CATRINA (2020), 21(1): 61-73

Benthic fauna and microbial communities as bio-indicator for the characteristics of the marine environment in the Suez Bay, Red Sea, Egypt

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ABSTRACT

Environmental variables as well as benthic fauna and bacterial communities were measured to assess water quality and sediments in the Suez Bay. A total of 62 species belonging to five taxonomic groups (Polychaeta, Mollusca, Crustacea, Echinodermata, and Urochordata) were collected from benthic fauna at thirteen stations along the tidal area of the Suez Bay. Polychaetes topped the various groups and are known as a strong indicator of pollution in aquatic environments. Polychaetes recorded 38.71% and 47.3% of the total number of species and individuals, respectively, in Suez Bay. Bacterial populations are present in the water with an annual density of 21598 cfu / 100ml with an average of 1661.4. At the same time they are present in the sediments with a numerical density of 16331 cfu/g with an average of 1256.23. Dissolved oxygen (DO), Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) of tested samples ranged between 3.2 - 6.45 mgO2/l; 0.995 -2.298 mg/l; 2.298- 4.69 mg/l, respectively. This investigation revealed that, with the exception of the alien; dominant and adherent rocks species (*Spirobranchus kraussii* and *Brachidontes pharaonis*); the microbial components increase their dominance, while the benthic fauna decreased and vice versa during the entire study period. In addition, this study indicated a direct relationship with salinity, dissolved oxygen and total benthic fauna and at the same time there is an inverse relationship between these environmental variables and bacterial counts, thus indicating a predominant effect of human activities in the coastal area of the Suez Bay.

Keywords: Benthic fauna, microbial communities, bio-indicator, Suez Bay, Red Sea.

INTRODUCTION

The health of the sedimentary ecosystem can be assessed using information regarding the structure and abundance of its components from the biotic populations. (Maher *et al*., 1999). Macro-benthic faunal organisms play a major role in the circulation and recycling of nutrients in the aquatic ecosystem by accelerating the decomposition of organic matter into simple inorganic forms (Idowu and Ugwnmba, 2005). Camargo (1993) revealed that biological monitoring based on macro-invertebrates showed more important pollution indicator than physico-chemical monitoring alone. Benthic macro invertebrate assemblages and distribution frequently change in response to pollution stress in predictable ways, thus their importance as biological criteria for evaluation of anthropogenic influences of aquatic systems (Boyle and Fraleigh, 2003). The presence of the indicator bacteria is an important factor for water quality assessment (WHO, 2003). By fecal indicator bacteria including fecal coliform, total coliforms, fecal streptococcus and Aeromonas sp, the microbiological quality and health risks associated with contact with marine waters are usually evaluated (Thomas, 2009 and Bahgat, 2011). Meio-faunal organisms play an important role in the ecosystem, but they decrease as the microbial components increase in the Red Sea sediments (El-Serehy *et al*., 2016). There is an inverse relationship between benthic fauna and microbial organisms. For example, Timsah Lake recorded the highest number of benthic fauna and at the same time recorded the lowest number of microbial organisms. While the opposite was in the Western Lagoon, the highest number of microbial organisms and the lowest number of benthic fauna were recorded (Belal *et al*., 2020). This study was conducted in Suez Bay, to evaluate some of its physical and chemical properties on the one hand, and on the other hand, study population fluctuations in benthic fauna and bacteria and their relationship to these environmental changes. Hence the use of these living benthic organisms as a vital indicator and as a reflection aimed at the extent of pollution reached by Suez Bay, this important part of the Gulf of Suez.

MATERIALS AND METHOD

Study area

The Suez Bay is located in the northern part of the Gulf of Suez (Figure 1). It is located between the longitudes 32° 28' & 32° 34' E and latitudes 29°54' & 29°57' N. The horizontal surface area is 77.13 square kilometers, with an average depth of 10 meters. It is considered the meeting point of waters between the Red Sea and the Mediterranean Sea. Its movement of water in a anticlockwise (Meshal, 1970). Most of the factories, Petroleum Company and the Suez City are located north of the Suez Bay.

Sampling and analysis

Thirteen stations were chosen in the studied area, and performed from summer, 2019 to winter, 2020. Three random replicates were taken in each station using a square of 20X20 cm. All the materials in the box were carefully taken by shovel, then put into plastic boxes and add 10% formalin in sea water. After that, it was transferred to the laboratory, In addition, other surface water and sediment samples were collected for nutrients and sediment analysis measurements. Water and sediments for isolating the bacteria were placed in a box filled with ice, and then transported directly to the laboratory. The pH, temperature and salinity were

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measured at the time of collecting the samples at the different stations. Dissolved oxygen (DO) as well as nutrient salts: nitrite (NO_2-); nitrate (NO_3-), ammonia (NH_4+) and phosphate (PO_4^{3}-) were measured by Winkler method (APHA; AWWA AND WEF, 1995).

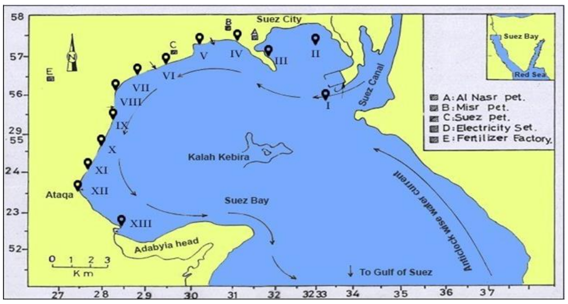

Figure (1): The Suez Bay map showing the sampling stations as drown previously by Belal (2019).

Laboratory examination

Macro-benthic fauna

The benthic animals were washed with running water in a sieve with a diameter of 0.5 mm, and what remains in the sieve are macro-benthic fauna were pick up with forceps, separated to different groups and counted, then placed in 70% ethyl alcohol for identification and preservation.

Bacterial population

To assess water quality, in microbiological terms, measuring indicator microorganisms was carried out in which faecal indicators were targeted. The collected samples were subjected for bacterial population including: total coliform (TC); *Escherichia coli* (*Ec*); faecal *Streptococci* (FS). Meanwhile, pathogenic bacteria of genus *Vibrio* sp. and *Aeromonas* sp. were also examined using membrane filtration techniques (APHA, 1998). M-Endo agar was used for TC count after 24 hr incubation at 37 °C. Difco^{TM} mFC agar was used for *Ec*. count after being incubated for 24 hr at 37°C. However, ME (m-*Enterococcus*) agar was used for counting of FS after being incubated for 48 hr at 37 °C. For detection of *Aeromonas* sp., bile salt irgasan brilliant green agar was used. Inoculated plates were incubated at 37 °C for 24 hr.

Enumeration of bacterial colonies

All isolated microbial-indicator (TC, FS and *Ec*) and pathogenic bacteria (*Aeromonas* sp. and *Vibrio* sp) were estimated, identified and confirmed (Bergey and Holt, 2000). Ten colonies of each type of bacteria were sub-cultured and confirmed. The colony forming unit (per 100 ml and 1g of water and sediment samples, respectively) was calculated after confirmation according to Elshenawy and Farag (2005).

Physicochemical Analyses of studied stations

The physical and chemical parameter of the studied stations were carried out to determine the nature of the Suez bay and how these measured parameters can affect the existence and distribution of benthic fauna and microbial communities.

