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Responses of Phytoplankton and Zooplankton Communities to Water Quality in Suez Gulf of the Red Sea, Egypt

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ABSTRACT

Marine plankton in the Red Sea are continuously exposed to various environmental pressures. This study provides a comprehensive analysis of both biological and environmental parameters across five distinct locations along the western coast of the Suez Gulf, Red Sea, Egypt (2021–2022). Our findings highlighted significant seasonal variations in total suspended solids (TSS), chemical oxygen demand (COD), nitrate, and phosphate concentrations, with notable differences observed during autumn. Additionally, the counts of total coliform and fecal coliform ranged from 2.0×10^2 to 4×10^5 and 3.0×10^2 to 7×10^2 MPN/100 mL in locations 1, 2, 3, and 4, respectively. The density of total coliform was consistently detected in all seasons in location 5. Sediment samples revealed metal concentrations ranging from 9 to 3,579 mg/kg for manganese (Mn), 0.25 to 6.5mg/ kg for arsenic, 2.6 to 4,543mg/ kg for iron, 0.03 to 14mg/ kg for chromium, 0.03 to 81mg/ kg for copper, 0.5 to 8.75mg/ kg for nickel, 0.03 to 176.5mg/ kg for lead, 0.03 to 4.25mg/ kg for cadmium, and 4.0 to 336mg/ kg for zinc. The dominant algal groups observed were diatoms, blue-green algae, and dinoflagellates. Maximum algal counts were recorded during autumn (411 org./mL) and spring (381 org./mL). The zooplankton community consisted of five groups: Protozoa, Rotatoria (Rotifera), Arthropoda (Crustacea), and larval stages of both Nematoda and Insecta, with crustaceans being the most prevalent, followed by rotifers. These findings suggest that human activities may significantly influence water quality in certain areas of the Suez Gulf.

INTRODUCTION

The Red Sea stands as a global biodiversity hotspot, notable for its exceptionally high rate of endemism surpassing that of many other marine regions (**Cochran *et al*., 2024)**. This remarkable biodiversity is partly attributed to its extensive coral reef systems, which span approximately 16,000km² **(DeCarlo *et al.*, 2021)**. The region's marine life is profoundly diverse, encompassing a wide array of vertebrate species and supporting complex ecosystem dynamics. This diversity is not only of ecological importance but also holds considerable economic and social value, notably enhancing the region's commercial fisheries **(Ramos & Lisbet, 2021)**. Indeed, the Red Sea's contribution to Egypt's marine fisheries accounts for nearly 47.94% of the total catch, and 14.8% of the nation's overall natural fisheries output **(Farrag *et al.*, 2018)**, highlighting its critical role in the country's aquatic resources sector.

At the northern extremity of the Red Sea, the sea divides near the Sinai Peninsula, forming the Gulf of Aqaba to the east and the Suez Gulf to the west. The latter is subjected to various pollution sources. Notably, shipping and oil transportation activities are significant contributors to marine pollution in the Gulf, alongside extensive offshore and inshore oil production operations. The Gulf is also impacted by agricultural runoff, industrial and domestic sewage, thermal pollution, tourism, and the operation of desalination plants. These pollutants exert multiple stressors on the marine environment, triggering profound changes in marine life, including phytoplankton, sea grasses, seaweeds, coral reefs, and invertebrates **(TEAM, 2000; NPA, 2003)**.

Heavy metal pollution, characterized by its affinity for proteins that disrupt metabolic functions **(Kosakivska *et al.*, 2021)**, poses a severe threat to aquatic organisms. Unlike organic pollutants, heavy metals cannot be easily removed from marine environments through chemical methods or biodegradation, leading to their persistence and potential accumulation beyond safe levels **(Sulistyowati *et al.*, 2023)**. Sediments act as the primary repository for heavy metals, serving both as reservoirs and potential sources of bioavailable metals, thereby complicating the biogeochemical dynamics of these contaminants. Understanding heavy metal concentrations in water and sediments is crucial for assessing pollution levels in coastal areas **(Tlig *et al.*, 2023)**.

Plankton communities, essential components of marine and freshwater food webs, owe their significance to photosynthesis, which provides a primary food source for various higher trophic levels **(Waniek & Holliday, 2006)**. Furthermore, their abundance and spatial distribution make them invaluable for monitoring water quality and pollution levels **(Zaki *et al.*, 2021)**. Phytoplankton diversity and abundance are influenced by a range of environmental factors, including nutrient availability, predation, and input from terrestrial sources. The composition of phytoplankton communities varies with hydrological conditions like light intensity, temperature, salinity, pH, nutrients, and water movement **(Etisa *et al.*, 2024)**. Coastal marine ecosystems are typically dominated by diatoms, but shifts in hydrological and climatic conditions can favor other phytoplankton groups. Such shifts in dominant species have cascading effects throughout the food chain, affecting fish populations, marine mammals, and birds **(Murphy *et al.*, 2016)**. Recognized for their rapid response to environmental changes, phytoplankton are excellent bioindicators of the effects of natural and anthropogenic alterations in coastal ecosystems **(Rimet & Bouchez, 2012)**. They reflect the complex interplay of environmental factors that shape near-shore and coastal phytoplankton communities **(Bhaskar *et al.*, 2011)**.

