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 nearshore 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).

![Fig. 1. Sampling sites and activities along Alexandria coast, Egypt](image)

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% H₂O₂ 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% H₂O₂ 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 of 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 (N₂) 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:
PHI = \Sigma P_n \times S_n \quad (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:

\[ CF_i = \frac{C_i}{C_r} \quad (2) \]

\[ \text{PERI} = \text{PHI} \times Cfi \quad (3) \]

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 (< 500\( \mu \)m), 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 300 μm) (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 500 μm, (b) from 500 to 1000 μm, and (c) from 1000 to less than 5000 μm. Microfibers with a relatively large size; class-c (> 1000 μm) the dominant size in water samples. In contrast, most other MP shapes were of small size, class-a (< 500 μm), (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 (>$1000\mu m$) formed the dominant size (like overlying water). In contrast, most of the other shapes of MP were of the small size, class a ($\leq 500\mu m$), 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

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

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 40% 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

<table>
<thead>
<tr>
<th>Location</th>
<th>Bed sediments *</th>
<th>Bed sediments **</th>
<th>Beach sediments *</th>
<th>Beach sediments **</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abu Qir</td>
<td>H</td>
<td>ED</td>
<td>H</td>
<td>ED</td>
</tr>
<tr>
<td>Sidi Bishir</td>
<td>ED</td>
<td>ED</td>
<td>ED</td>
<td>ED</td>
</tr>
<tr>
<td>EH</td>
<td>D</td>
<td>ED</td>
<td>ED</td>
<td>ED</td>
</tr>
<tr>
<td>El-Max</td>
<td>ED</td>
<td>ED</td>
<td>ED</td>
<td>ED</td>
</tr>
<tr>
<td>Sidi Kiryar</td>
<td>Mi</td>
<td>D</td>
<td>ED</td>
<td>ED</td>
</tr>
</tbody>
</table>

* 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


