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Monitoring of Microplastics in the Marine Environment and Their Ecological Risks; the Coastline of Alexandria, Egypt as a Case study

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ABSTRACT

Microplastics (MP) are one of the most significant pollutants in the marine environment. For the first time along the Alexandria coast from the eastern to the western side, Egypt, the study recorded MP in surface water and sediment (bed, and beach) from five stations covering two seasons in 2020. In addition, the study evaluated the potential ecological risk of MP using the polymer hazard index (PHI) and potential ecological risk index (PERI). Results indicated the fluctuation of MP abundance in water samples (1.3MP/ l). The wet season showed a higher abundance of MP. The MP content of beach sediment (446.9MP/ Kg) was more than that of the bed sediment (170.6MP/ Kg). Most MP particles were fiber-shaped, blue, and transparent, with sizes larger than 1mm. The chemical identification showed that polyamide and rayon were the most common polymers in most samples. The ecological risk indices indicate that Sidi Bishir area is classified as V level of risk, and the bed and beach sediments are subjected to extreme danger of MP pollution. The study recommends a deeper interest in the chemical analysis of polymers and standardizing the sampling and identification methods. Clear management strategies to control MP aquatic pollution with MP should be addressed.

INTRODUCTION

The aquatic environment is subjected to different types of pollutants such as nutrients **(El-Rayis *et al.*, 2012; Champagne *et al.* 2021)**, oil **(Abdelwahab *et al.* 2021; Moneer *et al.*, 2023)**, and metals **(Shaaban *et al.*, 2022a)**. The potential ecological risks of those pollutants are deeply assessed **(Shaaban *et al.*, 2021a, b, 2022b; Thabet *et al.* 2024)**. Recently, a growing interest has been given to marine debris, especially concerning plastics **(Chaczko *et al.*, 2018)**.

Plastics are the most dominant form of marine litter, over 20 million tons of plastic waste are in aquatic ecosystems **(Rasta *et al.*, 2021)**. Mainly, plastics enter the marine environment through land sources, and about 80% of the plastics are floating on the seas, as fragmentation of mega-and macroplastic objects that enter rivers, runoff, tides, winds, and through catastrophic events **(Guerranti *et al.*, 2020)**. Additionally, sea sources such as wrecked shipping and fishing gear contribute significantly to the plastic budget in the marine environment **(Kasamesiri *et al.*, 2023)**. Atmospheric deposition is another key source of plastic particles in the aquatic environment **(Sun *et al.*, 2022)**.

Plastic fragments and microplastic (MP) particles are documented in all compartments of the freshwater and marine environment (water, sediment, and biota), even in the Arctic Sea **(Chaczko *et al.*, 2018)**.

Microplastics (MP) are particles of plastic with a size smaller than 5mm. They pose direct and indirect hazards to aquatic ecosystems and risks to human health. These hazards can come from MP particles and their additives (as pollutants) or their interaction with surrounding pollutants, such as metals and other organic contaminants **(Tang *et al.*, 2024)**. This interaction results in synergetic and additive or antagonistic effects. Additionally, the small sizes of MP particles allow them to be easily distributed, available to aquatic organisms, and accumulate in them. In addition, the MP can be transferred through successive trophic levels in the food web **(Kasamesiri, *et al.*, 2023)**. Thus, the evaluation of MP pollution status and the assessment of ecological impacts and human health risks are a must.

Among the 20 top countries plastic waste-wise, Egypt ranked as the 7th highest country, contributing about 0.15- 0.39 million metric tons per year of marine plastic debris **(Jambeck Jenna *et al.*, 2015)**. According to the Egyptian Ministry of Trade and Industry, it is expected to accelerate consumption up to 7.4% per year, which pushed the consumption up to 2.8 million tons in 2022 **(PLASTEX, 2022, 2024)**. The most demanded and produced polymers in Egypt are polypropylene (PP), high-density polyethylene (HDPE), low-density polyethylene (LDPE), low-low-density polyethylene (LLPE), and polyethylene terephthalate (PET) **(Shabaka *et al.*, 2019)**. 75% of local production is for exports, while about 25% is used locally. It is expected by the Egyptian Plastic Exporters and Manufacturers Association (EPEMA) that in the next five years, Egypt will produce styrene/polystyrene, acrylic fibers, and propylene; increase the production of polypropylene, and expand its existing polyvinyl chloride (PVC) output and produce polyester and polyethylene terephthalate.

Alexandria is the largest city on the Mediterranean coast, with about 25% of the total national industrial activities, and is expected to contribute to adding considerable amounts of plastic debris to the Mediterranean. Alexandria City is estimated to load the Mediterranean marine environment with about 2209 tons/year of land-based marine debris **(Sharma *et al.*, 2021)**.

Upon surveying the conducted work on MP in the Egyptian aquatic environment, limited studies were found. Their main findings revealed that MP particles were monitored in surface water, sediment, and fish samples collected from the Eastern Harbor and Abu Qir Bay in Alexandria. The majority of obtained particles were categorized as secondary MP. The fiber shape was dominant in fish samples with sizes ranging between 100 and 500µm. Moreover, polyethylene was the most common polymer **(Shabaka *et al.*, 2019, 2020; Abdel Ghani *et al.*, 2022; El-Sayed *et al.*, 2022)**. Another study was a trial to establish a baseline for the shapes and colors of MP particles in the Egyptian near-shore water, sediments, and selected fish species in some areas along the Mediterranean and the Red seas. It was found that most of the detected MP were of fibers and fragments shaped, with transparent red and blue colors **(Sayed *et al.*, 2021)**.

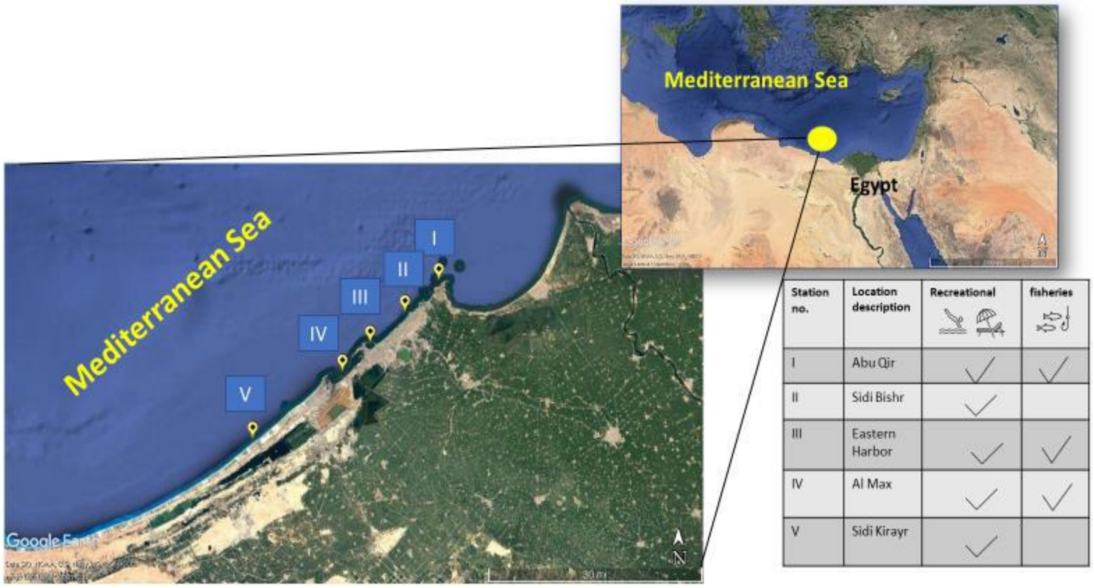
As a following step of quantifying and identifying the MP particles, it is recommended to assess the potential ecological risks of MP to control its impact on the marine environment **(Meng *et al.*, 2023)**. The polymer hazard index (PHI) and the potential ecological risk index (PERI) were applied for the risk assessment.

The present study aimed to (1) monitor the MP particles along the coastline of Alexandria in three compartments, inshore surface seawater, underlying bed sediment, and beach sand sediments, to identify the abundance, shape, color, size, and polymer composition of MP, and (2) evaluate the possible ecological risks of MP in the study area.

MATERIALS AND METHODS

1. Study area and sampling

The study area covers about 50Km along with the nearshore marine environment of Alexandria from Abu Qir in the west to Sidi Kirayr in the east (between 30° 2'43.03" to 29°37'4.94"E and 31°18'50.37" to 31° 1'30.02" N). The distribution of sampling sites and the dominant activities in each of them are represented in Fig. (1).