Zooplanktons occupy a pivotal position within the pelagic food web, bridging primary producers such as phytoplankton, with higher trophic levels including fish. Consequently, their abundance and community structure are critical in influencing the dynamics of fisheries resources **(Ratnarajah *et al.*, 2023)** and the biodiversity of apex trophic levels, such as birds and mammals. The impact of climate warming on zooplankton populations has ignited considerable scientific debate, given their sensitivity to environmental changes **(Gyllström *et al*., 2005; Mackas *et al*., 2007; Lewandowska *et al*., 2014; Šorf *et al.*, 2015; Hall & Lewandowska, 2022)**. Marine ecosystems are subjected to an influx of excess nutrients, contaminants, and other elements from terrestrial sources through rivers, atmospheric deposition, and sediment leachates **(Viitasalo & Bonsdorff, 2022)**. The complexities of ecosystem responses to global climate change, exacerbated by anthropogenic activities, are compounded by the synergistic interactions between climate and various environmental stressors. These include eutrophication, pollution, habitat alteration, overfishing, and the introduction of alien species, all of which profoundly impact ecosystem functionality across temporal and spatial dimensions **(Reusch *et al*., 2018; Lu *et al*., 2020; Bonsdorff, 2021; Viitasalo & Bonsdorff, 2022)**.

Insights into the cumulative effects of different environmental changes on specific natural communities, especially within the Suez Gulf of the Red Sea, are notably scarce, therefore this study aimed to evaluate the effects of specific environmental stressors on phytoplankton and zooplankton communities, particularly in response to anthropogenic activities across five distinct locations within the coastal waters of the western Suez Gulf during the period of 2021-2022.

MATERIALS AND METHODS

Water samples were systematically collected on a seasonal basis throughout the years 2021 and 2022, utilizing Nansen bottles crafted from Teflon to ensure inertness with all measured parameters. This study focused on five strategically selected locations that represent a diverse range of ecological habitats along the western coast of the Suez Gulf. These locations included Zafarana (1: 29.6452 N & 32. 39649 E), Porto Sokhna (2: 29.30641N & 32.239 E), Al Galala (3: 29.12325N & 32.37498 E), Petroleum Port (4: 2947.395N3226.4850 E), and Al-Attaka (5: 29.54216 N & 32.2781 E), as depicted in Fig. (1). In addition to water samples, sediment samples were obtained using a grab sampler provided by Hydro-bios, Kiel, Germany, to encompass a comprehensive analysis of the area's environmental condition.

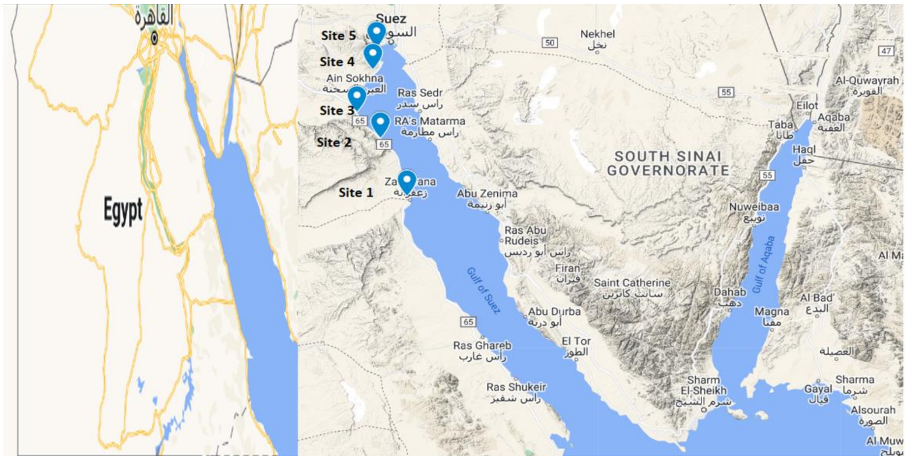


Fig. 1. Sampling locations (n=5) along Suez and Zaafrana transect

Physico-chemical analyses

The physicochemical parameters such as pH and electrical conductivity (EC, μS cm−1) were measured using a Portable Multi-parameter **(APHA, 2017)**. Dissolved oxygen (DO) was measured in field using a multiparameter portable DO Meter (HANNA HI 98193, Hanna instruments). Additionally, dissolved oxygen (DO) was measured using a bench-scale DO Meter. Samples for chemical oxygen demand (COD), ammonia (NH4+), total phosphorus (TP) and nitrogen (TN) were preserved by acidification to pH = 1–2, using sulfuric acid (0.1 N) and transported to the laboratory to determine TN and TP using standard methods **(APHA, 2017)**. Samples for other parameters were preserved in an ice box at 4°C and transported to the laboratory for analysis. Total suspended solids (TSS) and biological oxygen demand (BOD) were determined following standard methods **(APHA, 2017)**.

Heavy metals analysis

Heavy metals were determined in water and sediment samples using the Agilent 5100 Synchronous Vertical Dual View (SVDV) ICP-OES, with Agilent Vapor Generation Accessory VGA 77. All samples were digested in an acid solution using Anton-Paar microwave digestion system (Multiwave PRO) according to the method of **APHA (2017)**. For each series of measurements, intensity calibration curve was constructed composed of a blank and three or more standards from Merck Company (Germany). Accuracy and precision of the metal ions measurements were confirmed using external reference standards from Merck, while the standard reference material and quality control sample from National Institute of Standards and Technology (NIST) were used to confirm the instrument reading.

Polyaromatic hydrocarbons (PAH) characterization in water

The analysis of certain persistent organic pollutants (POPs), critical indicators of aquatic ecotoxicity, was conducted utilizing both GC (Gas Chromatography and Instruments Company, model SIGMA 2B) and high-performance liquid chromatography (HPLC, Agilent 1100, USA).

These methodologies align with Environmental Protection Agency (EPA) guidelines and were applied to quantify compounds including total petroleum hydrocarbons, volatile organic compounds (VOCs), phenols, gasoline range organics (GRO), diesel range organics (DRO), polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs).

