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Assessment of microplastic pollution in the Gulf of Suez: Abundance and polymeric composition in beach sediments

Nahla Z.Taher [1], Soha Shabaka[2], Yosry A. Soliman and Alaa M. Younis[3.1,]*

1. Department of Aquatic Environment, Faculty of Fish Resources, Suez University, Suez, 43518, Egypt
2. National Institute of Oceanography & Fisheries (NIOF), Egypt.
3. Department of Chemistry, College of Science, Qassim University, Buraidah, 51452, Saudi Arabia

***Corresponding Author: A.younis@qu.edu.sa ; Ala_den@yahoo.com**

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ABSTRACT

The Gulf of Suez is a crucial shipping route and a hub for mining and oil drilling operations, making its area particularly susceptible to the accumulation of marine plastic waste. This study evaluates the abundance and composition of microplastics (MPs) along the Gulf of Suez shores. A total of 268 MPs particles were extracted from the sediments, with an average of 204.3 ± 146.6 MPs/kg dry weight. The Kruskal-Wallis test did not show significant variations among stations. The recovered MPs were mostly hard fragments and fibers. Most of the sampled stations had a low Pollution Index (PLI), indicating a low prevalence of MPs. The predominance of polyethylene vinyl acetate (PEVA) and polytetrafluoroethylene (PTFE) suggests that marine-based sources and associated industrial activities are the main contributors. These findings offer a preliminary assessment of marine plastic pollution along the Gulf of Suez shores, highlighting the crucial need for monitoring offshore waters and sediments. Given the heavy shipping activity in the region, the offshore zone of the Gulf of Suez is expected to have higher levels of plastic pollution. The study also contributes to the expanding understanding of marine plastic pollution in the Red Sea region.

INTRODUCTION

The rapid increase in global plastic production has resulted in an accelerating input of marine plastic litter **(Geyer *et al.* 2017).** Plastic litter has been detected in all compartments and geographical regions **(Bitter and Lackner 2020)**, including remote areas **(Mishra *et al.* 2021).** The most significant impact of plastic pollution in the marine environment is the accidental suffocation and deaths of marine animals due to ingestion and entanglement **(Mæland and Staupe-Delgado 2020).** The ecological implications of microplastics (MPs) have been shown to pose serious consequences that are difficult to track, mitigate, and prevent **(Isobe *et al.* 2019).** MPs are plastic particles of less than 5 mm, either formed by the degradation of larger plastic litter under the hydrodynamic forces and photo-oxidation (secondary MPs) or enter the ocean as manufactured products (primary MPs) **(Galloway *et al*. 2017)**. The abundance of MPs in coastal regions is strongly linked to urbanization and population density **(Bitter and Lackner 2020)**. On the other hand, sea-based sources, particularly emissions from the maritime sector are significant in other regions **(Isobe *et al*. 2019).**

MPs have been shown to have the ability of adsorption and release of several pollutants such as polychlorinated biphenyl (PCB), polycyclic aromatic hydrocarbons (PAHs), and metals into marine environment **(Guan *et al.* 2020; Abbasi *et al.* 2021; Hanslik *et al.* 2022).** Most of these contaminates are toxic and can reach the food chain and become bioavailable **(Qiu *et al.* 2020; Younis, 2020; Norland *et al.* 2021; El-Naggar, *et al.* 2021; Hanafy *et al.* 2021; Abihssira-García *et al.* 2022; Liu *et al.* 2022; Younis *et al.*, 2022; Younis *et al.*, 2023).**

The Gulf of Suez is crucial navigational channel in Egypt. Several anthropogenic activities are affecting the Suez Canal environment such as oil and gas extraction, shipping, improper waste disposal practices, and coastal development. Oil spills, heavy metals, and toxic chemicals associated with human activities are affecting the marine environment of sediments of the Gulf of Suez **(Abo-El-Khair *et al.* 2016),** which have harmful effects on both the marine ecosystem and human health. However, to our knowledge, a few attempts have been made to study the distribution of MPs in the Gulf of Suez. This study aims to investigate the amounts, distributions, and polymeric composition of MPs pollution along the shores of the Gulf of Suez. The study results will assist in developing management plans and strategies to control and prevent plastic litter in the region.

MATERIALS AND METHODS

2.1 Study area and sampling technique

The Gulf of Suez is a semi-enclosed water body located in the northern part of the Red Sea, bordered by Egypt and Saudi Arabia, and an essential navigational channel for Egypt, connecting the Mediterranean Sea to the Red Sea via the Suez Canal The Gulf of Suez extends to approximately 280 km from its mouth at the Strait of Jubal to the city of Suez. In this study, sampling was conducted along the shores of the Gulf of Suez, covering a distance of 220 km (Fig 1). The sampling sites were affected by maritime, fishing, and industrial activities, such as gas and oil extraction.