Station no.	Location description	Recreational	fisheries
I	Abu Qir	✓	✓
II	Sidi Bishr	✓	
III	Eastern Harbor	✓	✓
IV	Al Max	✓	✓
V	Sidi Kirayr	✓	

Fig. 1. Sampling sites and activities along Alexandria coast, Egypt

From each of the five selected monitored sites, three 20L replicates of surface water samples were collected twice during 2020. The first sampling set was in March, while the second one was in September, representing the dry and wet seasons, respectively. The collected water samples were filtered through 5mm and 125µm steel sieves, and the obtained residues were washed with distilled water and kept in glass bottles for microscopic examination and chemical polymer identification, which is limited to the MPs >125µm fraction in the present study. Materials retained on a 5mm sieve were discarded.

Beach and bed sediment samples were collected simultaneously during water sampling. The beach sediments were collected from the intertidal zone using a 20-cm glass core, and the MP particles were investigated in the 5-cm upper layer. The bed sediments were collected using Peterson grab. The collected sediment samples were placed in cleaned covered aluminum foil dishes until further laboratory investigation.

2. Sampling process

For the water samples, with minor modifications, successive steps were conducted for the separation of their MP content according to **Masura *et al.* (2015)**. The filtration residue from each sample was oven-dried at 60°C for 24h, and then 20mL of 0.05M ferrous sulfate solution and 30% H_2O_2 were added to the beaker containing the residue to digest the organic matter **(Zhang *et al.*, 2017)**. The mixture was left to stand on a lab bench at room temperature for five minutes before proceeding to the next step, heating a solution to 50°C for an hour **(Prata *et al.*, 2019)**. The NaCl was then added to this solution (6.0g per 20mL of the sample) for density floating, using a concentrated saline NaCl solution (1.2g cm^{-3}). Following the transfer of the solution to a separation funnel, the beaker was rinsed with distilled water to transfer all remaining solids to the separation funnel, covered loosely with aluminum foil, and allowed solids to settle overnight. The settled solids from the separator were drained, and the supernatant was filtered using a membrane filter. Finally, the filters were dried for further examination **(Zhang *et al.*, 2020)**.

Regarding sediment (beach and bed) samples, 50g of dried sediment (at 60°C for 24h) was mixed with 200ml of saturated salt solution (NaCl with ρ = 1.2g cm^{-3}) and manually stirred with a clean glass rod for 1min **(Atas, 2019)**. After 5min of settling, the water solution above the sediment layer was carefully transferred to another glass beaker. This isolation procedure was repeated three times for each glass beaker to increase the recovery rate. Subsequently, 5mL of each of 0.05 M ferrous sulfate solution as a catalyst and 30% H_2O_2 was added into 200mL solutions. The mixture stood on a lab bench at room temperature for five minutes before proceeding to the next step. Then, as a water sample, the solution was heated to 50°C for 1h to complete the digestion of the organic matter **(Prata *et al.*, 2019)**. After 24h of sedimentation, the clear supernatant was filtrated through a membrane filter (with a pore size of 0.45µm) under vacuum filtration and rinsed with 30% hydrofluoric acid (HF) to remove any inorganic particles present.

In parallel, the grain size of sediments was determined according to the method of **Folk and Ward (1957)**. The mechanical sieving technique was applied to sediment samples using a standard set of sieves (PrUfsiebring A TGL 7354) mounted on an electric shaker (Test Sieve Shaker). The standard applied time was 15 minutes. The sieves were arranged from top to bottom in a 1 phi class interval beginning with -1Φ till 4Φ followed by a pan (for mud fraction).

3. Morphological and chemical identification

The abundance, shape, color, and size in the final extracted MP particles (less than 5000µm) from different types of samples were visually examined using a binocular visual microscope at 40X power, (S-20-2L, ITALY). The standard method of **GESAMP (2019)** shows many features to distinguish plastic particles from other materials including the irregular shape, rough and broken edges, response to physical stress (melting or curling under a hot needle), and never having cellular or organic structures.

The chemical composition of MP was identified using differential scanning calorimetry (DSC) and the Fourier transform infrared microscopy system (FTIR).

According to **Chialanza *et al.* (2018)**, each polymer has a unique melting point (Tm) determined by the DSC. Preliminary experiments were conducted under an inert atmosphere, with nitrogen (N_2) as the testing medium, using an aluminum crucible and lid to determine the melting point necessary for the microplastics. The equipment was calibrated using iridium (Ir) and zirconium (Zr) capsules. The microplastic samples (of the wet season) were gradually heated from room temperature to 380°C at a rate of 10°C per minute.

Samples of the dry season were analyzed using FTIR examination by PerkinElmer, FTIR spectrometer (spectrum two). Each spectrum was recorded within the range of 450 to 4000cm ^{1}. As per the outlines of **Phakopa *et al.* (2023)**, the obtained spectra were compared with the previous polymer database to identify the type of MP at each station.

The number of MP particles was expressed as particles/l in seawater and particles/kg dry weight (d.w.) in sediments.

4. Quality control and quality assurance

To ensure the reliability of the obtained results, water and sediment samples were collected in triplicates and separately examined for their MP particle types and abundance. Ranges and means of different types of detected MP in all samples were grouped in tables, while the means were represented in the relevant result discussion section. Only glass vessels were used, and all solutions were filtered through a plankton net with a mesh size of 5µm to minimize any sample loss. At least three procedural blanks were used within each sample batch to determine the presence of MP contamination during the entire experimental process.

5. Risk assessment of MP

- **Polymer hazard index (PHI)**

The chemical composition, concentration levels of MP, and hazard scores were considered in assessing the potential ecological risks of MP in surface beds and beach sediments. The PHI was computed from the following equation:

$$\mathrm{PHI} = \Sigma P_n \times S_n \qquad (1)$$

Where, P_n, and S_n are the percentages of specific polymer types collected in each sampling location, and the hazard scores of polymer types of MPs, respectively **(Ding *et al.*, 2022)**. The used S_n values were proposed by **Lithner *et al.* (2011)** as follows: 10599, 5001, 47, 4, 0, and 0 for polyacrylonitrile, polyvinylchloride, polyamide, rayon, and alkyde resin, respectively. Accordingly, the risk was classified into five hazard levels starting from level I (PHI < 10), level II (pHI = 10 - 100), level III (PHI = 100 – 1000), level IV (PHI = 1000 – 10000), to level V (PHI > 10000).

- **Potential ecological risk index (PERI)**

The PERI was measured as follows:

$$\mathrm{CF_i} = \frac{Ci}{Cr} \qquad (2)$$

$$\mathrm{PERI} = \mathrm{PHI} \times \mathrm{Cfi} \qquad (3)$$

Where, CF_i, C_i, and C_r are the concentration factor at each station, the measured concentration value of total MP in each sample, and the MP reference (background, or unpolluted) sample value, respectively. **Li *et al.* (2022)** used the safe MP value with no effect, which was proposed to be 540p/ Kg as a background value (C_r). Meanwhile, other studies used the lowest MP levels determined in the sediment **(Meng *et al.*, 2023)**.

Thus, the sediments were classified into 5 classes: minor (Mi), medium (Md), high (H), danger (D), and extreme danger (ED) with PERI values of (i) less than 150, (ii) between 150 and 300, (iii) between 300 and 600, (iv) between 600 and 1200, and finally (v) more than 1200, respectively.

RESULTS AND DISCUSSION

The potential microplastic particles were visually examined and identified according to many factors such as abundance, shape, color, size, and polymer composition. All plastic-like items were sorted by (1) shape into fibers, fragments, films, foams, and pellets, (2) color into blue, green, red, black, brown, orange, transparent, glossy, and white, (3) size into small (< 500µm), medium (0.5 - 1mm), and large microplastics (1 - < 5mm).

The polymer compositions were identified using differential scanning calorimetry (DSC) for wet season samples, and Fourier transform infrared (FTIR) for dry season samples due to the rarity of MP and the sensitivity of FTIR to low concentrations.

1. Morphological identification

- ***Microplastics in surface water***

Microplastics were detected in all surface water samples, with an average MP concentration ranging from 0.8 to 2.3 particles/l, with an overall average of 1.3 particles/l. The highest MP levels were found in March (wet season), while the lowest levels were found in September (dry season), except for the Abu Qir site (Fig. 2A). The increase in MP concentrations in seawater may be attributed to the dominant runoff in the area **(Park *et al.*, 2020)**. Spatially, Sidi Bishr station showed the highest levels of MP (with an average of 2.3 ± 0.0 particles/l), while Abu Qir had the lowest MP content (with an average of 0.8 ± 0.1 particles/l).