Microbiological examination

The analyses for total and fecal coliforms were performed in accordance with the protocols established by the American Public Health Association **(APHA, 2012)**. The presumptive test utilized lauryl tryptose broth to identify potential presence of both coliform types. Subsequent confirmatory tests for total and fecal coliforms were executed using brilliant green bile lactose broth (BGLB) and EC broth, respectively. Moreover, the assessment of the total viable count (TVC) employed the pour-plate technique, adhering to the ISO standard method **(ISO, 2013)**. For this procedure, one milliliter of suitably prepared serial decimal dilutions was plated in duplicate on tryptone glucose yeast extract agar (TGY agar). These plates were then incubated at 30°C for a period ranging from 48 to 72 hours. The resulting microbial growths were quantified as colony-forming units (CFU) per milliliter, providing a measure of the microbiological quality of the sampled water.

Algal counts and identifications

Phytoplankton water samples were collected in clean glass bottles. Following collection, Lugol's solution was promptly added to preserve the samples. Algae in the water samples were concentrated by the Sedgwick–Rafter methods **(APHA, 1965)**. Moreover, algal counts and their identification were carried out according to **Starmach (1966)**, **Streble and Krauter (1978)**, **Palmer (1980)** and **Omura *et al*. (2012)**. A Sedgwick Rafter counting cell was used for phytoplankton count by transferring 1mL from a well-mixed sample, and the results were expressed as the number of org/ml.

Zooplankton sampling technique and identification

The zooplankton community was efficiently concentrated from the water samples using a zooplankton net with a 55µm pore size, after which the samples were promptly preserved with Lugol's solution to ensure their integrity. For the purposes of identification and enumeration, a 1.5ml subsample was carefully extracted from the preserved sample using a wide-tipped pipette. This subsample was then introduced into a Hawksley counting chamber, which has a precise capacity of 1.5ml, allowing for meticulous examination under a microscope. The taxonomic identification of zooplankton to the genus level followed the methodology outlined by **Edmondson *et al.* (1963)** and **Conway *et al.* (2003)**. The abundance of zooplankton was quantified as the number of individuals per liter (ind.L-1).

Statistical analysis

Principal component analysis (PCA), utilizing Euclidean distance, was conducted to identify patterns of heavy metals in water and sediment, as well as PAH pattern in water, across various locations in the Suez Gulf **(Gad *et al.*, 2022)**. The Kruskal-Wallis statistical test was applied to assess differences in the variables between sites or seasons, with a significance level set at a critical P-value of < 0.05.

RESULTS

Physiochemical parameters

This study investigated the variance of physicochemical parameters across sampling locations and seasons (Fig. 2a, b). Significant variations in physicochemical parameters were discerned across the distinct sampling locations, as illustrated in Fig. (2a). Key observations included BOD (P= 0.0075) with an average concentration of 13.914ppm, COD (P= 0.0071) with a mean value of 14.042ppm, and DO (P= 0.072) presenting an average of 8.572mg/ L. Intriguingly, locations 4 and 5 were identified as exhibiting higher pollution levels in comparison to other evaluated locations. Upon comparing the results of parameters across different seasons, as depicted in Fig. (2b), a significant variation in TSS was noted (P< 0.05), with an average concentration of 10.267ppm. Furthermore, the analyzed pH values suggested a consistently slight alkaline nature of the water across all surveyed locations.

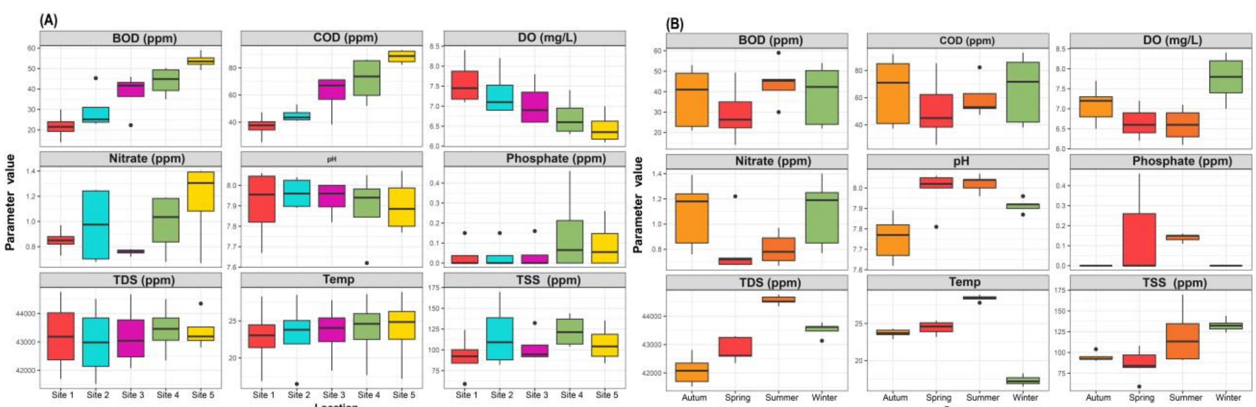


Fig. 2. Distribution of physicochemical parameters by **(a)** location and **(b)** season. Analysis by using Kruskal-Wallis test; (P < 0.05).