The parameters measured were temperature, pH, dissolved oxygen (DO), biological oxygen demand (BOD), and chemical oxygen demand (COD) and the ratio between them BOD/COD. Meanwhile, nitrite, nitrate and ammonium ion concentration were also measured. In addition, phosphate and silicate were also analysed. Salinity percentage for all water in the studied station was considered.

Characterization of sediment sample

Grain size and texture

The analysis of the grain size of the sediments (Texture), to find out the nature of the bottom in the study area, was carried out by means of a dry technique for each one phi interval (Folk, 1974). Using this technique, seven fractions were obtained from least to largest: mud (Ø5); very fine sand (Ø4); fine sand (Ø3); medium sand (Ø2); coarse sand (Ø1); very coarse sand (Ø0) and gravel (Ø−1). The different fractions of the samples were grouped into three main categories: coarse granular deposits (C.S.G) (Ø - 1 + Ø0 + Ø1), medium-grained deposits (M.S.G) (Ø2 + Ø3) and fine-grained deposits (F.S.G) (Ø4 + Ø5).

Organic matter content

Determination of organic matter content (TOM) for each sediment samples was calculated as ignition C loss at 550 according to the method of Dean (1974).

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

Where wt, is the weight of the sediment sample before and after ignition.

Statistical analyses

SPSS package deal (One way ANOVA) was used to calculate the differences among benthic fauna and bacterial communities at studied stations. Species diversity (H\`), species richness (SR), eveness (J') and community dominance index (CDI%) were performed to compare the variations among the benthos at different stations within the station at Suez Bay. These categories were calculating according to the Shannon-Wiener's equation (1963), Margalef (1958) and McNaughton (1968). Significant differences, principle coordinate analysis (PCO) and canonical correspondence analysis (CCA) were also performed using XLSTAT program, version 2014. The relationship between environmental variables; bacterial and benthic-faunal communities at different stations were proceed according to Gonzalez et *al*. (2008).

RESULTS

Physico-chemical parameters

As shown in Figure (2 A), the water temperature fluctuated between 24.6 and 19.3C° as recorded in stations IX and IV, respectively. The pH recorded allover the studied stations was slightly alkaline (pH 7.8 for St VI and VIII) to alkaline (pH 8.6 for St III). For the dissolved oxygen content, the highest DO was reported in station I (6.45mgO_2/l) while the lowest one was recorded in station VI (3.2 mgO_2/l). Meanwhile, BOD, as an index of the degree of organic pollution in water, St X recorded the highest value (Fig 2B) followed by St I, XI, II and IX which recorded 2.80, 2.75, 2.55, and 2.5 mgO_2/l, respectively. Chemical oxygen demand (COD), also showed variation among the studied stations where the maximum value was recorded in St IV and the lowest COD was recorded in ST VII (4.69 and 2.30 mg O_2/l, respectively). Water salinity measured showed a slight variation among the studied station with average range between 40.63 % to 37.70% for St XI and VIII, sequentially.

Among the various inorganic nitrogenous compounds, NH_4^+, NO_2^- and NO_3^- were measured which considered as the most important nutrients for aquatic animals (Fig 2C). For nitrite ion, the highest value of nitrite in water samples was manifested at St VIII (5.164 µmol/l), while the lowest amount detected in St V and IV (2.76 and 2.78 µmol/l, respectively). In the rest of studied stations, NO_2- was fluctuated between 3.02 and 4.86 µmol/l (Fig. 2C). For nitrate content, the recorded data showed that the maximum concentration of NO_3^- was 8.75 (µmol /l) at St VIII, while the minimum nitrate value was 4.89 (µmol/l) and recorded at St XIII. However, the dissolved ammonium measured in water in of the Suez Bay was varied between 3.02 µmol/l and 6.43 µmol/l, which recorded in St VII and St VIII, respectively. However, It is obvious that St VIII recorded the highest in the nitrogenous measured parameter (Figure 2 C). In parallel, the measured value of phosphate ion was also the highest in St VIII (4.33 µmol/l) the lowest concentration was 1.97 µmol/l and recorded in St V. However, the concentration of the reactive phosphate for the rest of studied stations was fluctuated from 2.05 µmol/l to 2.93 µmol/l. In addition, the measured values of silicate were slightly varied among the studied stations except for St XIII and XI which recorded the highest value (7.98 and 5.55 µmol/l, respectively) and St XII which recorded the lowest value (2.57 µmol/l).

Salinity, expressed in percentage, showed variation among the studied station in which St XI recorded the highest salinity value (40.63 %) compared to the rest of the selected stations (Fig. 2D).

Characterization of sediment samples

Grain size and texture

In the investigated area, the soil texture was sandy soil where the sand fraction was represented by the highest value in compared to all studied stations (Figure 3). Meanwhile, group of coarse fraction sediments (Ø−1+Ø0 +Ø1) estimated an average of 27.78 % of the total sediment percentage; while the medium sediment group (Ø2+Ø3) recorded the percentage 27.47 % and the fine fraction group (Ø4+Ø5) recoded the greatest one (44.75 %). The gravel percentage ranged from 1.06 to 45.2% with an average of 19.61%; the average sand ratio was between 49.65 and 96.99% and the average 72.61%, while the mud ranged between 0.15 and 43.21% with an average of 7.78% (Figure 3).

Sand (Ø2) recorded the highest mean value of samples (72.61%), while clay (Ø5) recorded the lowest rate (7.78%). Station XI recorded the highest percentage of gravel (45.20 %), while station XII estimated the lowest one (1.06). Sand attained its maximum percentage in St VII (96.99%), while station VIII recorded the least one (49.64%). As for mud, the highest percentage was recorded in St XII (43.21%), but the lowest percentage was in St VI (0.15%).

