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REVIEW ARTICLE

Occurrence and risks of microplastics in the ecosystems of the Middle East and North Africa (MENA)

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Abstract

The ubiquitous nature of microplastics (MPs) in nature and the risks they pose on the environment and human health have led to an increased research interest in the topic. Despite being an area of high plastic production and consumption, studies on MPs in the Middle East and North Africa (MENA) region have been limited. However, the region witnessed a research surge in 2021 attributed to the COVID-19 pandemic. In this review, a total of 97 studies were analyzed based on their environmental compartments (marine, freshwater, air, and terrestrial) and matrices (sediments, water columns, biota, soil, etc.). Then, the MP concentrations and polymer types were utilized to conduct a risk assessment to provide a critical analysis of the data. The highest MP concentrations recorded in the marine water column and sediments were in the Mediterranean Sea in Tunisia with 400 items/m^3 and 7960 items/kg of sediments, respectively. The number of MPs in biota ranged between 0 and 7525 per individual across all the aquatic compartments. For the air compartment, a school classroom had 56,000 items/g of dust in Iran due to the confined space. Very high risks in the sediment samples ($Er^i > 1500$) were recorded in the Caspian Sea and Arab/Persian Gulf due to their closed or semi-closed nature that promotes sedimentation. The risk factors obtained are sensitive to the reference concentration which calls for the development of more reliable risk assessment approaches. Finally, more studies are needed in understudied MENA environmental compartments such as groundwater, deserts, and estuaries.

Keywords Microplastics · Middle East and North Africa · Risk assessment · Aquatic systems · Biota

Introduction

Plastics are among the most used materials globally due to their durability, inexpensiveness, and versatility (Wu et al. 2022). In fact, global plastic consumption has been increasing over the past decades and reached 367 million tons in 2020 (PlasticsEurope 2021). Nevertheless, improper management of the generated plastic waste led to the accumulation of plastics in the environment (Geyer et al. 2017; Jambeck et al. 2015). Thereafter, plastics are prone to degradation and fragmentation processes attributed to factors such as mechanical abrasion, thermal degradation, photo-oxidation, hydrolysis, and biodegradation (Chamas et al. 2020). Accordingly, it becomes important to classify plastic litter by size. In other words, macroplastics (> 5 mm) degrade into microplastics (MPs) (1 µm–5 mm) and nanoplastics (< 1 µm) (Woods et al. 2021). Research on MPs has been growing due to their ubiquity in the environment. Their presence has been reported in oceans (Zhang 2017), rivers (Bellasi et al. 2020), farmlands (T. Jin et al. 2022), deserts (Abbasi et al. 2021; Wang et al. 2021), and the Arctic

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(Bergmann et al. 2022). Hence, MPs are capable of being transported between the different environmental compartments: terrestrial, air, freshwater, and marine (Beaurepaire et al. 2021; Dissanayake et al. 2022; Malli et al. 2022). For example, plastics can be introduced to the marine compartment from the freshwater compartment through estuaries (Malli et al. 2022) or from the air compartment through wind effects (Zhang 2017).

The presence of MPs in the environment causes ecotoxicological stresses. For instance, biota are exposed to MPs through ingestion (Maaghloud et al. 2020) which poses a risk of MP biomagnification across the food chain (Miller et al. 2020). Other stresses include feeding disruptions, irregularities in energy metabolism, and motion hindrance due to injuries (Anbumani and Kakkar 2021). Moreover, bacterial communities may colonize the surface of MPs (Pinheiro et al. 2021). Depending on where the bio-fouled MPs end up, they may act as vectors for invasive species (García-Gómez et al. 2021). Humans can be exposed to MPs through inhalation (Jenner et al. 2022) and ingestion of plastic-bearing food (M. Jin et al. 2021) and drinking water (Akhbarizadeh et al. 2020b; Yuan et al. 2022). In fact, MPs have been recently detected in human blood (Leslie et al. 2022). The interactions of MPs with persistent organic pollutants (POPs) and heavy metals as well as the presence of plastic additives suggest potential effects of MPs on human health (Campanale et al. 2020). Finally, MPs can cause damage to socioeconomic assets as their presence may negatively affect tourism and fishing activities (Beaumont et al. 2019; Woods et al. 2021). Given the above, it is crucial to monitor the occurrence and abundance of MPs in different parts of the world. Doing so on a global scale provides useful data for the development of characterization factors for life cycle assessments (LCA) for plastics (Corella-Puertas et al. 2022). Such studies would assist and push for legislating environmental policies regulating the emissions of plastics and MPs to the environment. Several metrics are currently used to assess the risk of MPs such as the pollution load index (PLI) based on the abundance of MPs in a defined zone and the hazard index (HI) based on the chemical composition of MPs (Ding et al. 2022; Jemaa et al. 2021; Picó et al. 2021). However, these indices suffer from some pitfalls. For example, the PLI fails to account for meteorological and hydrodynamic differences that could exist within the same zone under study. Moreover, the HI is only limited to a set of polymers with developed hazard scores (Lithner et al. 2011). More recent studies are assessing the ecological risk of MPs based on the predicted no-effect concentration (PNEC) derived from species sensitivity distributions (SSDs) (Adam et al. 2021; Jung et al. 2021; Koelmans and Ruijter 2022). However, this requires the development of an extensive database of PNEC values due to the differences in size, shape, and composition of MPs. As for human health risk, there is currently no acceptable daily intakes, reference doses, or toxicological thresholds to assess the adverse impacts of MPs on humans (Polidoro et al. 2022). This is again attributed to the wide range of sizes, shapes, and compositions of MPs. Hence, a tool is needed to assess MP risk with the information currently available.