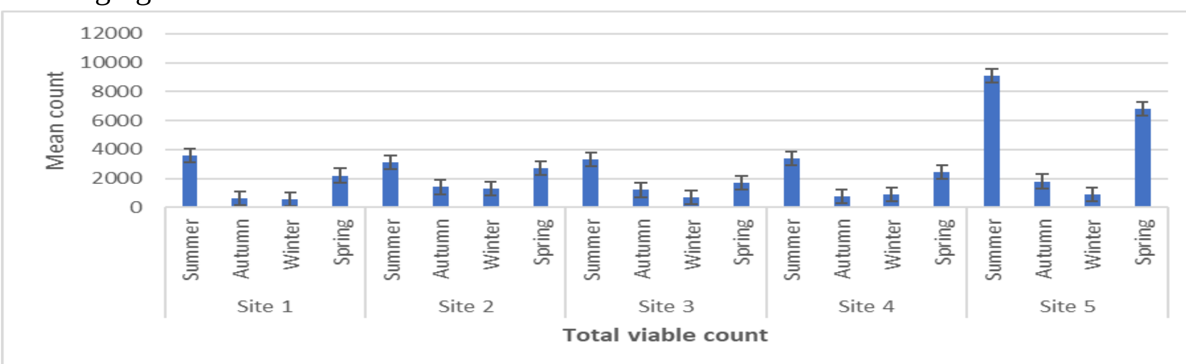
Microbiological examination

In the microbiological analysis of water samples from various sites in the Suez Gulf, the study focused on measuring the densities of total viable bacterial count (TVC), total coliform, and fecal coliform. The findings are presented in Fig. (3A, B). Fig. (3a) reveals that during the summer season, the TVC values were elevated across all sampling locations. The recorded TVC densities in locations 1 through 5 were 36×10^2,

31×10^2, 33×10^2, 34×10^2, and 91×10^2 Colony Forming Units (C.F.U)/mL, respectively. A notable seasonal impact on bacterial counts, with higher proliferation occurring in warmer conditions was observed.

Further, Fig. (3b) depicts the densities of total and fecal coliforms across the five locations. Notably, total coliform was detected mainly in the spring and summer seasons in water samples from locations 1 to 4. The range of total coliform and fecal coliform densities was 2.0×10^2 to 4.0×10^2, 2.0×10^2 to 5×10^2, 2.0×10^2 to 4×10^5, and 3.0×10^2 to 7×10^2 Most Probable Number (MPN)/100 mL in locations 1, 2, 3, and 4, respectively. Location 5 demonstrated a continuous presence of total coliform throughout all seasons, with densities varying from 4×10^2 to 32×10^3 MPN/100mL. Fecal coliform in location 5 was observed predominantly in the spring and summer, with densities ranging from 7×10^2 to 32×10^3 MPN/100 mL.

A



B

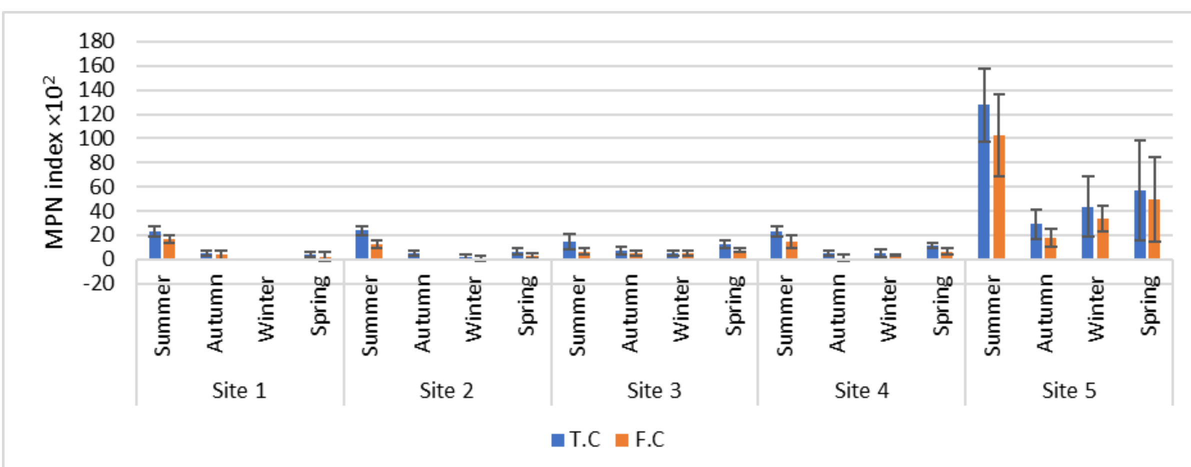


Fig. 3. (A) Total viable count; (B) Total and fecal coliform in water samples determined in five sampling locations in Suez Gulf

Heavy metals distribution

The study underscores the importance of monitoring the coastal areas and identifying various sources of contamination to preserve the delicate marine ecosystem of the Red Sea. It involved assessing heavy metal concentrations in sediments along the Red Sea coastline. Moreover, the study aimed to determine the contribution of natural processes and human activities to metal pollution in the area. Principal component analysis (PCA) was employed to elucidate the integrated relationship between the distribution of heavy metals in water and sediment across all sampling locations. The PCA ordination revealed a pronounced segregation of heavy metal variables between water and sediment samples, as illustrated in Fig. (4.) This marked distinction underscores the substantial differences in heavy metal concentrations between the water and sediment samples. The analysis determined that the first two principal components, PCA 1 and PCA 2, explained 74.2 and 11.1% of the variance in the dataset, respectively, for both water and sediment samples. Notably, the PCA vectors corresponding to the analyzed heavy metals were predominantly associated with sediment samples, signifying considerable concentrations of these metals within the sediments.

