—**	**—**
Amphibalanus amphitrite	**3600**	**1250**	**320**	**—**	**40**	**530**	**5740**	**956.67**
B-Decapoda	**—**	**—**	**—**	**—**	**—**	**—**	**—**	**—**
Alpheus sp.	**—**	**35**	**15**	**55**	**—**	**25**	**130**	**21.67**
Pilumnus longicornis	**15**	**—**	**—**	**30**	**—**	**20**	**65**	**10.83**
Portunus pelagicus	**10**	**—**	**—**	**25**	**—**	**45**	**80**	**13.33**
Leptodius exaratus	**15**	**60**	**50**	**45**	**40**	**45**	**255**	**42.5**
Porzellana longicornis	**—**	**65**	**190**	**75**	**—**	**60**	**390**	**65**
Macrophthalmus depressus	**—**	**50**	**30**	**45**	**—**	**85**	**210**	**35**
Metopograpsus messor	**20**	**65**	**50**	**95**	**—**	**75**	**305**	**50.83**
Hermit crabs	**—**	**80**	**100**	**140**	**—**	**160**	**480**	**80**
C-Isopoda	**—**	**—**	**—**	**—**	**—**	**—**	**—**	**—**
Paradella hepatophymata	**130**	**—**	**—**	**—**	**—**	**—**	**130**	**21.67**
Sphaeroma serratum	**6600**	**450**	**—**	**—**	**—**	**900**	**7950**	**1325**
D-Amphipoda	**—**	**—**	**—**	**—**	**—**	**—**	**—**	**—**
Melite fresnellii	**—**	**991**	**10**	**175**	**—**	**675**	**1851**	**308.5**
Elasmopus pecteniorus	**—**	**—**	**608**	**40**	**—**	**200**	**848**	**141.33**
Stenothoe gallensis	**—**	**—**	**454**	**485**	**—**	**—**	**939**	**156.5**
Echinodermata	**—**	**—**	**—**	**—**	**—**	**—**	**—**	**—**
Echinometra mathai	**—**	**50**	**75**	**320**	**—**	**—**	**445**	**74.17**
Ophiothrix savigni	**—**	**—**	**—**	**—**	**—**	**25**	**25**	**4.17**
Sea urchin	**—**	**—**	**—**	**25**	**—**	**15**	**40**	**6.67**
Holothoria arenicola	**—**	**85**	**30**	**—**	**—**	**35**	**150**	**25**
Holothoria impatines	**—**	**55**	**—**	**—**	**—**	**25**	**80**	**13.33**
Astropectine polyacanthus	**—**	**15**	**—**	**145**	**—**	**45**	**205**	**34.17**
Cephalochordata	**—**	**—**	**—**	**—**	**—**	**—**	**—**	**—**
Amphioxus sp.	**—**	**850**	**—**	**—**	**—**	**—**	**850**	**141.67**

Total no. of individuals	**46548**	**14608**	**7526**	**6487**	**2366**	**13582**	**91117**	**15186. 17**
Total no. of species	**25**	**36**	**36**	**36**	**13**	**41**	**57**	**31.17**

Table 3. Population density, sp. number, sp. richness (SR), equitability (E), diversity index (H’) and dominance % (CDI) of macro-benthic fauna in the investigated stations

Stations	**St. I**	**St. II**	**St. III**	**St. IV**	**St. V**	**St.VI**
T. indiv. /m^2	**46548**	**14608**	**7526**	**6487**	**2366**	**13582**
T. sp./m^2	**25**	**36**	**36**	**36**	**13**	**41**
(SR)	**2.23**	**3.65**	**3.92**	**3.99**	**1.55**	**4.20**
J' (E)	**0.54**	**0.77**	**0.89**	**0.85**	**0.82**	**0.76**
H'(loge)	**1.75**	**2.74**	**3.17**	**3.03**	**2.10**	**2.84**
CDI %	**64.07**	**38.68**	**18.60**	**22.94**	**48.48**	**37.03**

The Shannon-Wiener index has been used to monitor changes in marine benthic communities and to illustrate and evaluate environmental pollution. In the study area, the $\overline{H}$ values of the first station were equal to $\overline{H}$ = 1.75, and the corresponding environmental quality status (EQS) was “moderate” according to Table (5). While, the Gulf stations were divided into two groups: The first group, which included stations III (Ras Sudr) and IV (Abu Zenima), had an average H′ value higher than 3, and the EQS status was “high”. The second group, stations II (Eion Mosa) and VI (Al-Tur), had an average value of H′ =2.42, and the corresponding environmental quality status was “good” (Table 4).

Table 4. Classification threshold levels for benthic ecological quality status assessment based on the Shannon Wiener diversity index **(Wang *et al.*, 2020)**

H′	**Benthic community health**	**Site disturbance classification**	**Ecological quality status**	**Color code**
H′>3	**normal**	**undisturbed**	**High**	**Green**
2<H′≤3	**unbalanced**	**slightly disturbed**	**Good**	**Yellow**
1<H′≤2	**transitional to pollution**	**moderately disturbed**	**Moderate**	**Orange**
0<H′≤1	**polluted/transitional to heavily polluted**	**heavily disturbed**	**Poor**	**Red**

8.3. Seasonal variations

The distribution of the benthic fauna within the eastern shore of the Gulf of Suez varied widely among the various seasons. Winter and spring exhibited the highest diversity and density, with 49 and 53 species respectively, and densities of 26,578 and

28,215 individuals per square meter. On the other hand, each autumn and summer recorded the lowest diversity and density (39 & 44 species and 16660 & 19664 indivi./m^2, respectively).