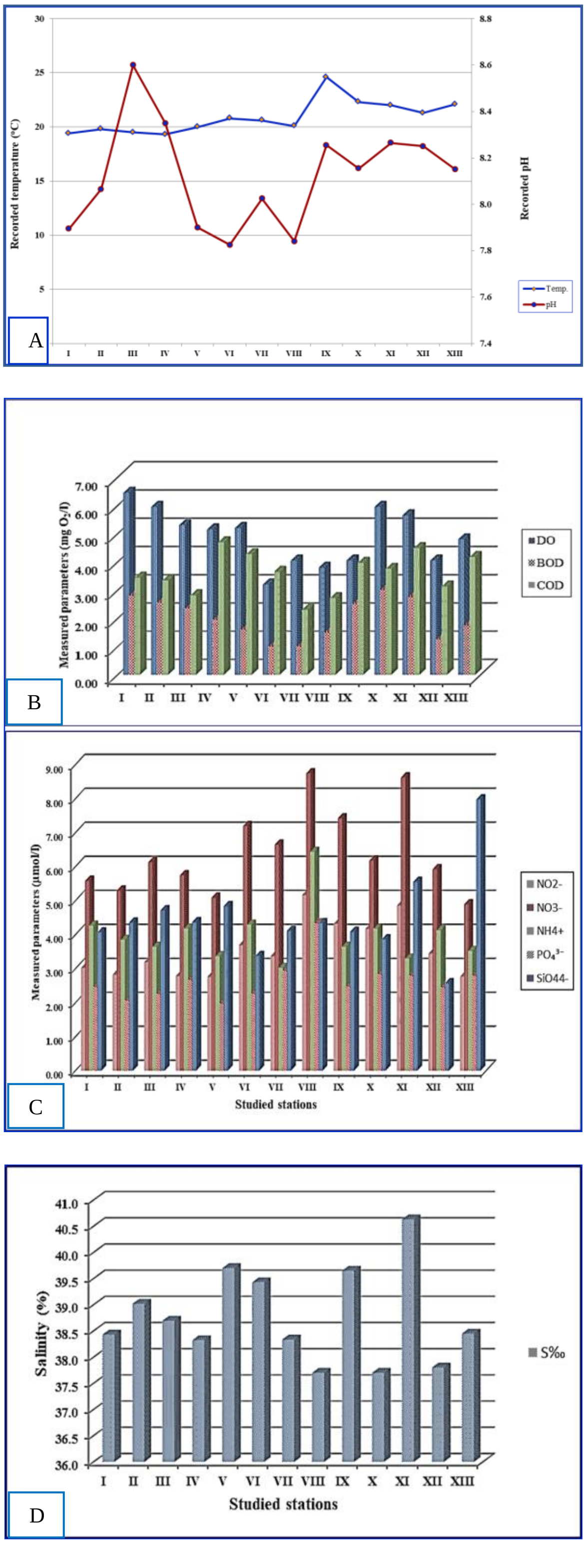

Figure (2): Physico-chemical parameters of water samples collected from different stations of the study area. (A),represents measured temperature and pH; B, illustrats DO, BOD and COD; C, different measured nutrients; D, shows the measured salinity (%).

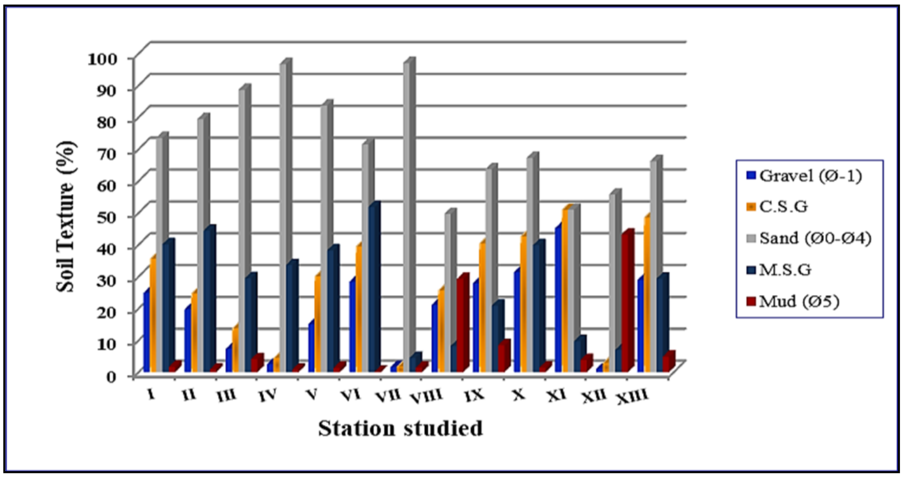

Figure (3): Soil texture of sediment samples collected from different stations at Suez bay.

Total organic matter (TOM %) and CO$_3$%

Total organic content of sample sediments recorded variation which considerably high among the selected stations. Stations VIII, IX and XII were higher than the rest of station samples (Figure 4). Among these stations, St IX was significantly the highest in TOM (16.89 %) followed by St VIII (15.99%) and St XII (12.45%). Meanwhile, St X and XIII recorded a moderate range of organic matter between 8.34 to 5.48 % (Fig. 4). The rest of the examined sediments were fluctuated in narrow range of 4.53 to 3.12 %.

For CO_3 content, St I was the lowest and recorded 17.11 %. However, in Sts II, III and IV, there was an sudden increase in CO3 content and recorded the highest value of 61.09 %. Although the increment of the CO_3 content recorded a unexpected decrease was recorded (ST V with 20.19 %), an increase in CO_3^- value was flown to increase (Fig. 4), This fluctuation was continued among the rest of selected station.

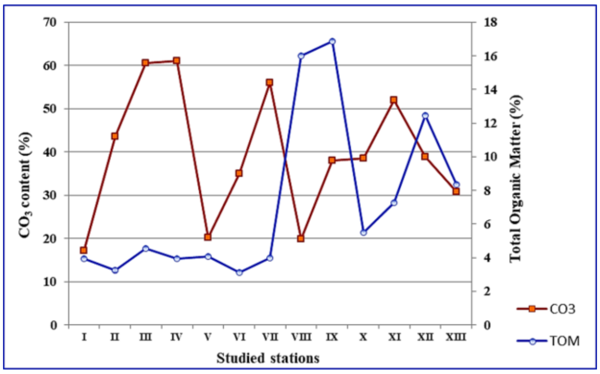

Figure (4). Total organic matter percent and Carbonate ion (CO_3^-) values, represented in percentage, recorded in selected stations.

Macro-benthic faunal assemblages in the Suez Bay

A total of 62 macro-benthic species belonging to 5 taxonomic groups were identified in the samples collected at selected stations in Suez Bay (Table 1). Among the groups recorded, Polychaeta was the most dominant group in terms of the number of species (24 species out of 62, represented by 38.7%). In parallel, the mean number of individuals was the highest (3631 individual/m² with 47.3%). However, Mollusca recorded the second dominant group with means of 2586 individual/m² and 22 species (35.48%). Crustacea recorded the third dominant group (12 species and 2234 individual/m²), followed by Echinodermata (3 species and 92 individual/m²). In addition, Urochordata recor-ded the lowest dominant group where only one species and 50 individual/m² were detected (Figure 5).

Eight species, namely *Spirobranchus kraussii*; *Perinereis nuntia brevicirrus*; *Perinereis nuntia typica*; *Lepidonotus squamatus*; *Brachidontes pharaonis*; *Planaxis sulcatus*; *Amphibalanus* Amphitrite and *Sphaeroma serratum*, comprised 85% of the total number of individuals encountered in the benthic fauna in Suez Bay. *Spirobranchus kraussii* was being the most dominant one in the area where its density ranged from 300 ind./m^2 in St. IX to 13500 ind./m^2 in St. X in the investigated area (Table 1).

Density and diversity of benthic fauna calculated in the Suez Bay showed a variation among studied stations (Table 2). There was a significant difference (P< 0.05) among St X and Sts III; IV; V and IX where, St I reported the highest diversity (H') and species richness (SR) (35 species and 3.52, respectively). In general, diversity tends to decrease, when community becomes numerically dominated by one or few species. The lowest evenness or equitability coupled with the lowest diversity index estimated as in the St II (E= 0.402 and H'= 1.262, respectively) .This is due to the domination of only one species, *Brachidontes pharaonis*, where it appeared by 10700 ind. /m^2 (represents 75.5 % of the total recorded individuals). The highest community dominance index was found in the St IV (CDI= 83.05%), as it recorded a small rate of evenness (E=0.46), and this is due to the uneven distribution between individuals of different species.

High evenness or equitability occurs when species are equal or virtually equal in abundance and is conventionally equ-ated with high diversity (Table 2). The community structure in the St V is characterized by higher species evenness (E=0.918) as numerical dominance is rela-tively evenly shared among 20 species which are present in this area. This results in higher species dive-rsity (H'= 2.749) consequently, recorded the lowest community dominance index (CDI=25.19%).

However, the St VI recorded the lowest individual density with the minimal species diversity, as it achieved the least richness in species as well (1405 ind. /m^2; 7 species and SR=0.83, respectively). Meanwhile, St X recorded high species and individual number (26 sp. and 37210 ind. /m^2, respectively). Therefore, this station has a relatively high species richness (SR= 2.378); diversity (H'= 1.831) and evenness (E=0.562).