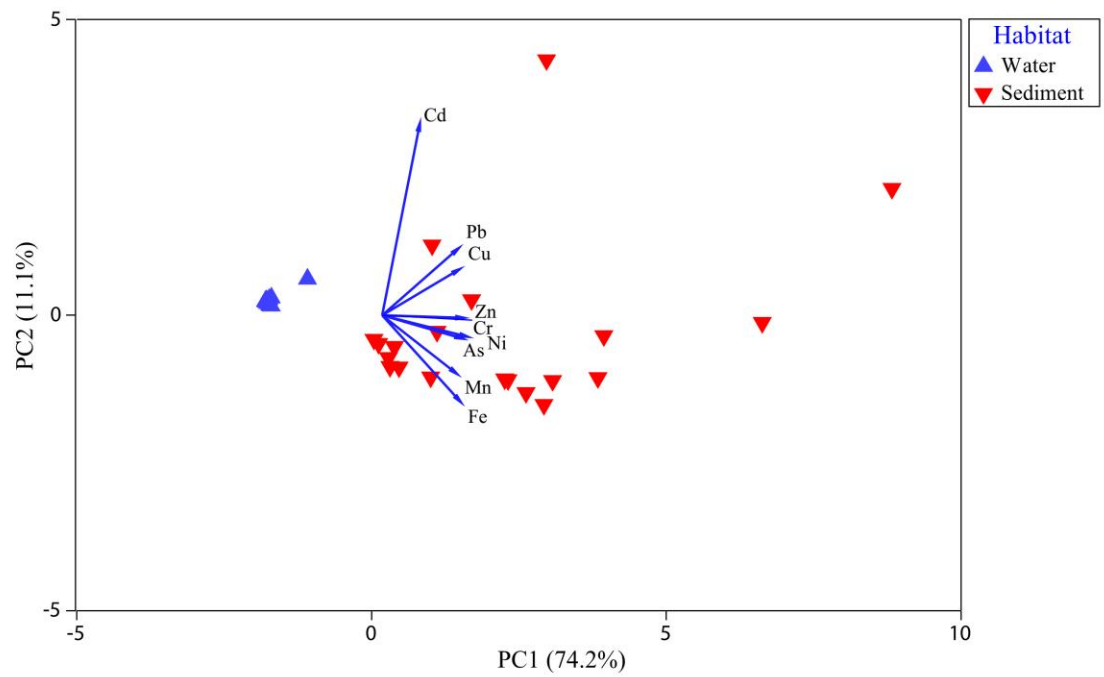


Fig. 4. PCA biplots characterize the patterns of heavy metals in water and sediment in different locations of Suez Gulf

Characterization of polycyclic aromatic hydrocarbons (PAHs) in water

This study conducted a detailed investigation of polycyclic aromatic hydrocarbons (PAHs) in water samples collected over the study period, employing PCA and the Kruskal-Wallis test (*P*< 0.05) for data analysis. The PCA indicated a clear cluster of most location 5 samples far from the other sampling sites, with clear association with the PCA vectors of PAH with this sampling site. Notably, seasonal analysis revealed that PAH concentrations were generally higher in winter compared to summer. For instance, the lowest concentration of anthracene was observed during the summer in location 1, reaching 0.013mg/ l, whereas the highest concentration of phenanthrene was detected in winter in location 5, amounting to 5.4mg/ l (Fig. 5).

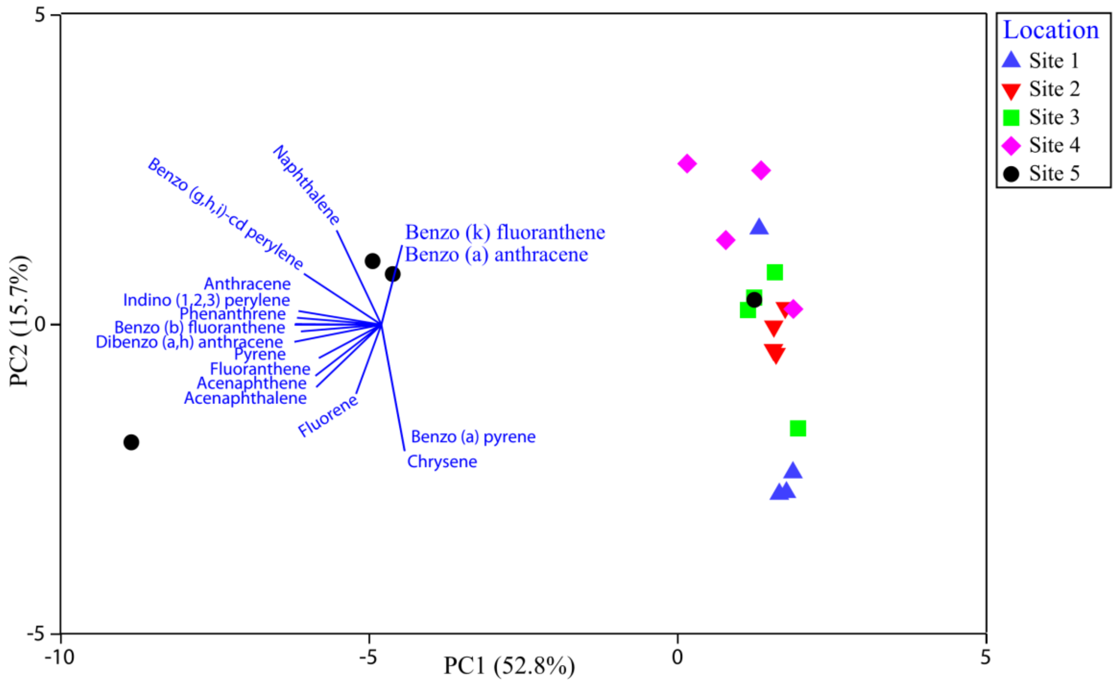


Fig. 5. PCA biplots of 16 PAH variables from water of different locations of Suez Gulf collected at different seasons; Arrows represent the PC1 and PC2 loading of each variable.