Table 5. Population density, sp. number, sp. richness (SR), equitability (E), diversity index(H') and dominance % (CDI) of macro-benthic fauna in the investigated area

Seasons	**Autumn**	**Winter**	**Spring**	**Summer**
T. indiv./m^2	**16660**	**26578**	**28215**	**19664**
T. sp./m^2	**39**	**49**	**53**	**44**
(SR)	**3.91**	**4.71**	**5.07**	**4.35**
J' (E)	**0.61**	**0.65**	**0.68**	**0.73**
H'(loge)	**2.22**	**2.54**	**2.71**	**2.75**
CDI %	**59.06**	**46.75**	**48.73**	**35.85**

In autumn, the macro-benthic community comprised 39 species; 13 polychaete species; 13 molluscs species; 10 crustaceans and 3 species belonging to echinodermates. *Spirobranchus kraussii*, *Brachidontes pharaonis* and *Sphaeroma serratum* constitute the key individuals during this season which are found with an average of 4800, 5040 and 1925 individual/m^2, respectively. While, a significant percentage of benthic organisms were recorded, ranging from 10 to 15 species per square metre. Therefore, the autumn season recorded the lowest number of species and individuals, the least species richness (SR= 3.91), the least equitable distribution (E= 0.61), and the least diversity ($\bar{H}$= 2.22). As a result of what was mentioned above, autumn recorded the highest dominance rate among organisms in all seasons (Tables 2, 5).

Forty-nine species of benthic fauna were procured in winter season; 17 polychaetes species; 15 molluscs species; 13 crustaceans species and 4 species of echinodermates. Winter manifested each the second highest density and diversity within the area (49 species and 26578indivi./ m^2). The leading individuals during this season were *Spirobranchus kraussii*, *Perinereis nuntia brevicirrus*, *Brachidontes pharaonis* and *Sphaeroma serratum* (8675, 1259, 3750 and 2740indiv./ m^2, respectively).

In spring, the community comprised 53 species, including 18 polychaetes, 15 molluscs, 14 crustaceans, 5 echinodermates, and one cephalochordate. The spring season also exhibited the highest diversity, with 32 species and 41,238 individuals per square meter. The substantial numbers of these species contributed to the high species richness observed during this season, which had the highest species richness in the study area (SR = 5.07). This pattern was similar to that observed in winter, where large quantities of the same key species also explained the richness.

Table 6. Simper analysis showing the average dissimilarity between different seasons with the main contributing species

Autumn & Winter average dissimilarity = 68.18		**Autumn & Spring Average dissimilarity = 69.71**	
Species	**Contrib%**	**Species**	**Contrib%**
Spirobranchus kraussii	4.75	*Spirobranchus kraussii*	4.41
Brachidontes pharaonis	4.55	*Brachidontes pharaonis*	4.02
Amphibalanus amphitrite	4.5	*Cirratulus cirratus*	3.89
Planaxis sulcatus	4.33	*Perinereis nuntia brevicirrus*	3.59
Perinereis nuntia brevicirrus	4.23	*Nainereis setosa*	3.35
Sphaeroma serratum	3.88	*Perinereis nuntia heterodonta*	2.98
Lepidonotus squamatus	3.81	*Perinereis cultrifera floridana*	2.9
Perinereis nuntia heterodonta	3.51	*Amphibalanus amphitrite*	2.75
Melite fresnellii	2.94	*Planaxis sulcatus*	2.66
Winter & Spring Average dissimilarity = 61.54		**Spring & Summer Average dissimilarity = 65.04**	
Species	**Contrib%**	**Species**	**Contrib%**
Spirobranchus kraussii	4.29	*Spirobranchus kraussii*	3.82
Amphibalanus amphitrite	3.88	*Brachidontes pharaonis*	3.8
Brachidontes pharaonis	3.72	*Planaxis sulcatus*	3.77
Planaxis sulcatus	3.5	*Perinereis nuntia heterodonta*	3.37
Cirratulus cirratus	3.38	*Cirratulus cirratus*	3.32
Sphaeroma serratum	3.33	*Amphibalanus amphitrite*	3.2
Perinereis nuntia heterodonta	3.02	*Nainereis setosa*	2.84
Nainereis setosa	2.91	*Perinereis nuntia brevicirrus*	2.81
Melite fresnellii	2.87	*Perinereis cultrifera typica*	2.69
Winter & Summer Average dissimilarity = 61.50		**Autumn & Summer Average dissimilarity = 69.38**	
Species	**Contrib%**	**Species**	**Contrib%**
Spirobranchus kraussii	4.63	*Brachidontes pharaonis*	4.86
Brachidontes pharaonis	4.21	*Spirobranchus kraussii*	4.82
Amphibalanus amphitrite	4.05	*Planaxis sulcatus*	4.63
Sphaeroma serratum	3.84	*Perinereis nuntia heterodonta*	3.95
Planaxis sulcatus	3.38	*Perinereis nuntia brevicirrus*	3.87
Perinereis nuntia brevicirrus	3.19	*Amphibalanus amphitrite*	3.56
Perinereis nuntia heterodonta	3.17	*Sphaeroma serratum*	3.28
Lepidonotus squamatus	3.08	*Perinereis cultrifera typica*	3.17

Table 7. Simper analysis showing the average similarity between different stations in each season with the main contributing species

Autumn		**Winter**	
Average similarity: 25.05		**Average similarity: 34.91**	
Species	**Contrib%**	**Species**	**Contrib%**
Nerita albicilla	17.26	*Perinereis nuntia brevicirrus*	19.82
Brachidontes pharaonis	16.88	*Brachidontes pharaonis*	9.4
Clypeomorus sp.	12.13	*Clypeomorus sp.*	9.3
Cellana eucosmia	9.1	*Planaxis sulcatus*	8.01
		Amphibalanus amphitrite	7.39
Spring		**Summer**	
Average similarity: 34.51		**Average similarity: 31.75**	
Species	**Contrib%**	**Species**	**Contrib%**
Perinereis nuntia brevicirrus	12.35	*Planaxis sulcatus*	12.5
Cirratulus cirratus	7.57	*Perinereis nuntia heterodonta*	10.61
Nerita albicilla	7.56	*Spirobranchus kraussii*	9.52
Spirobranchus kraussii	7.56	*Metopograpsus messor*	7.59
Brachidontes pharaonis	7.41	*Perinereis nuntia brevicirrus*	5.83
Leptodius exaratus	7.11	*Nerita albicilla*	5.52