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Table (1): Community of Macro-benthic fauna (animals/m²) at the different stations of the Suez Bay recoded at time period of the experiment, from Summer (2019) to Winter (2020).

Recorded species (No/m^2)	Studied Stations													Total
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	
							Polychaeta							
a-Sedentaria forms														
Spirobranchus kraussii	5900	—	2750	8300	—	—	9500	—	300	13500	10200	9700	8700	68850
Clymenella torquata	—	75	—	—	—	—	150	—	—	—	—	—	—	225
Chaetozone setosa	—	125	—	175	140	—	—	—	—	—	—	—	275	715
Cirratulus cirratus	—	—	—	140	350	—	150	—	—	100	—	50	—	790
Polydora sp.	—	—	265	—	—	—	—	—	—	175	250	—	—	690
Pista cristata	50	—	—	—	50	—	—	—	—	—	—	—	—	100
Capetella capitata	—	—	—	—	—	—	255	—	—	—	375	—	150	780
Nainereis laevigata	—	—	—	—	130	—	—	—	—	—	75	—	—	205
Orbenia ornata	200	—	—	—	—	—	—	—	—	—	200	—	—	400
b-Errantia forms														
Halla parthenopeia	—	—	—	75	—	—	—	—	—	—	—	—	50	125
Lumbriconereis funcalensis	—	—	—	—	—	—	—	—	—	—	—	—	100	100
Perinereis nuntia brevicirrus	450	415	475	400	175	275	575	—	425	575	500	325	405	4995
Perinereis nuntia vallata	—	125	—	270	—	—	—	—	—	225	—	200	—	820
Perinereis nuntia heterodonta	75	305	50	—	—	305	130	—	300	50	—	125	150	1490
Perinereis nuntia typical	175	130	130	125	300	—	455	—	125	255	225	—	175	2095
Perinereis cultrifera typical	—	375	75	130	50	325	150	—	130	175	130	75	125	1740
Perinereis cultrifera floridana	125	165	75	—	—	—	130	—	150	125	280	—	—	1050
Perinereis cultrifera perspicillata	130	—	—	—	—	—	—	—	—	305	—	—	150	585
Perinereis vancaurica	—	—	—	—	—	—	—	—	—	25	—	—	—	25
Lepidonotus squamatus	400	125	130	355	—	—	200	—	130	450	840	330	400	3360
Syllis sp.	225	—	225	—	—	—	—	—	—	—	475	80	—	1005
Eunice antennata	—	150	—	175	75	—	—	—	—	—	—	—	—	400
Glycinde multidens	—	—	—	—	—	—	125	—	—	—	50	—	—	175
Lysidice ninetta	—	50	—	—	—	—	—	—	—	—	—	—	—	50
							MOLLUSCA							
a-Polyplacophora														
Chiton olivaceus	—	—	—	—	—	—	—	—	—	50	—	—	—	50
b-Gastropoda														
Patella sp.	25	75	—	155	—	150	50	—	25	75	—	50	—	605
Diodora ruppellii	—	100	—	—	—	75	—	—	25	—	—	—	—	200
Planaxis sulcatus	600	175	630	—	—	—	730	—	—	1000	100	125	425	3785
Cellana eucosmia	150	225	—	175	—	—	—	—	—	—	—	—	—	550
Murex tripulus	75	—	—	—	125	—	—	—	—	—	—	—	—	200
Clypeomorus sp.	525	—	—	100	—	—	—	—	—	—	—	—	—	625

Table (1): continued

Recorded species (No/m^2)	Studied Stations													Total
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	
Cerithium caeruleum	130	–	–	–	–	–	130	–	–	–	–	–	–	260
Fusus marmoratus	280	–	–	100	25	–	–	–	–	–	–	–	320	725
Tectus dentatus	–	–	–	25	25	–	–	–	–	–	–	–	–	50
Trocus erythraeus	130	–	–	100	155	–	–	–	–	130	–	150	225	890
Nerita albicilla	275	75	–	75	150	–	–	–	–	–	–	–	–	575
Volema pyrum	–	–	25	–	–	–	75	–	25	–	–	–	–	125
Onchidium peronii	–	–	50	–	–	–	125	–	–	125	–	–	475	775
c-Bivalvia														
Brachidontes pharaonis	1400	10700	875	10350	180	250	2850	–	200	12200	8500	4950	2800	55255
Pinctada radiate	150	–	–	100	–	–	–	–	–	–	–	–	–	250
Gafrarium pectinatum	50	50	–	155	50	–	75	–	–	150	130	–	210	870
Circe (circenita)calipyga	125	50	50	50	–	–	–	–	–	25	–	–	–	300
Callista sp.	–	–	–	–	–	–	–	–	–	–	–	–	50	50
Atactodea striata	–	–	–	–	–	–	225	–	–	–	–	–	130	355
Tellinella staurella	–	–	–	–	–	–	80	–	–	–	–	–	–	80
Macoma sp.	–	–	–	–	–	–	655	–	–	–	–	–	–	655
CRUSTACEA														
a-Cirripedia														
Amphibalanus amphitrite	1750	350	–	500	325	–	850	–	150	2000	700	1750	2800	11175
b-Decapoda														
Portunus pelagicus	75	–	75	–	–	–	–	–	–	–	–	–	–	150
Leptodius exaratus	75	125	130	50	200	25	100	–	–	225	75	50	130	1185
Macrophthalmus depressus	–	–	175	–	–	–	–	–	–	–	–	–	–	175
Metopograpsus messor	125	50	150	50	50	–	–	–	–	–	50	–	–	475
Hermit crab	625	–	–	–	–	–	–	–	–	–	–	–	–	625
c-Isopoda														
Sphaeroma serratum	650	–	1175	–	–	–	1305	–	775	3495	1500	3380	1690	13970
Paradella heptaphymata	–	–	–	–	–	–	–	–	–	–	150	–	–	150
Cymodoce truncata	–	–	–	–	–	–	–	–	–	–	–	–	150	150
d-Amphipoda														
Dulichiella fresnelii	225	–	350	250	–	–	–	–	–	875	450	–	–	2150
Elasmopus pecteniorus	250	–	425	–	–	–	–	–	–	–	650	–	–	1325
Stenothoe gallensis	250	150	–	–	–	–	–	–	–	875	550	–	150	1975
ECHINODERMATA														
Astropectine polyacanthus	25	–	–	25	75	–	–	–	–	–	–	–	–	125
Sea urchin	–	–	–	–	–	–	–	–	–	25	–	–	–	25
Holothuria sp.	25	–	–	50	50	–	–	–	–	–	–	–	–	125
UROCHORDATA														
Ascidia sp.	50	–	–	–	–	–	–	–	–	–	–	–	–	50
Total individual/m²	**15770**	**14165**	**8285**	**22455**	**2680**	**1405**	**19070**	–	**2760**	**37210**	**26455**	**21340**	**20235**	**191830**
Total species/m²	**35**	**23**	**21**	**27**	**20**	**7**	**24**	–	**13**	**26**	**23**	**15**	**24**	**62**

Table (2): Biodiversity index of different studied stations at Suez Bay.