Phyto-zooplankton community

Phytoplankton characterization

The predominant algal groups in the Suez Gulf waters, including diatoms, blue-green algae, greens, and dinoflagellates, were systematically analyzed. Notably, significant variances in algal distribution ($P < 0.05$) were observed, particularly in locations 4 and 5 (Fig. 6a). The total algal counts reached the highest prevalence in autum (Fig. 6b). Average concentrations for the groups were recorded as follows: Dinoflagellates at 14.18, Green algae at 11.26, and Blue-green algae at 10.47. Diatoms constituted the majority of the algal community, with percentages ranging from 73.0 to 80.8%, attributed to the prevalence of species such as *Chaetoceros lorenzianus*, *Skeletonema* sp., *Guinardia flaccida*, *Gyrosigma attenuatum*, *Leptocylindrus minimus*, and *Nitzschia closterium*. Following diatoms, dinoflagellates were the second most dominant group, comprising 8.1 to 12% of the total algal count, represented notably by species such as *Ceratium* sp., *Goniaulax* sp., and *Prorocentrum gracile*. Other algal groups, including cyanobacteria, accounted for 5.0 to 11.7% of the algal population, while green algae ranged from 2.7 to 7.2%. Thus, the algal community's composition by percentage was ranked as diatoms > dinoflagellates > blue-green algae > green algae, as detailed in Table (1).

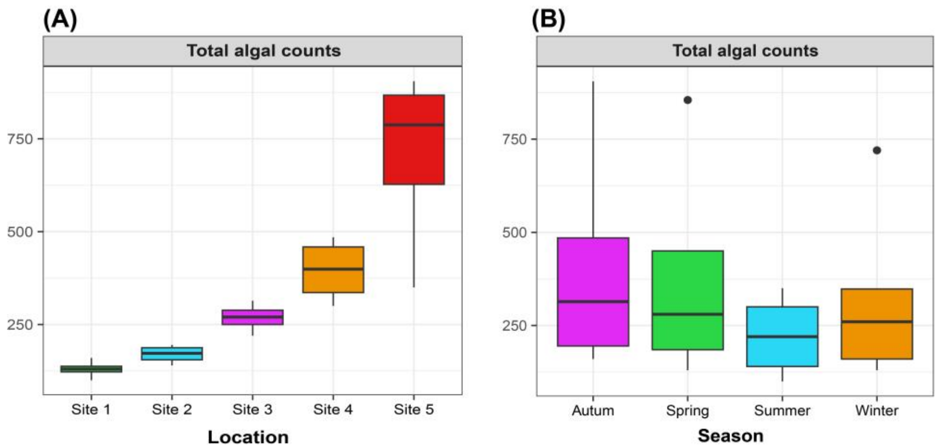


Fig. 6. Distribution of total algal count along the western coast of Suez Gulf water, Egypt, by **(a)** location and **(b)** season; Analysis by using Kruskal-Wallis test, (P< 0.05).

Zooplankton characterization

Throughout the study period (from autumn 2021 to spring 2022), the zooplankton community was comprised of five distinct groups: Protozoa, Rotatoria (Rotifera), Arthropoda (Crustacea), and the larval stages of both Nematoda and Insecta. Notably, Arthropoda, particularly crustaceans, emerged as the predominant group, with rotifers following in abundance.

Spatial analysis revealed notable variations in the zooplankton distribution across the sampled locations, as depicted in Fig. (7a). Locations 4 and 5 were identified as areas where all zooplankton groups showed pronounced dominance. Seasonal distribution patterns also displayed significant differences (P< 0.05), particularly in species such as *Pontigulasia* sp., *Arcella* sp., *Diplois* sp., and *Cyclopoids* sp., with mean values of 14.05, 10, 14.05, and 11.42, respectively, as shown in Fig. (7b).

In autumn 2021-2022, zooplankton counts varied from 13 ind./L at location 1 to 52 ind./L at location 3. The class Crustacea under Arthropoda was represented by Copepoda, Cladocera, and Ostracoda. Copepods had the highest counts, ranging from 7 to 32 ind./L, while ostracods (Cypris) were found in smaller numbers at different locations. Rotifers, Protozoa, and larval stages of nematodes and insects were also present, with varying counts in different locations.

During winter 2022, zooplankton counts ranged from 3 to 42ind./ L across the locations. Crustaceans were dominant in some locations, with notable variations in the abundance of copepods and rotifers. Protozoans and larval stages of nematodes and insects were not observed during this season.

Table 1. Seasonal variations of algal counts (Org./ml) in the different locations along the western coast of Suez Gulf water, Egypt

Algal group	Sampling locations						
	1	2	3	4	5	average	% of total algal counts
Summer 2021							
Diatoms	75	100	160	220	255	162	73.0
Blue-green algae	10	15	30	35	40	26	11.7
Green algae	7	12	14	20	25	16	7.2
Dinoflagellates	8	13	16	25	30	18	8.1
Total algal counts	100	140	220	300	350	222	
Autumn 2022							
Diatoms	130	130	247	390	765	332	80.8
Blue-green algae	10	25	35	30	25	25	6.0
Green algae	3	10	12	15	15	11	2.7
Dinoflagellates	17	30	20	50	100	43	10.5
Total algal counts	160	195	314	485	905	411	
Winter 2022							
Diatoms	95	120	213	257	610	259	80.2
Blue-green algae	15	14	12	19	20	16	5.0
Green algae	7	7	10	12	10	9	2.8
Dinoflagellates	13	19	25	60	80	39	12.0
Total algal counts	130	160	260	348	720	323	
Spring 2022							
Diatoms	100	125	200	350	690	293	76.9
Blue-green algae	12	20	30	30	30	25	6.6
Green algae	5	13	20	20	25	17	4.5
Dinoflagellates	13	27	30	50	110	46	12.0
Total algal counts	130	185	280	450	855	381	

In spring 2022, zooplankton counts ranged from 9 to 50ind./ L across the locations. Crustaceans were most numerous in location no. (5), followed by varying numbers of rotifers in different locations. Larval stages of nematodes and insects were detected in specific locations, while protozoans were absent in all locations throughout the period of study.