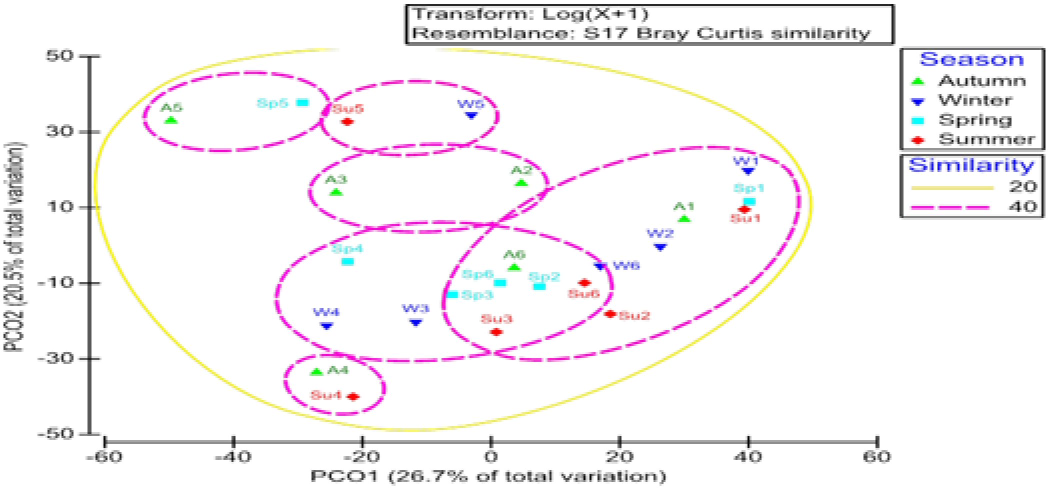


Fig. 7. PCO of benthic fauna assemblages in different seasons coupled to a cluster analysis. Solid and dashed lines represent the principal clusters identified as % of Bray Curtis similarity

In summer, 44 species and 19664indivi./ m^2 were recorded in the study area. From them 15 polychaete species; 14 molluscs; 11 crustaceans and echinodermata recorded 4 species. In this season, the four dominant species, *Spirobranchus kraussii*, *Brachidontes pharaonis*, *Amphibalanus amphitrite* and *Sphaeroma serratum* (4600, 2450, 1270, and 2275indivi./ m^2, respectively) were present in the study area in smaller quantities than in previous seasons, and the differences between their quantities and the rest of the various species were not large.

Accordingly, summer recorded the highest equivalence among indivi. (E=0.3), as well as the highest diversity among them ($\bar{H}$=2.75). As a result of the above, summer achieved the least dominance among species in the entire study area (Tables 2, 5).

PERMANOVA revealed non-significant seasonal variability in the benthic fauna community composition (df = 3, MS: 1581, Pseudo-F: 0.65, *P*-value = 0.878). No significant pair-wise comparisons were detected between seasons. In addition, the principle coordination analysis (PCO) revealed that the first two axes accounted for 26.7 and 20.5%, respectively, of the variance in benthic fauna assemblages among seasons (Fig. 7). In addition the simper analysis showed that the average similarity and dissimilarity between seasons, stations and contributed species (Tables 6, 7).

DISCUSSION

Water quality plays a major role in determining the health of species and habitats within the marine environment. Oxygen deficiency is a powerful guide to estimate the effects of eutrophication on fish and benthic species in the marine environment. This is mostly due to the decay of excess organic production **(Devlin *et al.*, 2011; Foden *et al.*,**

2011; Große *et al*., 2016). In aquatic and drinking water systems, dissolved oxygen levels should be above 6.5- 8.0mg/ L and between 80 and 120% to be considered safe. When DO levels drop below 5mg/ L any aquatic life present is put under an extreme stress. While, if DO levels remain below 1- 2mg/ L longer than a few hours, it can result in fish death **(Atlas Scientific, 2022)**. In the current study, dissolved oxygen ranged between 6.75± 1.08mgO_2/L and 6.05±1.05mgO_2/L; this was at station IV and station II, respectively. This result is considered somewhat appropriate and does not represent stress on marine life. This is in line with what was said by **Best *et al.* (2007)**, **Levin *et al.* (2009)** and **Breitburg *et al.* (2018),** as this value (above 6mg/ l) is considered appropriate for marine life, with the least amount of problems. While, concentrations less than 2mg/ l (hypoxia, i.e., oxygen deficiency) are considered to be hypoxic and cause severe problems. Threshold values ranging from 4 to 6mg/ l (or 40- 60% saturation) identify areas of deficient or reduced oxygen **(Foden *et al*., 2011; OSPAR, 2013)**.

Total dissolved solids (TDS) comprise inorganic salts as calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulphates besides small amount of organic matter that are dissolved in water **(Emara *et al*., 2013)**. In this study, TDS recorded its highest level (36130mg/ L) at the first station (NIOF). While, the lowest one was 34930mg/ L manifested at the sixth station (Al-Tur). The current study is in agreement with what was conducted by **Emara *et al.* (2013)**. In the same study area, it was found that TDS ranges with average values of 35644 and 35525mg/ L in both summer and winter, respectively. In general, TDS concentrations are higher than the maximum allowed in Law (4/94), which is TDS of 2000mg/ L. Accordingly, the high percentages of dissolved solids is attributed to the high spillage of petroleum hydrocarbons from petroleum companies spread in the region and to the presence of a fertilizer factory in addition to other activities in this region, such as fishing farms, fishing ports, sanitation, and agricultural drainage.