Measurment	Studied Stations													Total
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	
Indivi./m² †	15770	14165	8285	22455	2680	1405	19070	—	2760	37210	26455	21340	20235	191830
Sp./m² ††	35	23	21	27	20	7	24	—	13	26	23	15	24	62
(SR)	3.518	2.302	2.22	2.595	2.407	0.83	2.334	—	1.52	2.375	2.16	1.404	2.32	
Evenness (E)	0.711	0.402	0.76	0.463	0.918	0.91	0.61	—	0.85	0.562	0.599	0.57	0.642	
Divers.(H')	2.528	1.262	2.32	1.527	2.749	1.76	1.939	—	2.19	1.831	1.878	1.545	2.039	
CDI %	48.51	78.47	47.4	83.05	25.19	44.8	64.76	—	43.5	69.07	70.69	68.65	56.83	

†Population densities, No Individual/m²; †† species number/m²; SR, species richness; Evenness, E; diversity index, H') and dominance %, CDI %.

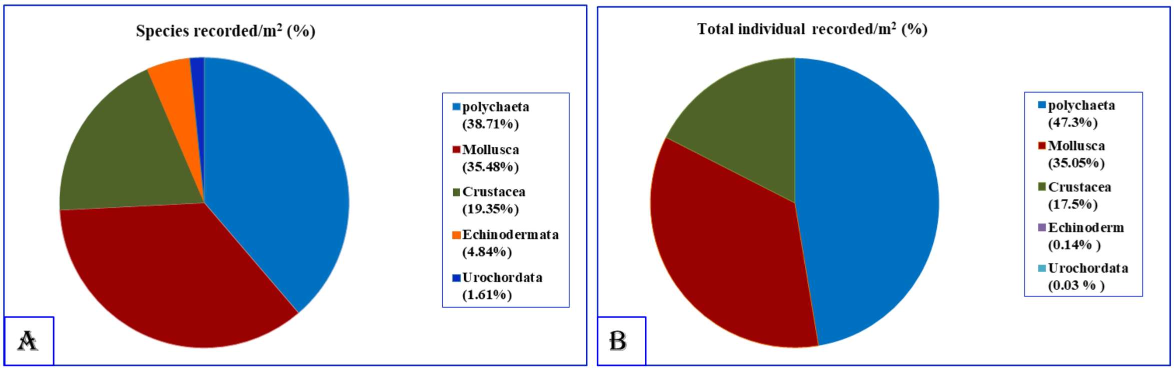

Figure (5): The dominance of recorded benthic taxonomic groups expressed in number of species (A) and number of individuals in the investigated area (B).

Microbial population of some selected microbial indicators in Suez Bay

In the Suez Bay, the annual number of bacterial communities in water was 21598 cfu/100 ml with an average of 1661.4 cfu/100 ml Fig 6 A&B). Meanwhile, sediments recorded less bacterial count (16331 cfu/g, with the average of 1256.23 cfu/g, Fig 7 A & B). From figure (6), it is clear that the annual bacterial counts were flourished in summer than those recorded in winter. In winter, TC was significantly the highest ($P \leq 0.05$) in ST XIII followed by St III (180 and 80 cfu/100 ml, respectively). Meanwhile, in summer, Sts XIII and IX were the highest and recorded 620 and 526 cfu/100 ml, respectively. Contamination with faecal coliform was reached its maximum count in St IV followed by St III, XI and VII (800, 400, 280 and 260 cfu 100 ml^{-1}, respectively). In meantime, St XIII and I recorded the lowest value of *Ec* contamination (Fig. 6). For summer season, St XIII was the highly polluted station and recorded 495 cfu/100 ml followed by Sts IX and VII (258 and 200 cfu/100 ml, respectively).

For contamination with faecal Streptococci seasonal variation was significantly different and recorded high contamination in winter than in summer, where STs IV and III recorded 500 and 400 cfu/100 ml, respectively (Fig 6 A). However, in summer St IX recorded the highest contamination compared to the rest of station (146 cfu/100 ml). This recorded value was significantly less than those recorded in winter (Fig. 6 B).

For highly pathogenic bacteria of genus *Aeromonas*, seasonal variation was highly increased in summer than in winter and recorded the highest contamination at St XIII (585 cfu/100 ml). In winter, Sts III and XI were the highest (300 and 260 cfu/100 ml, respectively). Contamination of water with *Vibrio* species at the studied stations revealed that in winter season was almost under the standard count where the highest count was recorded in Sts XIII followed by VIII (31, and 23 cfu/100 ml, correspondingly). In summer, a flourishment in bacterial count was reported (Fig, 6). St IX was significantly the highest and recorded 495 cfu/100 ml. Other stations, XIII and V, are also reported high *Vibrio* count but less than St IX (394 and 387 cfu/100 ml, respectively).

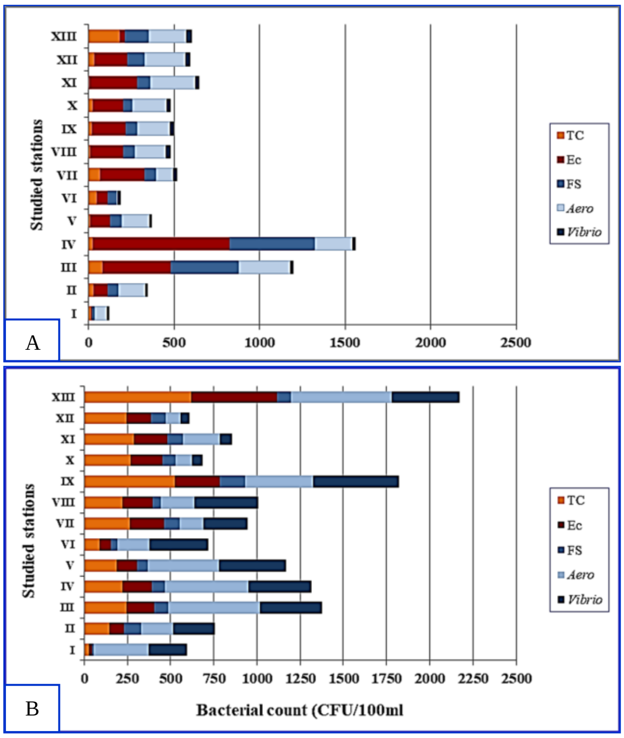

Figure (6): Seasonal variations of bacterial counts as an indicator of water pollution; A, bacterial count in winter; B, bacterial count in summer.

For sediment samples, bacterial contamination, in winter season, was slightly higher than those of water samples (Fig. 7 A&B). Total coliform recorded 1.5 fold higher than those recorded in winter. Meanwhile, *Ec* was less flourished and recorded 0.14 fold than recorded in winter. The same increment pattern was recorded by FS (1.5 fold of FS in winter). Pathogenic *Aeromonas* and Vibrio count also recorded an increment (13.6 and 90 % for *Aeromonas* and *Vibrio*, respectively). For comparison between studied stations, St XIII was the highest in TC count, in winter, and recorded 270 cfu/g. In summer, the TC count was less and ST IX was the most contaminated station (208 cfu/g). For Ec count in winter, St IV was the highest followed by ST III and VII (700, 500 and 400 cfu/g, respectively). This bacterial contamination was reduced and record less count in the rest of tested stations. However, St IX followed by Sts VII and V (174, 131 and 111 cfu/g, sequentially) were the highest in summer. For FS count, winter season recorded a flurishment which significantly ($P\leq$ 0.00.1) dropped in summer. In winter, St IV and III were the highest in count and recorded 475 and 450 cfu/g. In parallel, Sts XIII and XII were the highest and recorded 92 and 91 cfu/g (Fig 7 A&B). *Aeromonas* count, in winter St XI and XIII recorded the highest compared to the rest of the stations (290 and 250 cfu/g, respectively). Meanwhile, in summer, St I and XIII have the highest count (284 and 248cfu/g). For *Vibrio* count, although Sts XII and XIII recorded the highest count in both seasons of sample collection, flourishment of bacterial count was reported in summer and was fivefold of those in winter (46, 52cfu/g ,in winter, 269 and 259 cfu/g, in summer, respectively; Fig 7 A&B).