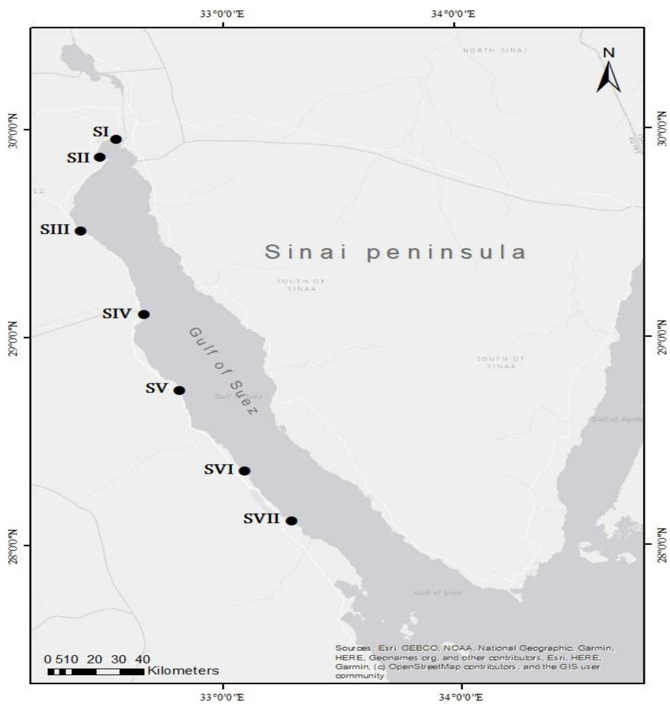

Figure 1: Study site and the sampling locations

The sampling was carried out in January 2020 at seven locations, with four stations randomly sampled at each site. Sediment samples were scooped with a stainless-steel spoon to a depth of 5 cm within a 1 m^2 quadrat, and approximately 1 kg of sediment was collected from each station. The sediment samples were preserved in tightly closed glass jars and transported to the laboratory for further analysis.

2.2 Sediments granulometric analysis

Approximately, 50 grams of the dried sediment samples were sieved for 15 min on an electric shaker machine (model BA200 N), as indicated in **Folk *et al.* (1970)**. The sieves were arranged from top to bottom as follows: >2, 2, 1, 0.5, 0.25, 0.125 and 0.063 mm. Percentile values of grain size data were extracted from the continuous cumulative curves of sand, silt, and clay and then used for calculating the graphic mean size, sorting, skewness, and kurtosis of each sample **(Folk *et al.* 1970; Hamouda *et al.* 2014).**

2.3 Extraction and processing of Microplastics

To eliminate non-plastic debris, the sediment samples were sieved through a 5 mm mesh and homogenized to form one sample at each station. A duplicate of 100 g of dried sediment was examined for each station. Plastic particles were extracted from each sediment replica using the density separation method **(Thompson *et al.* 2004; Tirkey and Upadhyay 2021**). The sediment samples were immersed in a saturated NaCl solution

(1.2 g cm^{-3}) and left overnight on a mechanical shaker. After a settling period of two hours, the supernatant was filtered through nitrocellulose membrane filters with a pore size of 0.45 µm using a vacuum pump. To separate high-density polymers, the remaining sample was subjected to a final separation step using a NaI solution (1.8 g cm^{-3}). The separation method was conducted several times to ensure a satisfactory recovery of plastic particles. Finally, the filters were dried at 50 ºC for 2 hours, and then stored in Petri dishes with glass lids.

2.4 Characterization and Identification of Microplastics

According to **Galgani *et al.* (2013)**, plastic-like particles do not possess cell structure and generally exhibit irregular shapes, sharp edges, and vivid colors. In the present study, the plastic particles were counted and categorized into fragments, filaments, pellets, and films. The sizes of microplastics were measured and photographed using Pixel-Pro 3.0 software (Labo-America Inc.) under a stereomicroscope.