Comparing the current results with other studies (Table 1), it is evident that the current obtained values are higher than those of other studies, except for **Shabaka *et al.* (2019)**. The difference may be due to using a manta net in sampling, which misses smaller particles (as those of 300µm) **(Prata *et al.*, 2019)**.

The shapes of MP in the surface seawater along the Alexandria coast showed the following trend: fiber > fragment > film or pellet (Fig. 2B). Fibers constituted 56 and 69% in wet and dry, respectively, followed by fragments (31% and 20%, respectively). Eastern Harbor (EH) and Sidi Kirayr completely lacked the film shape in wet and dry seasons. Pellets were only observed at El-Max and Sidi Kirayr stations with a percentage of less than 7%. The current results suggested that fisheries activities might be the source of microplastic pollution in the Alexandria coastal waters.

The surface seawater of the Alexandria coast was observed to contain nine different colors of MP particles with different proportions (Fig. 3C). When analyzing the fiber shape (the dominant shape of MP), the blue fibers were the most prominent, likely due to their usage in fishing activities **(Zhu *et al.*, 2021)**. The blue color made up about 33% of the MP in most locations, followed by red and black fibers in abundance. Only transparent fibers appeared in the surface water from Abu Qir.

The results of the current study are consistent with similar studies conducted in the Mediterranean Sea and China **(Güven *et al.*, 2017; Christian *et al.*, 2018; Jemaa *et al.*, 2021; Zhang *et al.*, 2021)**. They suggested that the blue microfibers originate from textiles, plastic fishing gear, and paints.

The study classified MP particles into three size classes: (a) less than 500µm, (b) from 500 to 1000µm, and (c) from 1000 to less than 5000µm. Microfibers with a relatively large size; class-c (> 1000µm) the dominant size in water samples. In contrast, most other MP shapes were of small size, class-a (< 500µm), (Fig. 2D).

- *Microplastics in bed sediment*

Microplastics can be either denser or lighter than seawater, and they sequestrate efficiently in sediments, which act as a long-term sink for marine pollutants. The denser ones sink to the bed sediment owing to the gravity sedimentation. Meanwhile, lighter MP particles are affected by the adsorption of persistent organics, oxidation, and biofouling processes that modify their density **(Li *et al.*, 2022)**.

The MP particles were detected in most collected-bed sediment samples, with an average concentration of 171 particles/kg $_{(d.w)}$. The higher values were recorded in the wet season (Fig. 3A), which could be attributed to weather conditions, rainfall, and wind speed which can transport plastics litters into the marine environment **(Cheung *et al.*, 2016; Wang *et al.*, 2021)**. Additionally, there was a noticeable fluctuation in MP concentrations between different stations, with a coefficient of variation greater than 60%. On the other hand, the current values are higher than those observed in other regions in the Mediterranean Sea (Table 1).

Bed sediments were characterized by grain sizes ranging from very coarse at Sidi Kirayr with the highest MP concentration. This follows the results shown by **Waldschläger and Schüttrumpf (2020)** and **Vermeiren *et al.* (2021)** when they found that the abundance of MP in sediments decreases significantly with increasing grain size. This finding is statistically confirmed in the present work by a significant correlation between grain size and the concentration of MP of bed sediment ($r^2 = 0.51$).

The observed MPs in bed sediment followed trends like those in seawater, with fibers being the most prevalent shape (constituted over 80%), followed by fragment or film, and the complete absence of pellet (Fig. 3B) indicating the lack of primary MPs.

Bed sediments contained eight colors of MP with different contribution rates. Fibers showed transparent, red, blue, black, brown, or green colors, indicating various sources of MP in the environment **(Chen & Chen, 2020; Fu *et al.*, 2020)**. Red microfibers were observed at all stations. The colored particles are more likely derived from abrasion or degradation of some plastic commodities, such as clothing and packing in addition to fishing gear **(Khan *et al.*, 2020; Wang *et al.*, 2020; Wicaksono *et al.*, 2021)** (Fig. 3C).

The discolored fragments (glossy and white MP) are more dominant at all stations, the main reason for discoloration is related to additives such as phenolic antioxidants **(Veerasingam *et al.*, 2016)**. Transparent MP particles were often associated with transparent food containers mainly consisting of polyethylene and polypropylene polymers **(Wicaksono *et al.*, 2021)**.

The microfibers with a comparatively large size; class c (> 1000μm) formed the dominant size (like overlying water). In contrast, most of the other shapes of MP were of the small size, class a (≤ 500μm), and rarely with size in between (class b).

- ***Microplastics in beach sediment***

Generally, the MP concentrations in beach sediments ranged from 147– 867 particles/kg $_{(d.w.)}$ with an average of 447 particles/kg $_{(d.w.)}$. Like bed sediments, the beach sediments of EH exhibited relatively high MP content, and the wet season showed elevated levels of MP (Fig. 4A).

The beach sediments of EH (with fine grain size sediment) showed extremely high levels of MP, about two orders of magnitude than those of Abu Qir (with very coarse grain size sediment), with averages of > 550 and < 300 particles/kg $_{(d.w.)}$, respectively. This reflects the role of sediment grain size in concentrating MP particles, which was statistically confirmed by a strong negative correlation ($r^2 = 0.71$).

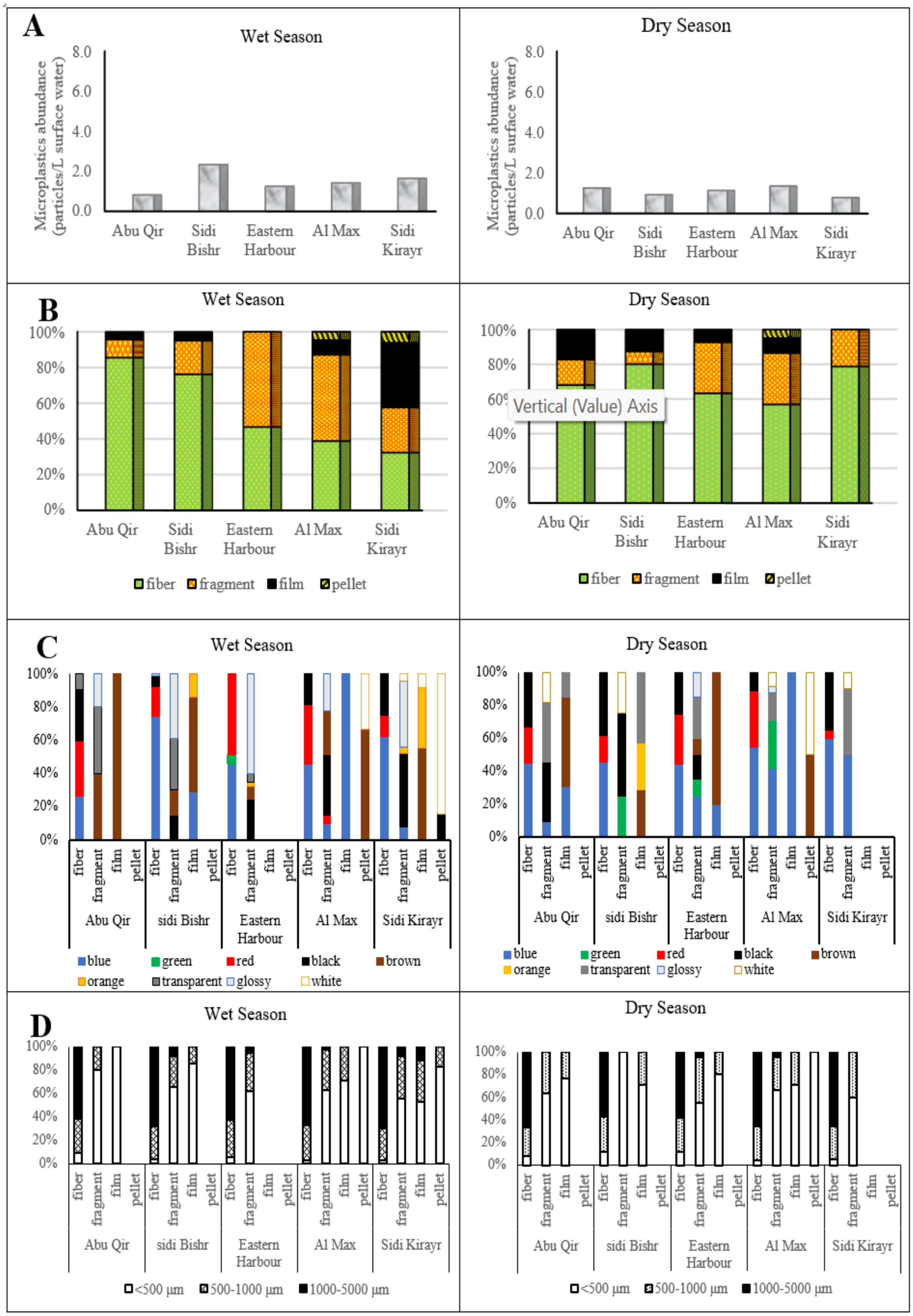


Fig. 2. The detected MP **(A)** abundance, **(B)** shapes, **(C)** colors, and **(D)** sizes in the seawater samples during sampling seasons along the Alexandria coast