For evaluating the environmental variables that affect the distribution of benthic-fauna and inhabitant bacterial communities, figure (8 A & B) is illustrating the function factors. Symmetric canonical correspondence analysis (CCA), among macro-benthic fauna; bacterial communities; stations and 14 environmental variables; was by representing 85.71% and 79.23%, respectively. The first axis was shown in figure (8 A) explained 58.86% of the total variance and was associated to NO_2; NO_3; S‰ and mud. They are the most influencing variables for benthic dominant species. Whereas in Figure (8 B) it turns out that bacterial communities, unlike the benthic fauna, they grouped in the opposite direction and were influenced by three important criteria, COD, SiO_4 and pH, which alone formed 75% of bacterial associations in water, while the temperature, pH and CO_3 showed a relationship of 40 and 90 and 80% in bacterial communities of sediments.

To study the possible associations between benthic fauna; bacterial comm-unities and stations, the principle coordinate analysis (PCO) was performed (Figure 9 A & B). In benthic fauna, stations II, III, IV and VII were associated with a high degree of similarity on the threshold of similarity 60% as well as Sts I and XIII. The relative grouping among Sts XII, IX and V are clearly visible at a similarity of 40%. The location of the Sts VI and VIII at the end of the negative side of the PCO axis as well as the Sts X and XI reflect the diffraction of these stations from the other selected stations (Figure 9 A). On the other hand, there was a great similarity between the bacterial communities and Sts IX, VII and V estimated at 60% because these stations are linked to sanitation, especially St VII, which is located in the Kabanon area and has the drain coming from the Ataqa sewage station. The similarity by 40% was displayed in Sts XII, X and I. While 20% similarity are represented by Sts I and VI; XIII, II and IV (Figure 9 B).

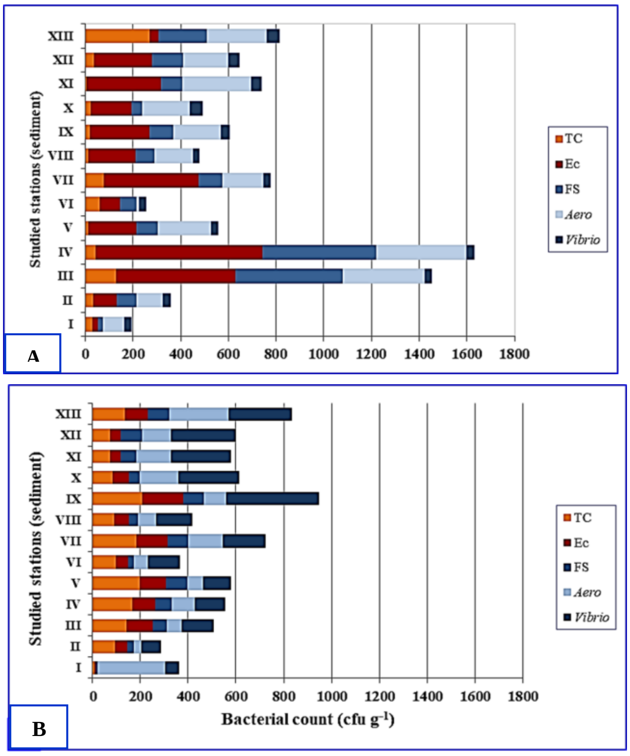

Figure (7): Seasonal variations of bacterial counts as an indicator of sediment pollution; A, bacterial count in winter; B, bacterial count in summer.

DISCUSSION

Variables that directly affect benthic fauna and bacterial organisms were measured to assess water quality and sediments in the Suez Bay .As temperatures rise, the solubility of oxygen and other gases in water decreases .When the water is very warm, it will not contain enough oxygen for the organisms to survive. In the present study, water temperature ranged from 19.3C° estimated at station IV to 24.6 C° recorded at station IX with an average of 20.91. Station IX (Ataqa Electric Power Station) is located under the influence of the water used to cool the machines that were pushed to this area with pollutants in addition to thermal pollution in this region (Belal and Ghobashy, 2012). These results are explained by the CCA, as it confirmed that station IX and X, the temperature was the main factor affecting them. In addition, St IX estimated the highest counts of *Vibrio* sp.; the highest tem-

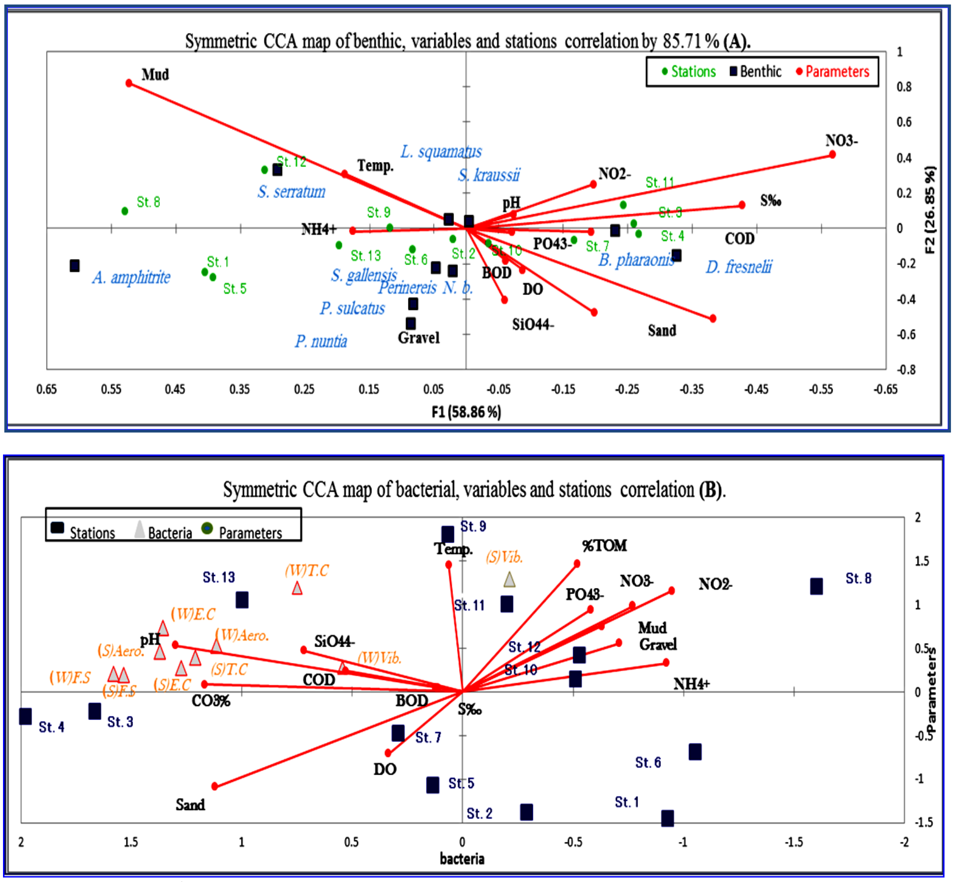

Figure (8): Biplot of canonical correspondence Analysis (CCA), Relationship between environmental parameters; stations and (A) macro-benthic fauna (B) bacterial communities (W= water; S= sediments, ex :(W) T.C= Total coliform in water).