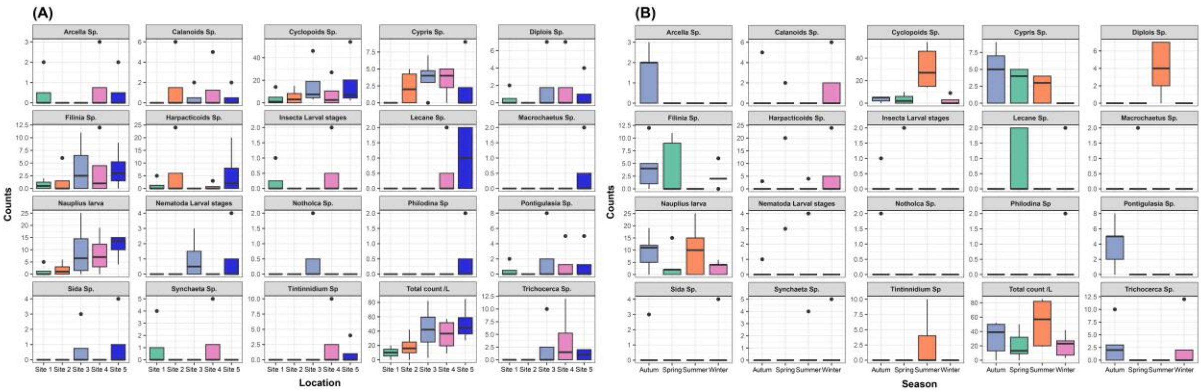


Fig. 7. Distribution of zooplankton (Protozoa, Rotatoria (Rotifera), Arthropoda (Crustacea), and larval stages of both Nematoda and Insecta) by **(a)** location and (b) season

DISCUSSION

Physicochemical parameters are the primary determinants of the allocation of marine habitats, communities and ecosystems. Any variation in these parameters could have broad effects on basic ecological structures and processes. These changes might exert impacts on the whole marine coastal resources. Seasonally variations of heavy metals ratio in seawater are possibly affected by the physical and chemical properties of seawater, such as temperature, salinity, pH, and levels of dissolved oxygen **(Wong *et al*., 2000; Abouhend & El-Moselhy, 2015)**.

Concerning the microbiological analysis in this study, the highest densities of TVC were recorded (60×10^2 MPN/100mL) in location (5) during summer, which is probably due to the effect of high temperature during this season and the untreated wastewater at the drain which spill close to location (5). These results are in agreement with those of **Hamed *et al*. (2013)** and **Ismail and Hettiarachchi (2017)**. The results revealed the seasonal variation in total viable bacterial count, total and fecal coliform in water samples collected from the Suez gulf sampling locations. The highest value of total bacterial count was recorded in location (5) during summer season. While the lowest value of total viable count was in location (1) during winter season. All sampling locations were free from fecal contamination, except for sampling location (5), which could be attributed to the terrigenous origin and human activities in the region such as the marinas, land-filling, industrial activities, wastewater discharging pipes, and tourism **(Salem *et al*., 2014)**. Except location (5), all other mentioned values are within the acceptable limits and guidelines of the European Commission (EC) Guide Standard **(ECDG, 2002)** and the Egyptian Law No. 4 of 1994 for protection of the marine environment.

The current results of heavy metal distribution in the area's sediments under study showed that the Gulf Suez could be affected by several pollution sources, such as industrial waste products, fertilizers, and other industries. A significant increase in the concentration of different pollutants in the sediments is considered a threat to the living biota due to their high persistence **(Thompson *et al*., 2007; Koigoora *et al*., 2013)**. In the present investigation, the highest heavy metals concentrations were observed in sediments during winter, while the lowest values were recorded during summer and our results are consistent with the outcomes of **Srikanth *et al*. (2014)**. **El-Metwally *et al.* (2019)** found that sediments in the Suez area had the highest heavy metal load in winter due to wastewater discharge and maritime activities. High contamination of Cd, Zn, and Pb is linked to phosphate or shipping, while elevated Fe and Mn levels are primarily due to the natural input of terrigenous sediments **(Abouhend & El-Moselhy, 2015)**. The current study found that the concentrations of Ni, Fe, Mn, and Cd in sediment samples were heavily polluted, according to the US Environmental Protection Agency's heavy metals regulations. A previous study by **Madkour (2005)** detected high levels of Fe and Mn in sediments and coral reefs. Heavy metals in Gulf Suez and Red Sea could contaminate coastal aquaculture, making them toxic for both fish and human consumption. Hence, regular monitoring is recommended to protect water bodies and to reduce environmental risk. The fish market in Egypt relies on these regions, and a monitoring system is recommended in polluted areas.

Seasonal variations showed that the concentrations of hydrocarbons were higher in winter than in summer. The lower concentrations of hydrocarbons in summer are attributed to the elevation in the evaporation rate for hydrocarbons in that season owing to the increase in water temperature. Generally, the reported concentration was lower than the harmful concentrations determined for seawater **(Abo-El-Khair *et al.*, 2016)**. Conversely, the recorded concentrations are much far below the accepted level assumed by EEAA of Egypt, as well as the given international standard of 500µg/ l. The Water Quality Standards and Guidelines limit the benzo (a) pyrene (BaP) at 0.7lg /L according to EEAA Law, 1994. On the other hand, the current results revealed that S-5 (Al-Attaka) exhibited higher concentrations of Benzo (b) fluoranthene, Benzo (k) fluoranthene and Dibenzo (a,h) anthracene compared to other sites. In great agreement with the current observations, **El-Naggar *et al*. (2021)** reported that high percentage of PAHs in some area of the Red Sea could be attributed to the presence of high human activities where boating activities are likely to contribute significantly to the PAHs levels found in the area of study—particularly when there is a petroleum leak or sloppy engine oil disposal from boats and ferries. In addition, concentrations of PAHs in some areas were in dockyards where shipping maintenance work takes places, which could contribute to PAHs in the seawater. During the autumn season, the level of PAHs was higher than in summer in some studied locations in the Red Sea.