To determine the plastic polymers, thermal analysis techniques were utilized following methods outlined in previous studies **(Abdel Ghani *et al.* 2022; El-Sayed *et al.* 2022; Shabaka *et al.* 2022)**. A Differential Scanning Calorimeter (DSC) (model-4000, Perkin-Elmer) was employed to study the polymeric composition of the extracted MPs. Aluminum crucibles were filled with the extracted MPs, and measurements were conducted under an inert N2 environment with a flow rate of 20 ml min^{-1}. The temperature was set to increase from 30 to 400 ºC, with a heating rate of 20 ºC min^{-1}. To calibrate the heat flow, an Indium standard melt was used, while Zn and Indium standards were used for temperature calibration. The thermal analysis data was processed using the PerkinElmer software: Pyris™ 6, USA. The enthalpy melting temperature (Tm) and area under melting peak were used to identify the type of MPs, according to the inclusion criteria defined in previous studies **(Shabaka *et al.* 2020, 2022; El-Sayed *et al.* 2022).**

2.5 Quality control.

To minimize the risk of airborne contamination, the processes of extraction and microscopic identification were carried out within a laminar hood. Cotton lab coats were worn during sample extraction and processing to prevent contamination. Stainless steel and/or glass tools were used and rinsed with distilled water and wiped with acetone. It was observed that the types of MPs recovered from the samples were not observed in the procedural blanks, and the salt solution used for extraction was free from contamination.

2.6 Pollution Load Index

To evaluate the extent of MP pollution in surface sediments across the Gulf of Suez, a Pollution Load Index (PLI) was calculated using the approach developed by **Tomlinson *et al.* (1980).** The PLI for each station was calculated as follows.

$$Cf_i = {}^{C_i}/_{C_0} \quad (1)$$

$$PLI_i = \sqrt{Cf_i} \quad (2)$$

$$PLI = \sqrt[n]{PLI_1 * PLI_2 \ldots\ldots * PLI_n} \quad (3)$$

The Concentration Factor (CF_i) of MPs is determined by dividing the MP concentration at each station (C_i) by the background MP concentration (C_0). The background MP concentration adopted in the current study was 1.79 items/ kg dw as indicated in ***Guo et al*****., (2021).**

2.7 Statistical analysis

Statistical analysis was performed using Statistica (Ver.7, StatSoft, Inc.). Non-parametric Kruskal–Wallis and Median tests were applied to detect the spatial distribution of MPs concentrations among stations.

RESULTS AND DISCUSSION

3.1 Microplastics abundance and pollution load index

The Gulf of Suez serves as a crucial shipping route, with over eighteen thousand commercial vessels passing through its waters every year. In addition, mining and oil drilling operations are major economic activities in the area. These activities are closely linked to the use of plastic products, resulting in the accumulation of marine plastic waste. Considering the significant dependence on the maritime sector in the Suez Canal, it is imperative to conduct a preliminary assessment of marine plastic pollution along the Gulf of Suez shores. This study is particularly crucial as there is currently a few research on this vital area. Understanding the current situation is necessary to develop effective strategies for managing marine plastic waste. Shore sediments collected from the study area ranged from very-fine sand to coarse sand (Table 1). A total of 268 MPs particles were collected from the sediments, with an average of 204.3 ± 146.6 MPs/ kg DW. As shown below in (Fig 2) the highest concentration was recorded in SIV (335.0± 205.1 particles kg^{-1} DW) and the lowest in SVII (100.0± 56.6 particles kg^{-1} DW). Kruskal–Wallis test did not show significant variations among stations (□^{2} = 8.0, H= 4.43, p= 0.62). **Guo *et al.* (2021)** classified the PLIi as follows: low (<10), medium (10-20), high (20-30), and extremely high (>30). In the current study, the majority of stations had a low PLI, with the exception of SIII and SIV, which had medium levels of pollution.

Table 1. Granulometric analysis of sediment samples along the shores of the Gulf of Suez

Description	Sieves	SI		SII		SIII		SIV		SV		SVI		SVII	
		gm	%	gm	%	gm	%	gm	%	gm	%	gm	%	gm	%
Very coarse sand	2 mm	1.23	**2**	2.79	**6**	6.23	**12**	7.55	**15**	0.64	**1**	5.57	**11**	0.55	1
Coarse sand	1mm	0.63	**1**	13.14	**26**	15.39	**31**	0	**0**	4.065	**8**	0.34	**1**	4.755	10
Medium sand	0.5 mm	2.74	**5**	18.16	**36**	14.47	**29**	6.2	**12**	10.61	**21**	9.79	**20**	10.99	22
Fine sand	0.250 mm	13.28	**27**	5.05	**10**	10.72	**21**	17.23	**34**	29.69	**59**	17.13	**34**	24.50	49
Very fine sand	0.125mm	16.58	**33**	2.95	**6**	3.09	**6**	22.05	**44**	3.74	**7**	15.55	**31**	7.79	16
Coarse silt	0.63mm	11.03	**22**	4.1	**8**	0.22	**0**	0	**0**	1	**2**	1.43	**3**	1.08	2
Clay	< 0.63 mm	7.48	**15**	3.82	**8**	0	**0**	0	**0**	0.3	**1**	0	**0**	0.26	1
Granulometric analysis		Very fine sand		Medium sand		Coarse sand		Very fine sand		Fine sand		Fine sand		Fine sand	