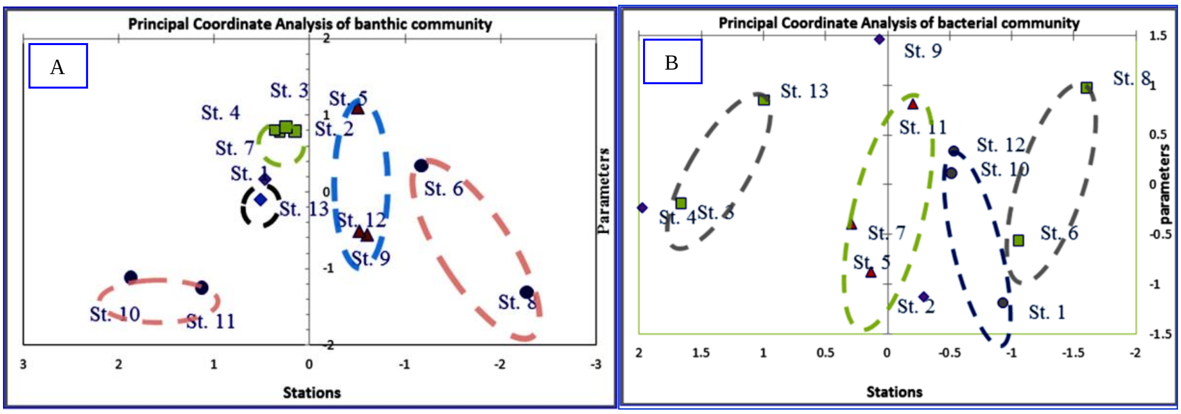

Figure (9): Biplot of principle coordinate analysis (PCO), A; analysis of macro-benthic fauna, B; analysis of bacterial communities in different stations.

perature and low density and diversity of benthic fauna. These results are in line with what (Boer *et al.*, 2013) decided that some species of Vibrio sp. greatly reduced at> 10 ° C, while the other species of Vibrio sp. increased rapidly at> 20° C . Thus, they hypothesized that, Vibrio sp. exhibited significant spatial heterogeneity across different benthic environments. It is worth noting that *Vibrio sp* in this study is higher than that recorded by Kumar *et al.*, (2017), which scored 0.01×10^2 x 3.12×10^2 cfu/ml.

The solubility of elements and compounds increases with increasing pH levels, which makes toxic chemicals "more mobile" and increases the risk to aquatic life by absorbing these harmful substances. The pH fluctuated between 7.83 and 8.6 with an average of 8.12. While salinity ranged from 37.7‰ to 40.63 ‰. These results are consistent with Abu Al-Khair *et al.*, (2016), where salinity ranged from 37.65 ‰ to 42.23‰ and pH recorded the same value (8.17) in the southern and northern parts (Suez Bay) of the Suez Gulf.

According to the United States Environmental Protection Agency (USEPA, 1999), the level of oxygen in marine waters ranges from 5 to 10 mg / l. This is considered an indication of the health status of the water, while values less than 5 mg / l are considered dangerous to the marine environment and its creatures. In the present study, the Dissolved Oxygen (DO) content in the water samples, ranged between 3.2 to 6.45 mg / l with an average of 4.89. The lowest value was found in station VI while the highest one was in station I. Abu Al-Khair *et al*., (2016) found that the concentrations of dissolved oxygen were higher in the northern parts (7.44 mg / l, Suez Bay) than in the southern parts (6.83 mg / l) of the Gulf of Suez . While Hamed *et al*., (2010) found high concentration of DO (8.76-10.17 mgO_2/l) in the Suez Bay. The high degradation of organic matter is the reason for the low dissolved oxygen content in the water, which indicates a high level of pollution in the water. When oxygen is low in water, it is considered a shelter for bacteria and other pathogens, which are anaerobic and cause harm to human health (Khalil *et al*., 2014).

If the BOD/COD ratio for untreated wastewater is 0.5 or greater, the waste is considered to be easily treatable by biological means. If BOD/COD < 0.3, biodegradation will not proceed, thus it cannot be treated biologically, because the wastewater generated from these activities inhibits the metabolic activity of bacterial seed due to their toxicity or refractory properties (Abdallaa and Hammamb, 2014). The current study reported that , differences in the biological oxygen demand(BOD)values in the samples were between 0.995 - 2.995 mgO_2/l while the chemical oxygen demand (COD) values for the collected samples were recorded between 2.298 to 4.69 mgO_2/l. Abo-El-Khair *et a*l.,(2016) recorded higher values, in the Gulf of Suez, where the BOD and COD were 0.64-4.72 mgO_2/l and 9.16-12.75 mgO_2/l. These higher concentrations were found to be depending on the quantities of biodegradable organic materials and the effects of land based sources and/or human activities (Emara et al., 2013 and Shriadah, 2002). However, in this study, both the highest (DO) and the highest BOD/COD ratio was observed at St I (6.45 and 0.884 mgO_2/l, respectively) which indicated that the percentage of biodegradable content was higher than non-degradable contents. In addition, St 1 achieved both the highest diversity (35 species) and species richness (SR=3.518) of the benthic fauna. These results were confirmed by the CCA by the presence of St I in the negative side of the axis 1 which confirms that it is far from pollutants and not affected by them. While, it recorded the lowest numbers of bacteria (*Ec*; TC. and FS in water and sediments, in addition to *Vibrio* sp. in sediment samples). The results demonstrated that the higher the dissolved oxygen, the more benthic fauna, and at the same time the number of bacteria decreased. These results are consistent with El-Serehy *et al*., (2016) who decided that a very low density was recorded from the total of meio-fauna, while the population density of benthic microbes showed higher values during the study period. From this it can be said that by using benthic animals and bacteria it is possible to judge the quality of the marine environment. The St IV was the opposite of the first station (St I), and with the exception of the two dominant species (*Spirobranchus kraussii* and *Brachidontes pharaonis*), this station recorded a low density of bottom orga-nisms, while the bacteria achieved the highest abundance of E.C and F.S in both water and sediments. Also, station IV manifested the highest COD, which mean more oxidized organic matter in the water and reduces the levels of dissolved oxygen (DO). Decreased dissolved oxygen can lead to anaerobic conditions that are a haven for bacteria and other pathogens, which are harmful to higher aquatic life forms. Whereas in station VI the ratio was less than 0.3, and at this rate the process of biodegradation stops because the wastewater arising from these activities frustrates the activities of bacteria in the metabolic process, due to its toxicity. The lowest density, diversity and species richness were recorded at the VI station (Zayatiyat Port). In addition to that it recorded the lowest pH, the least (DO), the least BOD, and also the lowest BOD/COD ratio and the lowest percentage in the organic matter in the sediments. A very low oxygen demand indicates either clean water or the presence of a toxic or non-degradable pollutant. This dramatic change in the environmental variables in this station indicates the quantity and type of pollutants that are received at this port (El-Agroudy *et al*., 2007). Annually there is about 1.75 X 108 m^3/year of oil wastes, from refineries, are discharged to the Suez Bay. In addition, it estimated a great amount of petroleum hydrocarbons in its sediments (359.6 mg/g) as reported by Belal (1995). The location of the stations VI and VIII at the end of the negative side of the PCO axis reflect the diffraction of these stations from the other stations.