Biochemical oxygen demand (BOD) and chemical oxygen demand (COD) are factors used to measure the quality of a water body. BOD is a measure of the amount of oxygen required by bacteria to break down organic components present in water/wastewater. COD is the total measurement of all chemicals (organic and inorganic substances) in water/wastewater. High levels of BOD and COD indicate the presence of a large amount of organic matter and oxidizable materials, which may cause oxygen depletion, severe harm to aquatic life and its organisms, and a major imbalance in ecosystems **(Samudro & Mangkoedihardjo, 2010)**. The current results proved that the highest average concentration of BOD (BOD = 3.93± 0.65 mgO_2/L) was at the first station (NIOF), while the lowest levels (BOD = 3.2±0.48 mgO_2/L) were recorded at the sixth station (Al-Tur). On the other hand, the average COD concentrations ranged from 4.89± 1.04 to 3.64± 0.62mgO_2/L, and this was recorded at the third and first station, respectively. Upon comparing the existing results of BOD and COD, it was found that the values of BOD are higher than those found by **Fahmy *et al.* (2016)**, while being lower than values of COD.

They recorded spatial averages of 1.58 and 8.03mgO_2/ L for BOD and COD, respectively, in the coastal waters of the Red Sea. The high percentages of BOD are evidence of the presence of a high amount of organic compounds in the wastewater that is dumped into the marine environment, especially the Suez Bay, and this enhances the growth of microorganisms in the wastewater, and this is what happened at the first station (NIOF) (Fig. 8).The BOD/COD ratio helps determine the level of organic pollution in the water body and the potential for oxygen depletion. Absolutely, here's a different way to understand the relationship between BOD/COD ratio and biodegradability of waste as stated by **Abdallaa and Hammam (2014)**:

1-High biodegradability (BOD/COD > 0.6): The waste contains a high proportion of organic matter that microorganisms can easily break down.

2-Moderate biodegradability (BOD/COD between 0.3 and 0.6): The organic matter is somewhat more complex and may require an additional help from microorganisms to biodegrade efficiently.

3-Low biodegradability (BOD/COD < 0.3): This waste contains a large amount of organic matter that's difficult, or even impossible for microbes to decompose, and it can be toxic. In the present work, the BOD/COD ratio was greater than 0.6, so the waste was biodegradable to some extent. This is what happened at the first station, where the highest BOD/COD ratio was recorded (BOD/COD = 1.11±0.3). Therefore, the presence of a high amount of organic compounds in the wastewater dumped in the Suez Bay promotes the growth of bacteria and other algae, which work to decompose these organic materials and consequently, consume oxygen in this process.

Nutrients play a major role in assessing water quality. They are essential for supporting healthy marine ecosystems, but their excess can lead to significant oxygen depletion and eutrophication. Eutrophication, which applies to both fresh and marine waters, is generally known as the process of enriching water with plant nutrients, including, first, nitrogen and phosphorus, which in turn stimulate aquatic primary production and, in its most dangerous consequences, leads to visible algal blooms, algae froth and promoting the growth of benthic algae of submerged and floating macrophytes **(Vollenweider, 1992)**. It is clear that human activities have caused an increase in the size and proliferation of macro- algae such as *Ulva* and *Enteremorpha* spp. in marine and estuarine environments. This bloom may contribute to a decline in the sea grass populations and the non-flowering macro-algal beds, causing hypoxia and reducing the diversity of benthic invertebrates **(Lyons *et al.*, 2012)**. In the present study, nitrite (No_2) in surface water ranged from 2.27± 0.53 to 3.09± 0.9µmol/ l, nitrate (No_3) concentration ranged from 3.44± 0.52 to 4.40± 1.03µmol/ l, the dissolved ammonium (NH_4) in surface water in the studied area varied between 1.80± 0.50 and 3.27± 0.71µmol/ l, and the concentration of the reactive phosphate (PO_4) varied between value of 1.66± 0.44 and 2.20±0.39µmol/ l. It is clear that the nutrient concentrations in the current study are higher than those recommended by the United Nations Environment Programme/Food and Agriculture Organization/World Health Organization **(UNEP/FAO/WHO, 1996)**, which specified the ideal concentrations in highly eutrophic coastal waters as 0.15µmol/ L, with the exception of hyper eutrophic systems with concentrations greater than 0.3µmol/ L. Additionally, the nutrients in the current study are higher than the detailed work done by **Ignatiades *et al.* (1992)**, who measured nutrients and determined eutrophic waters as follows: (P-PO4: 0.34 µM); (N-NO3 + N-NO2: 0.53 µM) and (N-NH4: 1.15 µM). It is worth noting that the first station NIOF, which is located in the Suez Bay recorded the highest concentrations of all nutrient salts compared to the remaining stations (stations from 2- 6, which is located in eastern side of the Suez Gulf), and they are as follows: nitrite; nitrate; ammonia; and phosphate in the investigated area (3.09±0.9; 4.40±1.03; 3.27±0.71 and 2.20±0.39µmol/ l, respectively). Therefore, this station suffers from hyper eutrophication. These results are in line with what **Belal (2019a)** found, as this station recorded phosphates higher than the highest environmentally permissible value (1.15µmol/ L). According to the study of **Levent *et al.* (2001)**, more nutrients in the water lead to more macro algae growing. This can be good at first, because it increases the overall production in the ecosystem. However, if there are too many algae, they clump together and block light from reaching the bottom. This creates low-oxygen zones (hypoxia) that harm benthic fauna. Since fish and other predators eat benthic invertebrates, fewer invertebrates also mean less food for them. Accordingly, the current results are in line with what **Hamed and Said (2000)** stated that the Gulf of Suez can be divided regionally into two regions. The Suez Bay area is considered one of the eutrophic (highly productive) areas (Fig.8). This is associated with sewage and/or industrial activities distributed along the western coast of the Gulf. This type of pollution will lead to a gradual deterioration in the quality of water in the Suez Bay. The rest of the Gulf region is considered oligotrophic (low productivity) due to the seriousness of oil pollution.