Table 1. Comparison between the present study and previous study in the Mediterranean Sea from water, bed, and beach sediment

Region	**Study area**	**Year**	**Sample**	**Average concentration**	**Reference**
South-Eastern Mediterranean	Along the Alexandria coast, Egypt	2020	Water (B)	1.29	The present study
			Bed sediment	170.632	
			Beach sediment	446.866	
	Eastern Harbor, Alexandria, Egypt	2017	Water (B)	24	**(Shabaka *et al.*, 2019)**
			Beach sediment	242	
	Israeli surface waters	2013-2015	Water (M)	0.0077	**(Hal *et al.*, 2016)**
Southern Mediterranean Sea	North Tunisian coast	2017	Beach sediment	316.03	**(Abidli *et al.*, 2018)**
Eastern Mediterranean Sea	Lebanese coast	2019	Water (M)	0.0038	**(Jemaa *et al.*, 2021)**
		2018		0.0043	**(Kazour *et al.*, 2019)**
	Iskenderun Bay	2017		0.0073	**(Gündoğdu, 2017)**
	Iskenderun Bay and Mersin bay	2016		0.0027	**(Gündo and Çevik, 2017)**
	Samos Island, Greece	2017	Beach sediment	37.2 - 1.1	**(De Ruijter *et al.*, 2019)**
Western Mediterranean	(Balearic sea) Tarragona Coast	2018	Water (N)	0.0013	**(Expósito *et al.*, 2021)**
	Tarragona Coast	2017	Bed sediment	32.4	
	(Lyon gulf) Tet and Rhone delta	2016	Water (M)	0.00018 - 0.00019	**(Constant *et al.*, 2018)**
	Mar menor	2017-2018	Bed sediment	53.1	**(Bayo *et al.*, 2019)**
	Spanish Mediterranean coast	2014-2015		113	**(Filgueiras *et al.*, 2019)**
North-Western Mediterranean	Gulf of Lions	2015	Water (W)	0.00023	**(Lefebvre *et al.*, 2019)**

concentration unit of MP in the water sample was MP/l; concentration unit of MP in bed and beach sediments was in MP/Kg

B= Bulk surface sample M = manta net N = Neuston net W= WP2 plankton net

Generally, for seawater and bed sediment samples, fibers were the dominant shape of MP in most beach sediment samples, making up over ٤0% of the total MP content. Fragments and films followed the fibers in terms of the abundance of MP shapes, with no pellets found in beach sediment, in contrast to surface seawater (Fig. 4B). The presence of fragment MP is likely ascribed to anthropogenic activities and indicates the presence of secondary MP particles, which are produced when larger plastics and their fragmentation break down **(Park *et al.*, 2020)**.

Based on the shapes, colors, and size distribution of MP in beach sediments, the situation is like what was observed in bed sediment. For the transparent MP (Fig. 4C) and microfibers with comparatively large sizes, class c (> 1000μm) was the dominant MP. In contrast, most other shapes were with the small size of class a (<500μm), and rarely with the size of class b (Fig. 4D). The appearance of transparent MP suggests that they originate from transparent food containers made of polyethylene and polypropylene polymers, commonly used for fishing nets and lines in Alexandria. This may be linked to the discoloration and bleaching caused by digestion processes **(Li *et al.*, 2020)**.

2. Chemical identification

During the wet season, various polymer types were detected in the study area using the DSC technique. The surface seawater and bed sediment at Abu Qir and Sidi Kiryar did not show any detected polymers due to the rarity of MP in those locations.

The high-density polyethylene (HDPE) was the most common polymer in surface seawater, followed by polyamide (PA). In bed sediment, polymer types were varied between HDPE, polystyrene (PS), and polyethylene terephthalate (PET). Additionally, the variety of polymers in beach sediment was wide, including polyethylene (PE), PET, PS, polyvinyl chloride (PVC), polyethersulfone (PES), and polytetrafluoroethylene (PTFE). This was attributed to the relatively elevated levels of MP in those samples.

During the dry season, the concentrations of MP were relatively low, thus the DSC thermograms did not show any polymer peaks. However, the FTIR spectra exhibited polymer peaks across all samples. This is related to the low sensitivity of the DSC technique to the small quantities of MP. Consequently, it is recommended to use the FTIR technique for low-concentration samples.

Accordingly, during the dry season, the PA followed by rayon were the most common polymers detected by FTIR in most sample types (Fig. 5). For the seawater sample, the general trend of polymer types was as follows: PA > rayon, alkyd resin, polyacrylonitrile, and PVC. The same trend was observed in bed sediments.

3. Ecological risk assessment of MP

The potential ecological risk was examined by measuring the PHI, and PERI. The results of PHI for water, bed, and beach sediments are illustrated in Fig. (6).

Based on the percentage of each polymer and its hazard score, the calculated PHI results reveal Sidi Bishir sediments (bed and beach) showed high hazards, with class V of PHI classification, that related to the presence of PVC polymer however in a relatively low percentage. Moreover, the unique appearance of polyacrylonitrile (13 %) in the water of El-Max Bay is responsible for the extremely high PHI value.

Overall, most study areas with different matrices (water or sediments) are between IV and V levels of HPI (values > 1000, and 10000, respectively), because of polyamide appearance in considerable percentages (> 30 % of most samples).

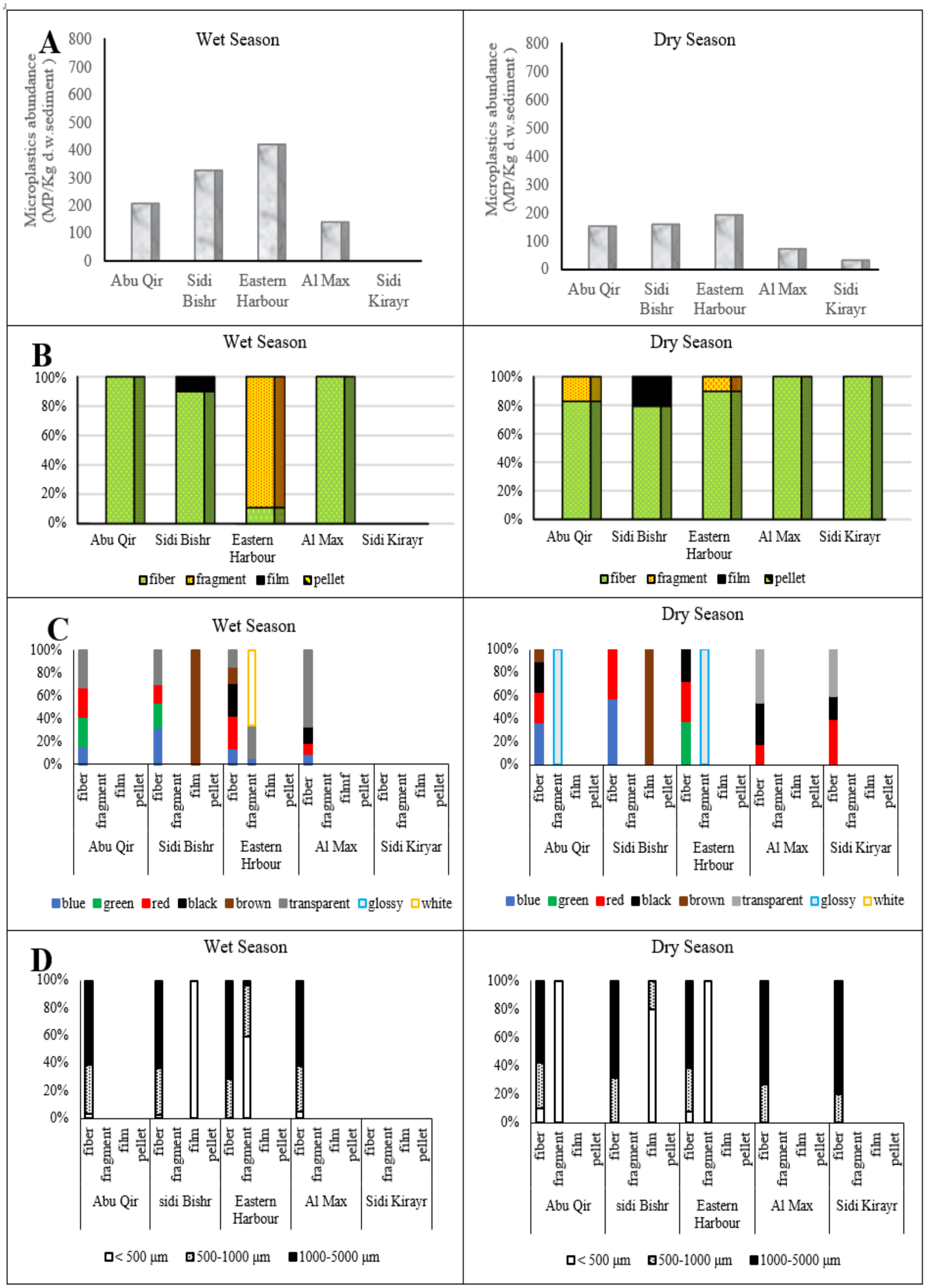


Fig. 3. The detected MP **(A)** abundance, **(B)** shapes, **(C)** colors, and **(D)** sizes in the bed sediment during sampling seasons along the Alexandria coast