In the present study, the total phytoplankton in the whole investigated seasons showed the highest counts during autumn, with an average of 411 Organism/ ml), and spring (average of 381 Org./ml). While, summer represents the lowest counts (average of 222 Org./ml). This study reveals that autumn was the most productive season in the Red Sea which is in accordance with the results obtained by **Nassar and Hamed (2003)** and **Nassar and Khairy (2014)**. The peak of autumn was due to the co-dominance of different algal species.

Nitrate is the most stable form of inorganic nitrogen in the oxygenated waters. In the present study, dissolved nitrate attained a maximum of 1.39mg/ L during autumn in location 5, which sustained the highest abundance of the phytoplankton (905 Org./ml) and a minimum of 0.67mg/ L during summer for the same location, coinciding with the lowest phytoplankton counts (222 Org./ml). The findings presented in this study are consistent with those of **Nassar and Hamed (2003)**. The documentation of 80 algal species in our study corresponds to data reported by various researchers on the Red Sea and surrounding habitats. For instance, a similar number of species were recorded in the northern part of the Suez Gulf, known as Suez Bay (80 spp.) **(Nassar & Hamed, 2003)**, along the Jeddah coast of the Saudi Arabian Red Sea (73 sp.) **(Touliabah *et al.,* 2010)**, and in the Egyptian waters of the eastern Mediterranean (88 sp.) **(El-Sherif *et al.,* 2010)**. A previous study by **Nassar and Khairy (2014)** reported that the diatoms were the most dominant group, constituting approximately 76.4% of the total counts of phytoplankton, followed by dinoflagellates, represented by 14.63% of the total abundance. However, the blue-green algae and green algae comprised nearly 9.0% of the total counts of phytoplankton along the north western part of the Red Sea. These findings are congruent with the current study as the percent compositions were in order: diatoms > dinoflagellates > blue-green algae > green algae.

From this study, it is clear that the numbers of zooplankton in the water samples were rare compared to other marine system studies **(Heneash, 2022; Ould Rouis *et al.,* 2022)**. Additionally, some groups of zooplankton were not found in some water samples, and three of studied locations were completely devoid of zooplankton communities during different seasons of the study. It is important to mention that, arthropods are the group of zooplankton community that prevailed during the study due to the presence of numbers of crustaceans, especially copepods, followed by cladocerans and ostracods with less numbers. During the study, protozoan group recorded small numbers, and they disappeared completely during the seasons of winter and spring 2022. The natural changes, as well as rapid changes, associated with human use of estuaries, such as changes to freshwater flow, sediment supply, nutrient loads, contaminants, climate change, and invasive species mean estuaries, are much more dynamic than many other aquatic systems **(Kennish, 2002)**. Long-term monitoring with a spatially distributed sampling design is critical to capturing and accounting for the full range of environmental drivers **(Bashevkin *et al.,* 2022)**. Besides, the increase in air temperature as a result of climatic changes may be a cause for an increase in water salinity, which in turn led to a decrease in zooplankton counts or the complete disappearance of some of them.

Zooplanktons are a critical component of aquatic communities, comprising a crucial link between primary production and upper trophic taxa of high management interest such as fishes. Zooplanktons are also indicator species for climate change **(Richardson, 2008)**. A study of **Bashevkin *et al.* (2022)** on zooplankton monitoring in the upper San Francisco Estuary during five decades (1972–2020) recorded that a decline in important fishes was observed, most likely due to a reduction in food supply from zooplankton. **Wells *et al.* (2022)** on environmental drivers of a decline in a coastal zooplankton community stated that major changes in North Atlantic zooplankton communities in recent decades have been linked to climate change, but the roles of environmental drivers are often complex. High temporal resolution data are required to disentangle the natural seasonal drivers from additional sources of variability in highly heterogeneous marine systems. Here, physical and plankton abundance data, spanning 2003–2017 from a weekly long-term monitoring location on the west coast of Scotland, were used to investigate the cause of an increasing decline to approximately -80± 5% in annual average total zooplankton abundance from 2011 to 2017.

A study by **Hall and Lewandowska (2022)** on the shift in zooplankton dominance in response to climate-driven salinity changes found that zooplankton diversity and composition had changed, possibly due to varying salinity tolerances among species. They also noted that rotifers dominated in low-salinity areas (74%), while cladocerans and copepods dominated in high-salinity areas (69%). Their results suggested that the zooplankton community could shift to a rotifer-dominated one in areas with declining salinity due to the intolerance of other zooplankton groups to fresher conditions.

CONCLUSION

This study explored the combined impact of various environmental stressors on natural communities by analyzing biological and environmental data from five locations in the Suez Gulf during 2021 and 2022. The study revealed seasonal variations in parameters such as TDS, COD, nitrate, and phosphate levels, with significant differences observed in autumn. Total coliform and fecal coliform counts varied across locations, along with heavy metal concentrations, which were found to be below Marine Water Quality Standards. Algal diversity, including diatoms, blue-green algae, greens, and dinoflagellates, peaked in autumn and spring. Zooplankton diversity, which consisted of Protozoa, Rotifera, Crustacea, and larval Nematoda and Insecta, showed variations that suggest potential impacts from human activities on water quality in the Suez Gulf. Thus, marine plankton in the Suez Gulf face challenges from various environmental stressors such as water acidification, global warming, and eutrophication.

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