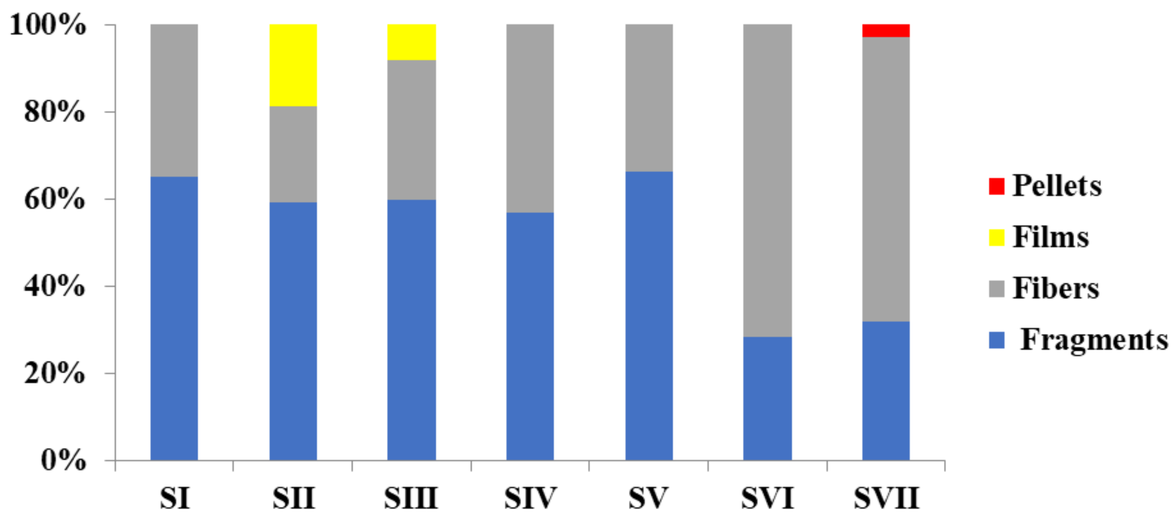

Figure 2. Percentage composition of microplastic types

The findings of this study indicate a low prevalence of MPs in the beach sediments, which is consistent with prior research conducted on the Red Sea coast **(Martí *et al.* 2017; Zeeshan Habib and Thiemann 2022).** According to Zeeshan Habib and Thiemann (2022), the comparatively lower level of MPs contamination observed in the Red Sea Coast can be attributed to the reduced waste input from land-based sources in comparison to the Mediterranean Sea and Arabian Gulf. Approximately, 80% of marine plastic pollution originates from Land-based sources ***(Jambeck et al. 2015; Siegfried et al.* 2017),** according to United Nations Environment Program (UNEP), the remaining 20% comes from marine-based sources such as fishing and maritime activities. These findings emphasize the need for surveys in offshore waters and sediments in the Gulf of Suez as these areas may be more susceptible to heavy plastic pollution than the shores.

The majority of the recovered plastic particles were mainly hard fragments and fibers, which were regarded as secondary MPs. Primary MPs in the form of pellets were observed at SVII (Fig 2). MPs sizes ranged from 100 to < 5000 µm, with the prevalence of sizes from 200 to < 2000 µm (Fig.3). In the Red Sea, the occurrence of primary MPs is largely attributed to maritime activities, in particular industrial shipping. There have been reports of cargo shipping accidents in the Gulf of Aqaba and Wadi El-Gemal National Park along the Red Sea Coast of Egypt, which have resulted in the spillage of pellets mainly composed of low-density polyethylene (LDPE) **(Abu-Hilal and Al-Najjar 2009; Brümmer *et al.* 2022).**