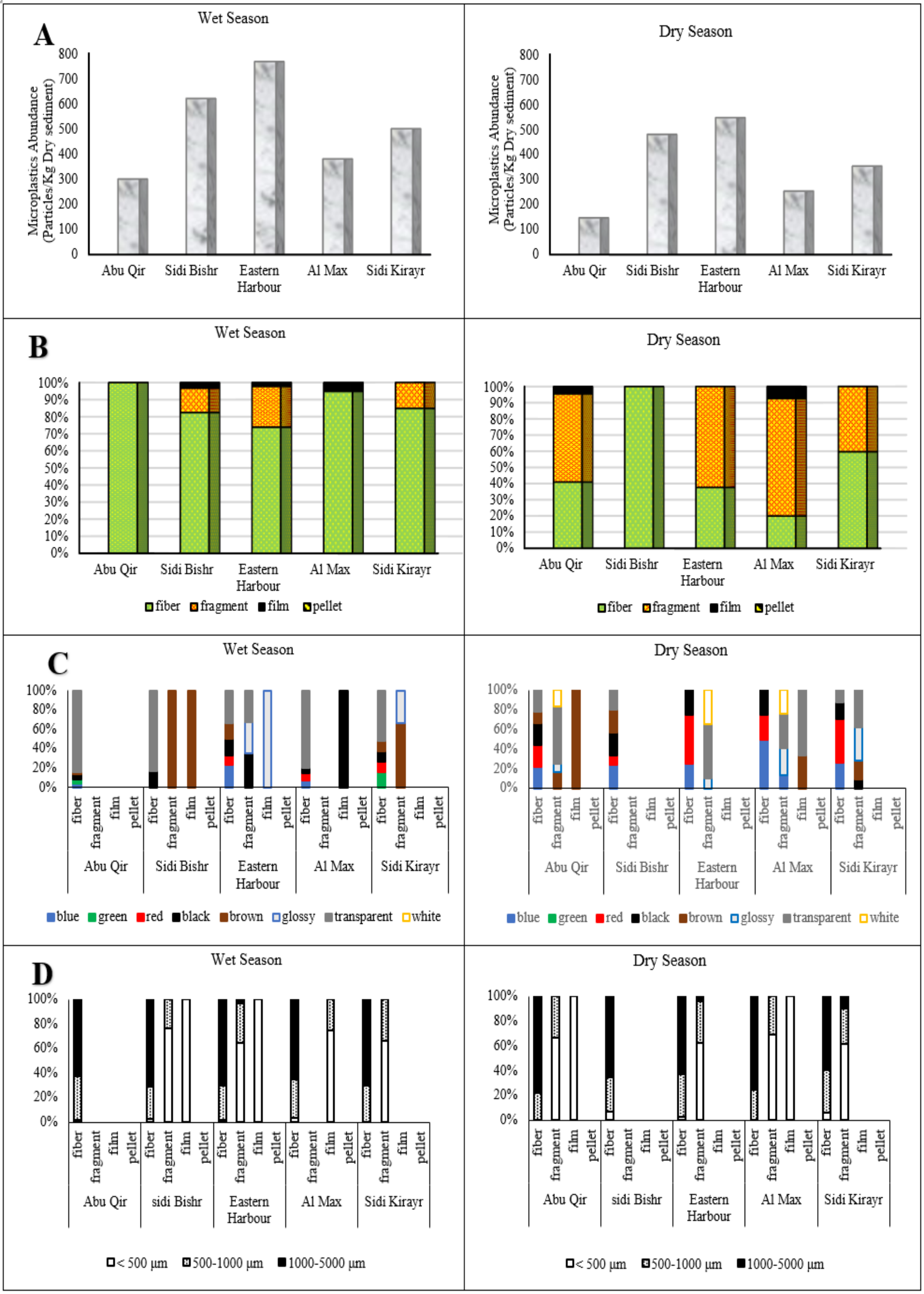


Fig. 4. The detected MP **(A)** abundance, **(B)** shapes, **(C)** colors, and **(D)** sizes in the beach sediment samples during sampling seasons along the Alexandria coast

Consequently, and after applying the PERI (equations 2, and 3), most beach sediments pose extreme danger with MP, even using 540 particles/kg or the lowest recorded MP in the studied sediments as background values (Table 2).