One of the most important classes of inorganic nitrogen in sea water is nitrate, nitrite and ammonia. Comparing the current results of nutritional salts, it was found that nitrite and ammonia (2.76- 5.16 µ mol/l and 3.02-6.43 µ mol/l, respectively) are higher than what the Riley and Chester (1971) found in oxygen-rich waters (0.01-3 µmol/l and 0.15-3 µ mol/l, respectively). Both phosphorus and nitrogen are important nutrients for the growth of plants and animals, but the slight increase in phosphorus can accelerate plant growth, algae bloom, low dissolved oxygen, and the death of some fish, invertebrates and other aquatic animals. Yang *et al*., (2008) concluded that typical concentrations of phosphorus for the eutrophic coastal waters are on top of (0.15 µ mol/l). The extremely eutrophic systems concentrations of phosphorus are (0.3 µ mol/l) (UNEP/FAO/WHO, 1996). The recorded results indicated that, the phosphate concentration was higher than the environmentally allowed (1.97- 4.33 µ mol/l). Also, the present results was higher than that of Suez Bay (0.44-2.56 µ mol/l) which estimated by Hamed *et al*.,(2010) . Station VIII recorded the highest values of all nutrients in Suez Bay, this station receives a drain from the fertilizer factory as well as the old slaughterhouse. Belal (2019) asserted that this region has high eutrofication and its sediment reached the dead zone and therefore there are no bottom organisms on absolutely in this region. Total coliform in water and sediments, and *Aeromonas* sp. in sediments recorded the highest values in station XIII. This station is in the EL-Adabia area where sanitation is dumped directly into the sea water from home activities as it causes bacterial contamination in addition to the rest of the pollutants .This is consistent with (Mohamed *et al*., 2013) who indicated that household activities and pollutant leakage from sewage systems causes pathogenic bacteria in addition to ammonium nitrate, phosphate, heavy metals and fine organic compounds.

In conclusion, in the study area and with the exception of Station 1, all stations from 2 through 13 are contaminated with a high amount of Escherichia coli and fecal streptococci according to the World Health Organization in both water and sediments. It represents values above the acceptable limit (*Ec* and FS; >100 cfu/100ml), whereas, the total coliform in station XIII achieved higher numbers than recommended by World Health Organization (TC >500 cfu/100 ml). Accordingly, there is a direct relationship between the number of benthic animals and dissolved oxygen and this indicates the quality of the marine environment, but the latter was inversely related to the ratio of the bacterial population in both water and sediments. This means that the more dissolved oxygen, the more benthic animals and the fewer bacteria and vice versa. In consequence from the recorded data, it can be said that benthic fauna and bacterial communities can be used together as a better indicator of the quality of water and sediments in the marine environment than the use of the environmental parameter alone.

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الحيوانات القاعية والمجتمعات الميكروبية كمؤشر حيوي لخصائص البيئة البحرية في خليج السويس، البحر الأحمر، مصر

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الملخص العربي

هذه الدراسة تهدف إلى قياس المتغيرات البيئية ، الحيوانات القاعية وبعض من الأنواع البكتيرية لتقييم جودة المياه والرواسب في جونة السويس . تم التجميع من ثلاثة عشر موقع (محطة) على طول منطقه المد والجزر لجونه السويس(من بور توفيق وحتى الأدبية) في الفترة من صيف (2019) إلى شتاء (2020). بالنسبة لدراسة المتغيرات البيئية فقد تراوحت قيم الأكسجين الذائب (DO) ، الأكسجين المستهلك بيولوجيا (BOD) الأكسجين المستهلك كيميائيا (COD) من العينات المختبرة بين 3.2 - 6.45 ملجم / لتر ؛ 0.995 -2.298 ملجم / لتر ؛ 2.298 - 4.69 ملجم / لتر ، على التوالي . أوضحت النتائج المسجلة أن تركيز الفوسفات كان أعلى من التركيز المسموح به بيئيا (1.97 - 4.33 µ مول / لتر). وهذا يساعد على ازدهار الطحالب وانخفاض الأكسجين المذاب وموت بعض الأسماك والكائنات الأخرى. تم حصر 62 نوعا من الكائنات القاعية ينتمون إلى خمس مجموعات تصنيفيةPolychaeta) ، Mollusca، Crustacea، Echinodermataو .(Urochordata سجلت عديدات الأشواك (Polychaeta) أعلى النسب في التنوع والكثافة (38,71 ٪ و 47.3 ٪ من إجمالي عدد الأنواع والأفراد ، على التوالي) . بينما تمثلت الذيل حبليات (Urochordata) بنوع واحد و 50 كائنًا حيًا / م 2. بالنسبة لدراسة وجود الأنواع البكتيرية فقد سجلت بكتريا البراز الكلية أعلى عدد في المحطة الثالثة عشره يليها المحطة الثالثة والسابعة. أما بكتريا المكورات العصوية فقد لوحظ زيادة أعدادها خلال فصل الشتاء وكانت أعلى من الأرقام المسموح بها عالميا في المحطتين الثالثة والرابعة. وبالنظر إلى وجود البكتريا الممرضة في منطقه الدراسة فقد تبين من خلال تتبع بكتيريا الإيروموناس والفيبريو أن جونه السويس تحتوى على ملوثات كانت السبب الأقوى في نمو هذه الأنواع البكتيرية خلال فصل الصيف في المحطة الثالثة عشر.

كشفت هذه الدراسة أنه، باستثناء الكائنين الغازيين المهيمنين على عشائر حيوانات القاع ؛ والملتصقان على الصخور Spirobranchus kraussii) و (Brachidontes pharaonis، تميل المكونات الميكروبية إلى فرض هيمنتها (زيادة أعدادها) في نفس الوقت الذي تقل فيه الكائنات القاعية خلال فترة الدراسة بأكملها. وعل سبيل المثال فان المحطة الأولى سجلت أعلى (DO) وأعلى نسبة (BOD / COD) و 6.45 , 0.884 مجم / لتر على التوالي). بالإضافة إلى ذلك ، حققت المحطة الأولى أعلى تنوع (35 نوعًا) وثراء الأنواع (SR = 3.518) للحيوانات القاعية. بينما سجلت أقل عدد من البكتيريا Ec) ؛ .TC و FS في الماء والرواسب ، بالإضافة إلى ..Vibrio sp في عينات الرواسب). أوضحت النتائج أنه كلما زاد الأكسجين المذاب ، زاد عدد الحيوانات القاعية ، وفي الوقت نفسه انخفض عدد البكتيريا. وبذلك تشير هذه الدراسة إلى وجود علاقة موجبة (طردية) مع كل من الملوحة والأكسجين الذائب واللافقاريات القاعية ، وفي ذات الوقت هناك علاقة (سالبة) أي عكسية بين الملوحة والأكسجين الذائب وبين المجموعات البكتيرية ، مما يشير بالتالي إلى إمكانية استخدام الكائنات القاعية والبكتريا في الحكم على جودة البيئة البحرية أفضل من استخدام المتغيرات البيئية منفردة . وأيضا أشارت الدراسة إلى وجود تأثير سائد للأنشطة البشرية المنشأ في المنطقة الساحلية لجونة السويس.

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