Heavy metals are important bio- indicators of both the environment of water bodies and the health of marine organisms, especially fish **(Fatima *et al*., 2014)**. In fact, heavy metals are natural elements in the aquatic environment; they serve as the basic cofactor for many enzymes necessary for many metabolic activities **(Jan *et al*., 2015)**. Some of these minerals are considered vital to the health of organisms and fish at permissible levels **(Padrilah *et al*., 2018)**. However, these elements are usually considered toxic when they begin to exceed these levels **(Cobbina *et al*., 2015)**. Currently, heavy metal pollution is one of the most toxic and widespread pollutants, as they are capable of transformation, active migration, and bioaccumulation **(Masindi & Muedi, 2018)**. Moreover, heavy metal pollution may have devastating effects on the ecological balance of the receiving environment and on the diversity of different groups of aquatic organisms **(Ashraj, 2005; Farombi *et al*., 2007)**. In the current study, the means value of some heavy metals concentrations in seawater follows the order: Zn > Pb >Cu as Zn=13.181µg/L, Pb =3.143µg/L, and Cu= 0.848µg/L, respectively. Comparing the heavy metal concentrations observed in this study with background levels in seawater, the results indicate that the levels of Zn, Pb, and Cu generally exceeded the background concentrations found in the open ocean. For instance, Zn concentrations in the open ocean are typically less than 1 µg/L (Bryan & Langston, 1992; UNEP, 1993).

Fig. 8. Eutrophication at the first station (NIOF) along the Suez Bay (north of Suez Gulf). Photos by Aisha Belal

Pb concentrations in open ocean ranged between 0.02- 0.07µg/ L **(Law *et al.*, 1994)**. While, Cu concentrations in open ocean was found in the range of 0.14- 0.90µg/ L, and in coastal water it recorded values ranging from 0.35- 0.40µg/ L **(Law *et al.*, 1994)**. It is recommended that the concentrations of metals should be much lower than those recommended for the protection of biological species at 99%, which are as follows: copper: 0.3µg/ L, zinc: 7µg/ L, lead: 2.2µg/ L **(ANZECC/ARMCANZ, 2000)**. From the results obtained from the ongoing study, it became clear that the concentrations of all metals are higher than those recommended by **ANZECC/ARMCANZ (2000)**. Furthermore, the concentration of metal in the current study is higher than what was claimed by **Athar and Vohora (2001)**, as in natural marine waters, the typical concentrations of metals are as follows: copper at 0.3 µg/L, lead at 0.03 µg/L, and zinc at

5 µg/L. Despite the recommendation that these metal levels shouldn't harm aquatic organisms, the high concentration of copper (Cu), lead (Pb), and zinc (Zn) in the Suez Bay and subsequently the Suez Gulf, exceeding environmental limits, suggests that metals will likely enter the food chain.

In the current study, the concentrations of zinc (Zn) and lead (Pb) were found to be higher than those reported by **Belal (2019a)** in the same area, where Zn was 10.79 ± 8.943µg/ L and Pb was 0.9065± 0.731µg/ L, while copper (Cu) recorded lower concentrations at 2.5431± 0.757µg/ L. A study by **El-Metwally *et al.*** (2019) in the Gulf of Suez showed Cu and Zn concentrations within a similar range to the current study, with Cu at 0.85 - 2.61µg/ L, Zn at 2.13 - 14.42µg/ L, and Pb at 0.11 - 0.31µg/ L. However, Pb concentrations are higher in this study.

Comparing the results with those from other areas, Zn and Pb concentrations in this study are higher than those found by **Belal and Dar (2020)** in the Bitter Lakes, where Zn and Pb were recorded at 7.432 and 2.033µg/ L, respectively. Cu concentrations, on the other hand, are lower in this study (7.076µg/ L). The current study also recorded higher Zn and Pb concentrations but lower Cu concentrations compared to the findings of **Abdel-Wahab *et al.* (2022)** in the Bitter Lakes, Suez Canal, where Zn, Pb, and Cu were 3.355± 2.731, 1.376± 0.562, and 2.256± 2.909µg/ L, respectively.

In the sediments of the studied area, the concentrations of metals were ordered as Cu > Pb > Zn, with mean values of Cu (2.928 - 3.999µg/ g), Pb (2.208 - 3.158µg/ g), and Zn (1.411 - 2.971µg/ g). These results are consistent with those found by **Nour *et al.* (2022)** in the Suez Bay, Gulf of Suez, where Cu, Pb, and Zn concentrations ranged from 0.23–7.53µg/ g, 0.74–6.92µg/ g, and 0.78–15.57µg/ g, respectively.

Compared to the study by **El-Sawy *et al.* (2023)** in the Gulf of Suez, the current study showed higher Pb and Zn concentrations, but lower Cu concentrations, with El-Sawy *et al.* reporting Pb, Zn, and Cu at 1.47, 0.76, and 18.79µg/ g, respectively. The current study also revealed that heavy metal concentrations in sediments are higher than those on Big Giftun Island and Abu Minqar Island in the Red Sea, where Cu, Pb, and Zn were reported as 0.13, 0.62, 0.08µg/ g, and 0.27, 1.19, 2.89µg/ g, respectively **(Abdelaal *et al.*, 2024)**.