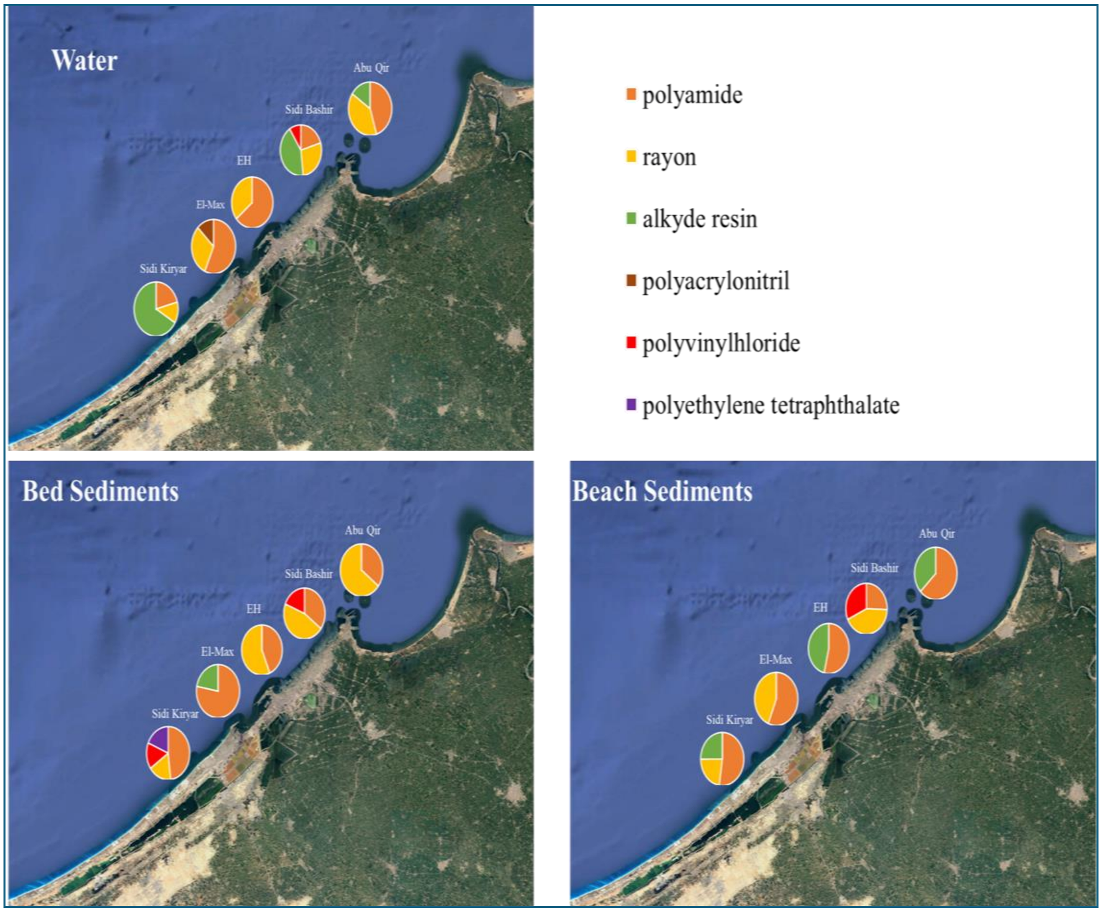


Fig. 5. Polymer types of microplastics in the dry season by FTIR

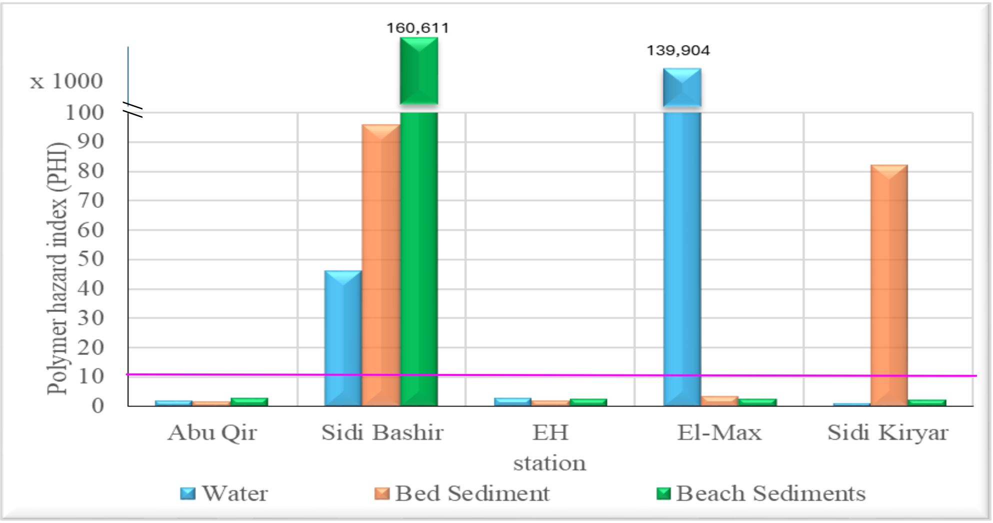


Fig. 6. The polymer hazard index (PHI) of MP in the water, bed, and beach sediments of the study area

Table 2. The potential ecological risk index (PERI) classes of bed and beach sediments in the study area

Location	Bed sediments		Beach sediments	
	*	**	*	**
Abu Qir	H	ED	H	ED
Sidi Bishir	ED	ED	ED	ED
EH	D	ED	ED	ED
El-Max	ED	ED	ED	ED
Sidi Kiryar	Mi	D	ED	ED

* Using 540 particle/Kg as background value Cr in measuring Cfi

** Using the lowest recorded MP value in the studied sediments as background value Cr in measuring Cfi

Mi is a minor PERI (value less than 150),

H is high PERI (value between 300 and 600),

D is danger PERI (value between 600 and 1200),

ED is an extremely dangerous PERI (value more than 1200).

CONCLUSION

The MPs were visually and chemically identified in surface seawater and sediments along the Alexandria shoreline in the first condensed monitoring study.

During the wet season, the MPs in water and sediment were more abundant due to weather, rainfall, and wind speed which can transport plastic litter into the marine environment. Transparent fiber and fragments MP were dominant due to polyethylene (PE) and polypropylene (PP) polymers used in transparent food containers and fishing nets and lines for the frequent fishery activities in Alexandria. Additionally, the prevailing sizes were higher than 500µm in surface water and sediment.

Generally, the PA and rayon were the most common polymer types in most samples. The current results were higher than other studies in the Mediterranean Sea, which could be attributed to many factors such as the different nature of the surrounding environment, the grain size of sediments, and sampling processing.

Applying the ecological risk indices (PHI and PERI), it was revealed that the Sidi Bishir area is classified as V level of risk, and the bed and beach sediments are subjected to extreme danger of MP.

However, the current study is considered a first step toward understanding the extent of microplastic contamination, the following points merit an immediate attention to better understand this pollution and know how dangerous it is:

1- It is important to expand the scientific effort to know the extent of the danger of microplastics to the marine environment and living organisms, especially humans. Until now, the safe minimum daily amount of MP for humans has not been determined for all polymers.

2- Methods of collection and identification of microplastics should be standardized to enable better comparison of data and their incorporation into probabilistic risk assessment models.

3- Though the type of polymer was primarily identified in the present study, it is necessary to give greater attention to the instruments used for the chemical composition identification of MP and relate it to the source of the microplastics.

Finally, while much of the focus on MP has been on the marine environment, plastic pollution is a terrestrial problem. Management strategies, to reduce the amount of plastic used, should minimize plastic waste at the source and provide incentives for recycling, in addition to improving landfill facilities that ought to be identified and implemented by all countries adjacent to the Mediterranean Sea to protect the marine environment.

REFERENCES

Abdel Ghani, S.A.; El-Sayed, A.A.M.; Ibrahim, M.I.A.; Ghobashy, M.M.; Shreadah, M.A.; Shabaka, S. (2022). Characterization and distribution of plastic particles along Alexandria beaches, Mediterranean Coast of Egypt, using microscopy and thermal analysis techniques. Sci. Total Environ., 834: 155363. https://doi.org/10.1016/j.scitotenv.2022.155363.

Abdelwahab, O.; Thabet, W.M.; Nasr, S.M. and Nafea, S. (2021). Oil Spill Cleanup Using Chemically Modified Natural Fibers: Trial for Practical Application. Egypt. J. Aquat. Biol. Fish., 25 (2): 475.

Abidli, S.; Antunes, J.C.; Ferreira, J.L.; Lahbib, Y.; Sobral, P. and Trigui El Menif, N. (2018). Microplastics in sediments from the littoral zone of the north Tunisian coast (Mediterranean Sea). Estuar. Coast. Shelf Sci., 205: 1–9. https://doi.org/10.1016/j.ecss.2018.03.006.

Atas, D.D. (2019). Sampling Microplastics in Beach Sediments and Analysis Using FTIR Spectroscopy. https://urn.fi/URN:NBN:fi:amk-2019060314343

Bayo, J.; Rojo, D. and Olmos, S. (2019). Abundance, morphology and chemical composition of microplastics in sand and sediments from a protected coastal area: The Mar Menor lagoon (SE Spain). Environ. Pollut., 252: 1357–1366. https://doi.org/10.1016/j.envpol.2019.06.024.

Chaczko, Z.; Kale, A.; Santana-Rodríguez, J.J. and Suárez-Araujo, C.P. (2018). Towards an IOT Based System for Detection and Monitoring of Microplastics in Aquatic Environments Zenon. IEEE 22nd International Conference on Intelligent Engineering Systems. https://doi.org/10.1109/INES.2018.8523957**.**

Champagne, P.; Dorgham, M.M.; Liang, Sh.; Favreau, G. and Shaaban, N.A. (2021). Time series relationships between chlorophyll-a, physicochemical parameters, and nutrients in the Eastern Harbour of Alexandria, Egypt. Environ. Monit. Assess., 193: 826 https://doi.org/10.1007/s10661-021-09604-y.

Chen, M.C. and Chen, T.H. (2020). Spatial and seasonal distribution of microplastics on sandy beaches along the coast of the Hengchun Peninsula, Taiwan. Mar. Pollut. Bull., 151: 110861. https://doi.org/10.1016/j.marpolbul.2019.110861.

Cheung, P.K.; Cheung, L.T.O. and Fok, L. (2016). Seasonal variation in the abundance of marine plastic debris in the estuary of a subtropical macro-scale drainage basin in South China. Sci. Total Environ. 562: 658–665. https://doi.org/10.1016/j. scitotenv. 2016.04.048.

Chialanza, M. R.; Sierra, I.; Parada, A. P. and Fornaro, L. (2018). Identification and quantitation of semi-crystalline microplastics using image analysis and differential scanning calorimetry. Environ. Sci. Poll. Res., 25 (17): 16767–16775. https://doi.org/10.1007/s11356-018-1846-0.

Christian, N.; Gallardo, C.; Lenz, M. and Thiel, M. (2018). Capture, swallowing, and egestion of microplastics by a planktivorous juvenile fish. Environ. Pollut., 240: 566–573. https://doi.org/10.1016/j.envpol.2018.04.093.

Constant, M.; Kerherve, P. and Sola, J. (2018). Floating Microplastics in the Northwestern Mediterranean Sea: Temporal and Floating Microplastics in the Northwestern Mediterranean Sea: Temporal and Spatial Heterogeneities. Proceedings of the International Conference on Microplastic Pollution in the Mediterranean Sea (ICMPMS). https://doi.org/10.1007/978-3-319-71279-6.