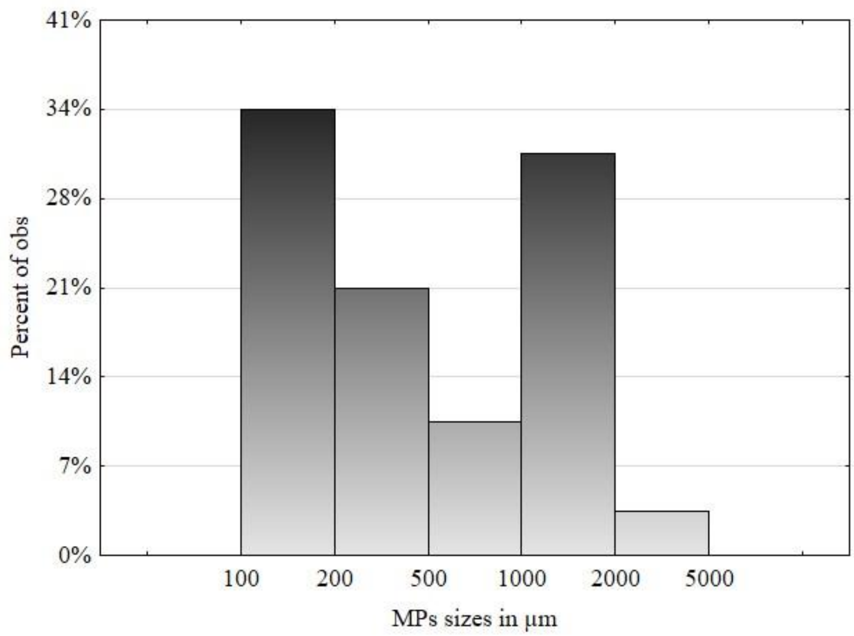

Figure 3. Histogram of MPs sizes

3.2 Polymeric composition of plastics content

DSC has detected four types of thermoplastic polymers; polyethylene vinyl acetate (PEVA), Nylon, polypropylene (PP), and polytetrafluoroethylene (PTFE). PEVA dominated the sampling stations, nylon were recorded at SIII. PTFE were detected at SIV, SVI, and SVII. PEVA has been extensively used in antifouling paints and adhesives, it has emerged as a popular and less toxic substitute for polyvinyl chloride (PVC) in various products imported from China **(Meng 2014; Yu *et al.* 2016)**. In agreement with **Turner (2010), Molino *et al.* (2019), and Abdel Ghani *et al.* (2022),** the maintenance and cleaning of ship hulls associated with shipping activities, can lead to the deposition of paint polymers in seawater. On the other hand, PTFE, also known as Teflon, is a synthetic fluoropolymer used in various industrial applications due to its resistance to heat, chemicals, and corrosion. However, it can potentially accumulate in marine organisms and pose ecological and health risks once released into the environment. Trace amounts of PTFE have been found in seawater and marine life **(Bergmann *et al.* 2017; Digka *et al.* 2018; Yakushev *et al.* 2021)**.

Table 2. Sampling coordinates and microplastics concentrations (mean ± standard deviation).

Station	Name	longitude	latitude	Items/ Kg DW
SI	Suez City	32°32'40.99"E	29°57'16.15"N	180.0± 56.6
SII	Al-Adabia	32°28'24.23"E	29°55'16.54"N	210.0± 212.1
SIII	Ein-Sokhna	32°23'47.46"E	29°30'47.70"N	195.0± 49.5
SIV	Zaafarana	32°39'5.22"E	28°53'45.43"N	335.0± 205.1
SV	North-Ras Ghareb	32°51'46.45"E	28°34'41.41"N	295.0± 304.1
SVI	Ras-Ghareb	33° 5'3.16"E	28°21'54.66"N	115.0± 35.4
SVII	Ras-Shuquir	33°17'30.47"E	28° 7'13.63"N	100.0± 56.6

In the current study, the prevalence of PEVA and PTFE over the widely used polymers such as polyethylene (PE) and PP indicate the dominance of marine-based sources and associated industrial activities over land-based activities. Land-based sources are associated mainly with PE isomers polyethylene terephthalate (PET), polystyrene (PS) and PP **(Aragaw 2021)**. It is important to note that the lower frequency of occurrence of PE in comparison to PEVA and PTFE along the shores of the Gulf of Suez is the primary reason for its absence from the current results rather than a complete lack of presence.

CONCLUSION

The Gulf of Suez is a crucial shipping route and home to significant mining and oil drilling operations that are closely linked to the use of plastic products, leading to a build-up of marine plastic waste. This study highlights the low prevalence of MPs in the shores of the Gulf of Suez, with the majority of stations having a low PLI. The prevalence PEVA and PTFE over widely-used polymers such as PE and PP indicates the dominance of marine-based sources and associated industrial activities over land-based activities. The study's findings offer valuable insights into the current state of marine plastic pollution along the shores of the Gulf of Suez and underscore the importance of ongoing monitoring of offshore waters and sediments. These areas are expected to have higher levels of plastic pollution due to the heavy shipping activity in the region. Furthermore, this research contributes to a growing body of knowledge on marine plastic pollution in the Red Sea region and emphasizes the importance of reducing plastic waste at its source to protect the marine environment.

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