The current results showed that Cu and Pb concentrations are higher than those found by **Abdel Wahab *et al.* (2022)** in the Bitter Lakes, but Zn concentrations are lower (Cu at 1.753±0.464µg/ g, Pb at 0.398± 0.355µg/ g, and Zn at 8.643± 1.821µg/ g). In comparison with station VI (Al-Tur region), the metal concentrations in water are close, except for Pb, which is higher than that of **Elgendy *et al.* (2023)**, who reported Zn concentration at 2.8 – 19.55µg/ L, Cu at 0.37 – 2.09µg/ L, and Pb at 0.43 – 2.55µg/ L. However, in sediments, the results of **Elgendy *et al.* (2023)** are higher for all metal concentrations than in the current study, where they found Zn at 78.02µg/ g, Cu at 12.35µg/ g, and Pb at 72.81µg/ g. The canonical correspondence analysis (CCA) confirmed that station VI was the most affected by metals, especially lead.

As mentioned above, these high levels of heavy metal concentration are due to many types of pollution that flow into the Suez Bay and from there to the Gulf of Suez. These sources include: wastewater from the city of Suez (Al-Kabanun) and from ships waiting to cross the Suez Canal; Operational spills and leaks from ships loading or unloading their goods at various ports, in addition to waste from industrial companies, such as oil refineries, (SUMED pipeline stations, Petrojet and various oil companies spreading on the shores of Suez), various factories, electrical and thermal power plants, and all of this waste is discharged directly or indirectly into the Gulf of Suez (**Mohamed *et al*., 2007; Khader *et al*., 2019)**. It is worth noting that this waste contains a very large group of chemical residues that may affect water quality and the diversity of marine organisms in this important area.

Coastal areas are experiencing a rise in crude oil and gas exploration, which unfortunately leads to pollution by persistent and harmful substances called total petroleum hydrocarbons (TPHs). These TPHs are especially concerning because they are attracted to fats (lipophilic) and don't easily break down (persistent). This allows them to build up in the food chain (biomagnify) to dangerous levels in fish and shellfish, where they accumulate in the flesh and muscles **(Akinola *et al*., 2019)**. In Temsah Lake, **Ahmed *et al.* (2001)** concluded that, the highest concentration of polycyclic aromatic hydrocarbons (PAHs) was 48.9µg kg-1, which was detected in bivalves. Likewise, **Ahmed *et al.* (2013)** reported that residues of aliphatic and polycyclic aromatic hydrocarbons (PAHs) were detected in some fish species collected from Temsah Lake. In the current study, it was found that the mean concentration of TPHs in water was higher in winter than in summer (66.68 and 25.39µg/ L) for winter and summer, respectively. It was found that the V station (PetroBil) recorded the highest concentrations of TPHs, by achieving (149.2 and 35.5µg/ L) for winter and summer, respectively. Thus, it recorded an annual average of (92. 35µg/ L). This result could be attributed to the high petroleum activities near this station. In a case study reported by **Belal (2019b)** of an oil spill from one of the power stations in Suez Bay; it was found that the average total concentration of TPHs in the sediment was 431.49µg/ g in autumn (after the oil spill). While in spring, it was estimated with an average of 194.96µg/ g (before the oil spill). The results of the study also included the disappearance of oil-sensitive organisms such as amphipods and echinoderms. Comparing the current results in terms of spatial change, the different stations achieved higher concentrations of TPHs than what **Hamed and Said (2000)** achieved in the same areas. In the northern part of the Gulf of Suez (Suez Bay), an average concentration of 4.86µg/ L was recorded. Additionally in their study, there were records of 3.31, 6.14 and 1.99µg/ L for each of Ras Sudr, AbuZenima and Safaga, respectively. This is due to the fact that this region has been affected by a steady increase in the activities of oil fields and petroleum companies of all kinds in the study area. Furthermore, in the current work, the concentrations of TPHs in water were higher than what was recorded by **Ezz El-Din *et al.* (2021)** in the northern region of the Gulf of Suez, where they recorded 20.35 ± 8.27, 11.55 ± 4.19 for winter and summer, respectively. The study found unacceptable levels of TPHs in the area, particularly in the water, which could lead to a higher risk of skin cancer in adults. Fortunately, the risk appears to be lower for children. These findings highlight the need to investigate the sources of this TPHs pollution and take steps to reduce and treat it, minimizing potential health risks. Regarding sediments, the average concentration of TPHs was higher in winter than in summer (as in water) and was recorded (25.76 and 16.05μg/ g) for both winter and summer, respectively. In terms of spatial variations, the highest concentration of TPHs were at stations III and V, where they were recorded (54.77 and 38.21μg/ g, respectively) with annual means of 34.16 and 33.58, respectively. While, station II recorded the lowest value of TPHs (2.44μg/ g), with an annual mean of 8.07. The canonical corresponding analysis (CCA) also confirmed that the fifth station (Petro-Bil) is the most affected by hydrocarbons.

Adeniji *et al.* (2017) stated four levels of TPHs contamination to evaluate marine sediments based on a proposal by **Massoud *et al.* (1996)**. They were as follows: uncontaminated (10-15mg/ kg), slightly contaminated (15-50mg/ kg), moderately contaminated (50-200mg/ kg), and severely contaminated cases (>200mg/ kg). Consequently and based on the classification of **Adeniji *et al*. (2017)**, the concentrations of TPHs in sediments follow the third group, which is moderately contaminated (50-200mg/ kg).

In the current study, sand deposits dominated most of the study area (85.58%), which covers the eastern part of the Gulf. Coarse-grained sediments were distributed in the northwestern part of the Gulf (Suez Bay). A clear upward trend was also recorded in the percentage of silt and clay from the east Gulf stations to the Suez Bay, which recorded the highest percentage of this group (mud =3. 86 %). Therefore, the order of sediment texture percentages was sand > gravel > mud, with sand comprising 85.58%, gravel 12.78%, and mud 1.71%, respectively. The ongoing work is consistent with the findings of **El-Moselhy and Abd El-Azim (2005)** in that the sand deposits dominated most of the study area, which covers the offshore part of the bay. Coarse-grained sediments were distributed in inshore stations, usually at low depth. A clear upward trend was also recorded in the percentage of silt-clay in the offshore stations.