De Ruijter, V.N.; Milou, A. and Costa, V. (2019). Assessment of microplastic distribution and stratification in the shallow marine sediments of Samos Island, Eastern Mediterranean Sea, Greece. Mediterr. Mar. Sci., 20: 736–744. https://doi.org/10.12681/mms.19131.

Ding, R.; Ouyang, F.; Peng, D.; You, J.; Ding, L.; Ouyang, Z.; Liu, P. and Guo, X. (2022). A case study of distribution and characteristics of microplastics in surface water and sediments of the seas around Shenzhen, southern coastal area of China. Sci. Total Environ., 838 (1): 156063. https://doi.org/10.1016/j.scitotenv.2022.156063.

El-Rayis, O.A.; Thabet, W.M.; Hussein, R.A. and Hemeda, I.E. (2012.) Assessment of water quality in Alamein Marina Recreational Lagoon. J. Egypt Public Health Assoc., 87 (5-6): 116-123.

El-Sayed, A.A.M.; Ibrahim, M.I.A.; Shabaka, S.; Ghobashy, M.M.; Shreadah, M.A. and Abdel Ghani, S.A. (2022). Microplastics contamination in commercial fish from Alexandria City, the Mediterranean Coast of Egypt, Environ. Pollut. https://doi.org/10.1016/j.envpol.2022.120044

Expósito, N.; Rovira, J.; Sierra, J.; Folch, J. and Schuhmacher, M. (2021). Microplastics levels, size, morphology, and composition in marine water, sediments, and sand beaches. Case study of Tarragona coast (western Mediterranean). Sci. Total Environ., 786: 147453. https://doi.org/10.1016/j.scitotenv.2021.147453.

Filgueiras, A.V.; Gago, J.; Campillo, J.A. and León, V.M. (2019). Microplastic distribution in surface sediments along the Spanish Mediterranean continental shelf. Environ. Sci. Pollut. Res., 26: 21264–21273. https://doi.org/10.1007/s11356-019-05341-5

Folk, R.L. and Ward, W.C. (1957). Brazos River bars, a study in significance of grain size parameters. J. Sediment. Petrol., 27: 3-27.

Fu, D.; Chen, C.M.; Qi, H.; Fan, Z.; Wang, Z.; Peng, L. and Li, B. (2020). Occurrences and distribution of microplastic pollution and the control measures in China. Mar. Pollut. Bull., 153: 110963. https://doi.org/10.1016/j.marpolbul.2020.110963.

GESAMP (2019) Guidelines for the monitoring and assessment of plastic litter and microplastics in the ocean (eds Kershaw P.J., Turra A. and Galgani F.), London, UK, GESAMP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection, 130pp. (GESAMP Reports and Studies, No. 99). http://dx.doi.org/10.25607/OBP-435.

Guerranti, C.; Perra, G.; Martellini, T.; Giari, L. and Cincinelli, A. (2020). Knowledge about microplastic in Mediterranean tributary river ecosystems: Lack of data and research needs on such a crucial marine pollution source. J. Mar. Sci. Eng., 8 (3): 216. https://doi.org/10.3390/jmse8030216.

Gündo, S., and Çevik, C. (2017). Micro- and mesoplastics in Northeast Levantine coast of Turkey: The preliminary results from surface samples. Mar. Pollut. Bull., 118 (1-2): 341-347. https://doi.org/10.1016/j.marpolbul.2017.03.002.

Gündoğdu, S. (2017). High level of micro-plastic pollution in the Iskenderun Bay NE Levantine coast of Turkey. EgeJFAS, 34 (4): 401-408. https://doi.org/10.12714/egejfas.2017.34.4.06.

Güven, O.; Gokdag, K.; Jovanovi, C. B. and Erkan Kıdeys, A. (2017). Microplastic litter composition of the Turkish territorial waters of the Mediterranean Sea, and its occurrence in the gastrointestinal tract of fish. Environ. Pollut., 223: 286-294. https://doi.org/10.1016/j.envpol.2017.01.025.

Hal, N.; Van Der Ariel, A. and Angel, D. L. (2016). Exceptionally high abundances of microplastics in the oligotrophic Israeli Mediterranean coastal waters. Mar. Pollut. Bull., 116 (1-2): 151-155. https://doi.org/10.1016/j.marpolbul.2016.12.052.

Jambeck, J.R.; Geyer, R.; Wilcox, C.; Siegler, T.R.; Perryman, M.; Andrady, A.; Narayan, R. and Law, K. L. (2015) Marine pollution. Plastic waste inputs from land into the ocean. Science, 347 (6223): 768-71. https://doi:10.1126/science.1260352

Jemaa, S.; Mahfouz, C.; Kazour, M. and Lteif, M. (2021). Floating Marine Litter in Eastern Mediterranean from Macro to Microplastics: Floating Marine Litter in Eastern Mediterranean from Macro to Microplastics: The Lebanese Coastal Area as a Case Study. Front. Environ. Sci., 9: 699343. https://doi.org/10.3389/fenvs.2021.699343.

Kasamesiri, P.; Panchan, R. and Thaimuangphol, W. (2023) Spatial–Temporal Distribution and Ecological Risk Assessment of Microplastic Pollution of Inland Fishing Ground in the Ubolratana Reservoir, Thailand. Water. 15: 330. https://doi.org/10.3390/w15020330.

Kazour, M.; Jemaa, S.; Issa, C.; Khalaf, G. and Amara, R. (2019). Microplastics pollution along the Lebanese coast (Eastern Mediterranean Basin): Occurrence in surface water, sediments, and biota samples. Sci. Total Environ., 696: 133933. https://doi.org/10.1016/j.scitotenv.2019.133933

Khan, F.R.; Shashoua, Y.; Crawford, A.; Drury, A.; Sheppard, K.; Stewart, K. and Sculthorp, T. (2020). “The plastic Nile”: First evidence of microplastic contamination in fish from the Nile River (Cairo, Egypt). Toxics, 8 (2): 22. https://doi.org/10.3390/TOXICS8020022.

Lefebvre, C.; Saraux, C.; Heitz, O.; Nowaczyk, A. and Bonnet, D. (2019). Microplastics FTIR characterization and distribution in the water column and digestive tracts of small pelagic fish in the Gulf of Lions. Mar. Pollut. Bull., 142: 510–519. https://doi.org/10.1016/j.marpolbul.2019.03.025.

Li, Y.; Lu, Z.; Zheng, H.; Wang, J. and Chen, C. (2020). Microplastics in surface water and sediments of Chongming Island in the Yangtze Estuary, China. Environ. Sci. Eur., 32: 15. https://doi.org/10.1186/s12302-020-0297-7.

Li, Z.; Liu, Y.; Zhang, D.; Feng, L.; He, X.; Duan, X.; Li, X. and Xie, H. (2022). Distribution and environmental risk assessment of microplastics in continental shelf sediments in the southern East China Sea: A high-spatial-resolution survey. Mar. Pollut. Bull., 177: 113548. https://doi.org/10.1016/j.marpolbul.2022.113548.

Lithner, D.; Larsson, A. and Dave, G. (2011). Environmental and health hazard ranking, and assessment of plastic polymers based on chemical composition. Sci. Total Environ., 409: 3309–3324. https://doi.org/10.1016/j.scitotenv.2011.04.038.

Masura, J.; Baker, J.; Foster, G. and Arthur, C. (2015). Laboratory Methods for the Analysis of Microplastics in the Marine Environment: Recommendations for quantifying synthetic particles in waters and sediments. NOAA Technical Memorandum NOS-OR&R-48.

Meng, X.; Bao, T.; Hong, L. and Wu, K. (2023). Occurrence Characterization and Contamination Risk Evaluation of Microplastics in Hefei’s Urban Wastewater Treatment Plant. Water, 15. https://doi.org/10.3390/w15040686.

Moneer, A.A.; Thabet, W.M.; Khedawy, M.; El-Sadaawy, M.M. and Shaaban, N.A. (2023). Electrocoagulation process for oily wastewater treatment and optimization using response surface methodology. Int. J. Environ. Sci. Technol., 20: 13859–13872. https://doi.org/10.1007/s13762-023-05003-7.

Park, T.; Lee, S.H.; Lee, M.; Lee, J.; Park, J. and Zoh, K. (2020). Distributions of Microplastics in Surface Water, Fish, and Treatment Plant. Water, 12 (12): 3333. https://doi.org/10.3390/w12123333.

PLASTEX 2024 (2022). Egypt, Okeanos signed a deal to manufacture plastics made from stones–Egypt Today. https://www.egypttoday.com/Article/1/115856/Egypt-Okeanos-sign-deal-to-manufacture-plastics-made-from-stones (accessed 3.12.23).