Total organic matter (%TOM) represents the decomposed organic tissues of the sea grasses, algae, planktons, fecal pellets and any other decomposed dead benthos. The percentage of TOM in sediments in the study area ranged from 32.77 to 37.06% with an average of 34.86% . Station I (NIOF) recorded the highest means of TOM percentages (37.06%) in the studied stations and this was attributed to the huge amounts of sewage runoff from the agriculture and sewage drains. This was confirmed by canonical corresponding analysis (CCA), that the first station (NIOF) is the most affected by mud and TOM. The current results from determining TOM in sediments are higher than what was recorded by **Elgendy *et al.* (2018)**, they determined that TOM percentages in Port

Tawfiq harbor ranged between 10.74 and 20.75%, with an average of 15.86%. While, the TOM ratio showed a variation from 14.57 to 25.36%, with an average of 21.70% in the port of Tersana. They attributed these results mainly to household sewage, hydrocarbons from boats, and oil leaking from tanks and boats.

The community assemblages of macro- benthic fauna were studied and organized according to physicochemical as well as biological parameters to study the biodiversity in the right side of the Gulf of Suez and its northern region represented by the Suez Bay. The survey revealed that the macro-benthic community, comprised 57 species and 91117indivi./ m^2, were collected during the study, is affiliated with 5 phyla. The order of the major taxonomic groups in terms of diversity and density were: polychaeta > mollusca > crustaceans > echinoderms > cephalochordates. The two most dominant species in the study area are the serpulid polychaete (*Spirobranchus kraussii*) and the bivalve (*Brachidontes pharaonis*), which are invasive organisms of an Indo-Pacific origin **(Belal , 2019a)**. They are present at an annual average equal to 6893.8 and 2581.7indiv./ m^2. Together, they achieved 47.26 % of the total amount of benthos in the entire region.

Diversity characteristics can reflect the level of abundance and evenness of resources in different types of microorganisms. The results showed that the Shannon-Wiener index (H'), species richness index (SR), and evenness index (E) for each station were as follows: The highest abundance (density) of individuals in the study area was 46548indiv./ m^2 found at Station 1 (NIOF). This is due to the dominance of five species of benthos, the serpulid polychaete (*Spirobranchus kraussii*), gastropods (*Planaxis sulcatus*), (*Brachidontes pharaonis*), bivalves (*Brachidontes pharaonis*), cirripeds (*Amphibalanus Amphitrite*) and isopod (*Sphaeroma serratum*). These species recorded a total of 42,235indi./ m2, constituting 90.73% of the total population at this station and estimated at 46.35% of the total individuals in the study area. The CCA analysis showed that dominant species tolerated high levels of heavy metals and hydrocarbons. In other words, these pollutants didn't seem to have a negative impact on the dominant species.

However, despite this impressive density, a closer look reveals a surprising lack of balance: it achieved the lowest index of evenness (E = 0.54) and the lowest index of diversity ($\bar{H}$ = 1.75). This is due to the vast majority of individuals belonging to a few species and therefore, achieving the highest dominance (CDI = 64.07). In other words, while there are many different species present, the bulk of the population is concentrated in a select few. As mentioned above, this station represents the northern part of the Gulf of Suez (Suez Bay). In this study, this station recorded somewhat moderate concentrations of metals (Cu, Pb & Zn) and TPHs in both water and sediment. But it achieved the highest concentrations of organic matter and silt, and as manifested, the highest concentrations of NO_2, NO_3, NH_4 & PO_4, as well as the highest percentages of BOD and the highest percentages of BOD/ COD. This state of contradictions at this station matches what was decided and explained by **Grall and Shuvod (2002)** and **Savage *et al*. (2002)**, who decided that the organic matter from pollution can have a twosided effect on benthos, while moderate amounts of organic matter act like fertilizer, increasing the variety and abundance of benthos. While excessive amounts of organic matter deplete oxygen, harming most benthos but favoring and dominating a few opportunistic species. This can lead to a decrease in biodiversity and can create a misleading impression of increased total biomass, which is not necessarily an indicator of a thriving, diverse ecosystem. This trend indicates that the decline in macro-benthos biodiversity is related to the effects of anthropogenic activities, such as pollution and eutrophication **(Luo *et al*., 2013; Liu *et al*., 2023)**. **Luo *et al*. (2017)** stated that if opportunistic species dominate benthic communities, this indicates that the overall benthic communities are clearly polluted. In addition, in this study, the results are in agreement and harmony with the Environmental Information and Monitoring Program **(EIMP, 1999)** report on studying sediments and benthic organisms in the Suez Bay and the Gulf of Suez. It was determined that organic materials and nutrients (eutrophication) had a significant impact on sediments and benthic organisms in the northern part of the Gulf of Suez, the Suez Bay (Fig. 8). This does not apply to other stations in the Gulf of Suez.

In contrast to the first station, the third station (Ras Sudr , the Gulf stations), although it achieved a small percentage of individuals (36 species and 7526indiv./m^{2}),it recorded the highest evenness (E=0.89) and the highest diversity ($\overline{H}$=3.17). Therefore, it showed less dominance among individuals (CDI=18.60 %), and this is attributed to the equitable distribution of individuals within the species. The fifth station (Petro-Bil) recorded the lowest in both density of individuals (2366indiv./ m^{2}) and diversity (13 species). It is also recorded with the lowest in species richness (SR=1.55). This is due to petroleum pollution, because this station recorded the highest concentrations of TPHs in water and sediments. This is consistent with the finding of **Belal and Ghobashi (2014)**, who determined that no live animals were found in Petro-Bil because it was highly contaminated with petroleum hydrocarbons. Finally, the sixth station ranked the third in the number of individuals (13,582indiv./ m^{2}), but it recorded the highest species diversity (41 species) and the highest species richness (SR = 4.20). The study investigated heavy metal contamination in sediments of the El Tur coastal area. The highest levels of copper, lead, and zinc were found in the sixth station, exceeding environmental standards but not reaching toxic levels for benthic organisms. This aligns with previous findings of **EIMP (1999)** that the most Gulf of Suez sediments are uncontaminated or slightly contaminated, with no adverse effects on benthos. Additionally, **Elgendy *et al.* (2023)** suggested that these metals (zinc, lead, copper, nickel, and cadmium) may pose a moderate environmental risk based on environmental risk indices in El Tur coastal area.

A measure of marine health: Scientists use a special index (H') to assess the well-being of underwater communities on the seafloor (benthic communities). Higher H' values indicate a healthier environment **(Shannon & Weaver, 1963; Wang *et al*., 2020)**. In this study, different sampling locations were assigned a quality rating based on their H' scores. Locations with scores above 3 received a "High" rating, signifying a healthy environment. Locations scoring between 2.4 and 3 were rated "Good," and those below 2.4 were rated "Moderate" or better. The results showed a variation in health across the studied areas. Some stations (stations III and IV) displayed a "High" quality rating, while others (stations II and VI) fell into the "Good" category. The first station (I) received a "Moderate" rating, indicating a potential decline in its ecological health. These findings are consistent with the research of **Borja *et al.* (2008)**, who classified environments with "High" or "Good" H' scores as "undegraded," meaning they are healthy and undisturbed. In contrast, scores that indicate "Moderate," "Poor," or "Bad" quality reflect a degraded state, where the seafloor community is compromised. Based on this analysis, most of the studied locations in the Gulf stations appear to be in a healthy or slightly disturbed condition. However, the first station (NIOF) shows signs of moderate deterioration, warranting further investigation.

There is also a noticeable difference in the abundance and diversity of species depending on seasonal changes. Winter and spring led in both density and diversity, with 26,578 and 28,215 individuals per square meter, respectively, and 49 and 53 species, respectively. In contrast, autumn and summer recorded lower population densities, with 16,660 and 19,664 individuals per square meter, respectively, and fewer species, with 39 and 44 species, respectively. This may be due to the higher temperatures in the tidal areas during these two seasons. Moreover, spring achieved the highest species richness (SR = 5.07). Although summer had 44 species and ranked third in density, it recorded the highest diversity index (H = 2.75) and the highest evenness (E = 0.73), resulting in the lowest dominance (CDI = 35.85). This is attributed to the absence of dominant opportunistic species, leading to a fair and equal distribution of individuals among species. On the contrary, autumn recorded the lowest percentages in all biological indices, including the lowest species richness (SR = 3.91), the lowest diversity index (H = 2.22), and the lowest evenness (E = 0.61), and thus the highest dominance (CDI = 59.06). This is traced back to the presence of dominant opportunistic species, resulting in an unfair and unequal distribution of individuals among species.

Studies by **Belal (1995, 2001)**, **Belal and Ghobashy (2014)** and **Belal *et al.* (2016)** consistently reported that winter and spring are the most productive seasons for benthic macro-invertebrates and polychaetes in the Suez Bay, Gulf of Suez, and Temsah Lake, respectively. Conversely, summer and autumn exhibited the lowest abundance and diversity of these organisms.

Finally, PERMANOVA revealed a non-significant seasonal variability in the benthic fauna community composition (*P*-value = 0.878). No significant pair-wise comparisons were detected between seasons. Furthermore, the principal coordination analysis (PCO) revealed that the first two axes accounted for 26.7 and 20.5%, respectively, of the variance in benthic fauna assemblages among seasons. The results of SIMPER analysis show the discrimination between seasons based on species contributions. Species are ordered by their average contribution to the average dissimilarity, with the highest average dissimilarity between autumn and spring (69.71%) and autumn and summer (69.38%). Additionally, SIMPER analysis showed that the average similarity between autumn stations was 25.05%, with *Nerita albicilla* and *Brachidontes pharaonis* collectively contributing 34.14% of this similarity. The average similarity between winter stations was 34.91%, with *Perinereis nuntia brevicirrus* contributing 19.82% of this similarity. The average similarity between spring stations was 34.51%, with *Perinereis nuntia brevicirrus* contributing 12.35% of this similarity. Finally, the average similarity between summer stations was 31.75%, with *Planaxis sulcatus* and *Perinereis nuntia heterodonta* contributing 12.5 and 10.6% of this similarity, respectively.

CONCLUSION

The study revealed a compelling contrast between the benthic communities of the Gulf of Suez stations and the Suez Bay station. The Gulf stations exhibited higher diversity, with a greater number of species (41 vs. 25), a more even distribution of species, and a higher diversity index. This indicates a more balanced ecosystem where no single species dominates. In contrast, the Suez Bay station, although it had a much higher density of organisms, exhibited lower diversity. This suggests that the abundant organisms in the Suez Bay are likely "opportunists" that thrive on the high organic material input, leading to a dense population of a few well-adapted species. In simpler terms, while the Gulf stations had a richer variety of organisms, the Suez Bay station had a higher total number but a less diverse range. Despite the concentrations of heavy metals being higher than environmentally permissible levels, they did not reach toxicity levels for benthic organisms. The Gulf of Suez stations were somewhat affected by heavy metals, whereas the Suez Bay station was significantly impacted by the large quantities of organic matter and nutrients, primarily from domestic and industrial wastewater from the city of Suez and possibly from the numerous ships waiting to pass through the Suez Canal. This input led to eutrophication, which had the greatest impact on sediments and benthic organisms in the Suez Bay. The analysis suggests that most Gulf stations are in good or slightly impacted condition. However, the first station (NIOF) stands out as moderately degraded and warrants further study. Based on these findings, long-term coastal pollution poses a significant threat to the delicate balance of marine life, reducing species diversity and endangering fisheries. To prevent coastal ecosystems from reaching a point of no return, urgent action is needed to protect these vital ecosystems and the well-being they support.

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