Phakopa, J.; Sukhsangchan, R.; Keawsang, R.; Tanapivattanakul, K.; Asvakittimakul, B.; Thamrongnawasawat, T. and Worachananant, S. (2023). Assessment of Microplastics in Green Mussel (Perna viridis) and Surrounding Environments around Sri Racha Bay, Thailand. Sustainability. 15 (1): 9. https://doi.org/10.3390/su15010009.

Prata, J. correia; da Costa, J.P.; Duarte, A.C. and Rocha-Santos, T. (2019). Methods for sampling and detection of microplastics in water and sediment: A critical review. Trends Anal. Chem., 110: 150–159. https://doi.org/10.1016/j.trac.2018.10.029.

Prata, J.C., Costa, J. p. da., Girão, A. v, Lopes, Isabel., Duarte, A. c, Rocha-Santos, T. (2019). Identifying a quick and efficient method of removing organic matter without damaging microplastic samples. Sci. Total Environ., 686: 131–139. https://doi.org/10.1016/j.scitotenv.2019.05.456.

Rasta, M.; Sattari, M.; Taleshi, M.S. and Namin, J.I. (2021). Microplastics in different tissues of some commercially important fish species from Anzali Wetland in the Southwest Caspian Sea, Northern Iran. Mar. Pollut. Bull., 169: 112479. https://doi.org/10.1016/j.marpolbul.2021.112479.

Sayed, A.E.D.H.; Hamed, M.; Badrey, A.E.A.; Ismail, R.F.; Osman, Y.A.A.; Osman, A.G.M. and Soliman, H.A.M. (2021). Microplastic distribution, abundance, and composition in the sediments, water, and fishes of the Red and Mediterranean seas, Egypt. Mar. Pollut. Bull., 173: 112966. https://doi.org/10.1016/j.marpolbul.2021.112966.

Shaaban, N.A.; Tawfik, S.; El-Tarras, W. and El-Sayed Ali, T. (2022a). Are the water quality of the agricultural drainage and Nile River suitable for tilapia culture? A case study from Kafr El-Shaikh's fish farms, Egypt. Turkish J. Fish. Aquat. Sci., 22 (12): TRJFAS21395. https://doi.org/10.4194/TRJFAS21395.

Shaaban, N.A.; Tawfik, S.; and El-Sayed Ali, T. (2022b). Metals concentrations and ecological risk assessments of fish farms sediments in Kafr El-Shaikh, Egypt. Egypt. J. Aquat. Biol. Fish. 26(4), 377-393. 10.21608/EJABF.2022.250750.

Shaaban, N.A.; Shreadah, M.A.; El-Rayis, O.A. and Hamdan, A.M. (2021a). Metal bioavailability, toxicity, and ecological risk due to sediments of a lately rehabilitated lake (Mariut, Egypt). Environ. Monit. Assess., 193 (7): 1-14. https://doi.org/10.1007/s10661-021-09226-4.

Shaaban, N.A.; Tawfik, S.; El-Tarras, W. and El-Sayed Ali, T. (2021b). Potential health risk assessment of some bioaccumulated metals in Nile tilapia (Oreochromis niloticus) cultured in Kafr El-Shaikh farms, Egypt. Environ. Res., 200: 111358. https://doi.org/10.1016/j.envres.2021.111358.

Shabaka, S.H.; Ghobashy, M. and Marey, R.S. (2019). Identification of marine microplastics in Eastern Harbor, Mediterranean Coast of Egypt, using differential scanning calorimetry. Mar. Pollut. Bull., 142: 494–503. https://doi.org/10.1016/j.marpolbul.2019.03.062.

Shabaka, S.H.; Marey, R.S.; Ghobashy, M.; Abushady, A.M.; Ismail, G.A. and Khairy, H.M. (2020). Thermal analysis and enhanced visual technique for assessment of microplastics in fish from an Urban Harbor, Mediterranean Coast of Egypt. Mar. Pollut. Bull., 159: 111465. https://doi.org/10.1016/j.marpolbul.2020.111465.

Sharma, S.; Sharma, V. and Chatterjee, S. (2021). Microplastics in the Mediterranean Sea: Sources, Pollution Intensity, Sea Health, and Regulatory Policies. Front. Mar. Sci., 8: 634934. https://doi.org/10.3389/fmars.2021.634934.

Sun, J.; Peng, Z.; Zhu, Z.; Fu, W.; Dai, X. and Ni, B. (2022). The atmospheric microplastics deposition contributes to microplastic pollution in urban waters, Water Res., 225: 119116. https://doi.org/10.1016/j.watres.2022.119116

Tang, K.H.D.; Li, R.; Li, Z. and Wang, D. (2024). Health risk of human exposure to microplastics: a review. Environ. Chem. Lett., 22: 1155–1183. https://doi.org/10.1007/s10311-024-01727-1

Thabet, W.M.; Moneer, A.A.; Abdelwahab, O.; Ahdy, H.H.H.; Khedawy, M. and Shaaban, N.A. (2024). Ecological risk assessment of metal pollution in the surface sediments of Delta region, Egypt. Environ. Monit. Assess., 196: 351. https://doi.org/10.1007/s10661-024-12481-w.

Veerasingam, S.; Saha, M.; Suneel, V.; Vethamony, P.; Rodrigues, A.C.; Bhattacharyya, S. and Naik, B.G. (2016). Characteristics, seasonal distribution and surface degradation features of microplastic pellets along the Goa coast, India. Chemosphere, 159: 496–505. https://doi.org/10.1016/j.chemosphere.2016.06.056

Vermeiren, P.; Lercari, D.; Muñoz, C.C.; Ikejima, K.; Celentano, E.; Jorge-Romero, G. and Defeo, O. (2021). Sediment grain size determines microplastic exposure landscapes for sandy beach macroinfauna. Environ. Pollut., 286: 117308. https://doi.org/10.1016/j.envpol.2021.117308

Waldschläger, K. and Schüttrumpf, H. (2020). Infiltration Behavior of Microplastic Particles with Different Densities, Sizes, and Shapes-From Glass Spheres to Natural Sediments. Environ. Sci. Technol., 54: 9366–9373. https://doi.org/10.1021/acs.est.0c01722

Wang, G.; Lu, J.; Li, W.; Ning, J.; Zhou, L.; Tong, Y.; Liu, Z.; Zhou, H. and Xiayihazi, N. (2021). Seasonal variation and risk assessment of microplastics in surface water of the Manas River Basin, China. Ecotoxicol. Environ. Saf., 208: 111477. https://doi.org/10.1016/j.ecoenv.2020.111477

Wang, W.; Ge, J. and Yu, X. (2020). Bioavailability and toxicity of microplastics to fish species: A review. Ecotoxicol. Environ. Saf., 189: 109913 https://doi.org/10.1016/j.ecoenv.2019.109913

Wicaksono, E.A.; Werorilangi, S.S.; Galloway, T. and Tahir, A. (2021). Distribution and Seasonal Variation of Microplastics in Tallo River, Makassar, Eastern Indonesia. Toxics., 9 (6): 129. https://doi:10.3390/toxics9060129

Zhang, D.; Cui, Y.; Zhou, H.; Jin, C.; Yu, X.; Xu, Y.; Li, Y. and Zhang, C. (2020). Microplastic pollution in water, sediment, and fish from artificial reefs around the Ma'an Archipelago, Shengsi, China. Sci. Total Environ., 703: 134768. https://doi.org/10.1016/j.scitotenv.2019.134768

Zhang, D.; Fraser, M.A.; Huang, W.; Ge, C.; Wang, Y.; Zhang, C. and Guo, P. (2021). Microplastic pollution in water, sediment, and specific tissues of crayfish (Procambarus clarkii) within two different breeding modes in Jianli, Hubei province, China. Environ. Pollut., 272: 115939. https://doi.org/10.1016/j.envpol.2020.115939

Zhang, W.; Zhang, S.; Wang, J.; Wang, Y.; Mu, J.; Wang, P.; Lin, X. and Ma, D. (2017). Microplastic pollution in the surface waters of the Bohai Sea, China. Environ. Pollut., 231: 541–548. https://doi.org/10.1016/j.envpol.2017.08.058 .

Zhu, X.; Ran, W.; Teng, J.; Zhang, C.; Zhang, W.; Hou, C.; Zhao, J.; Qi, X. and Wang, Q. (2021). Microplastic Pollution in Nearshore Sediment from the Bohai Sea Coastline. Bull. Environ. Contam. Toxicol., 107: 665 - 670 https://doi.org/10.1007/s00128-020-02866-1.