Studies on MPs are mostly conducted in Europe, China, Africa, and North America (Orona-Návar et al. 2022a). Several papers highlight the abundance of MPs and plastic debris in Europe (Pedrotti et al. 2016; Suaria et al. 2016), Africa (Alimi et al. 2021), Latin America and the Caribbean (Orona-Návar et al. 2022a), and Southeast Asia (Curren et al. 2021). However, studies done in such parts of the world do not necessarily reflect the status of MP pollution in the Middle East and North Africa (MENA) region. The MENA region is characterized by substantial differences between countries in terms of economic development, political stability, and sustainable development (Baysoy & Altug 2021). This has direct implications on consumer behavior as well as the environmental regulations in each country. On average, a citizen in the MENA region produces more than 6 kg of plastic waste to the region's seas annually (Heger et al. 2022). This is comparable to regions such as Sub-Saharan Africa and East Asia and Pacific where the annual per capita volume of emitted plastics ranged between 5 and 6 kg (Jambeck et al. 2015). However, it is well-above values reported for North America (< 1 kg), Europe and Central Asia (1 kg), and Latin America and the Caribbean (~ 2 kg) (Heger et al. 2022; Jambeck et al. 2015). There have been previous reviews that report the occurrence of MPs in parts of the MENA region (Alimi et al. 2021; Ouda et al. 2021; Razeghi et al. 2021; Uddin et al. 2020), but they were limited to the marine compartment only. Uddin et al. (2020) only reviewed studies conducted in the Arab/Persian Gulf while Razeghi et al. (2021) only reported studies done in the aquatic system in Iran. Alimi et al. (2021) reviewed the occurrence of MPs in Africa, hence implicitly covering the North African region. As for Ouda et al. (2021), the review focuses on numerous emerging contaminants such as pharmaceuticals, nanomaterials, e-waste, and microplastics, with the latter being limited to the marine compartment only. Moreover, these studies do not account for the new surge of studies published in 2021 and 2022 where a significant increase in research output on MPs is observed. This is of key significance as the aforementioned time frame is associated with the ongoing effects of the COVID-19 pandemic. The latter has exacerbated the consumption of single-use plastics such as masks and other personal protective equipment (PPE) (Luo et al. 2022). Finally, the MENA region is considered a region under water stress due to the relatively few sources of freshwater compared to its area (Hussein et al. 2022). Its primary marine water resources (e.g., Mediterranean Sea, Red Sea, and Arab/Persian Gulf) are all semi-enclosed and undergo heavy ship traffic (Shabaka et al. 2020). This means that MP pollution in MENA water bodies can exacerbate the issue of water security in the region. Hence, this work has the following objectives: (i) review the occurrence of MPs in the different environmental compartments (marine, freshwater, air, and terrestrial) across the MENA region; (ii) quantify the ecological risk from the reported occurrence data using the "risk factor" approach; and (iii) analyze the research gaps found in the literature and to propose potential directions for MPs research in the MENA region.

Methodology

First, studies focusing on the occurrence of MPs in different environmental compartments in the MENA region were retrieved. A database was compiled from the information reported in these studies ("Literature search" section). Thereafter, a risk assessment is conducted based on those values to quantify and assess the extent of MP pollution in various regions of the MENA ("Risk assessment" section).

Literature search

Literature search was conducted through Scopus and Web of Science for studies on microplastics. The retrieved studies spanned the period between 2016 and June 2022, with the first study done in Qatar in 2016 (Castillo et al. 2016). The purpose of the search was to identify all articles and review papers on MP occurrence, fate, and transport conducted in the MENA region. The keywords used for searching were "microplastics" AND "*country*" where the latter was set as one of the region's countries (Algeria, Bahrain, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Mauritania, Oman, Palestinian Territories, Qatar, Saudi Arabia, Sudan, Syria, Tunisia, the United Arab Emirates, and Yemen) at the beginning of every search. From the retrieved articles, information on the (i) compartment (marine, freshwater, terrestrial, or air), (ii) matrix (e.g., water column, sediments, or biota for aquatic environments), (iii) MP concentration, (iv) dominant shapes and colors, (v) sampling methods, and (vi) polymer types were recorded for each study and summarized in Table S1. Some studies were excluded from the database as they were focusing solely on ecotoxicity, exposure, and degradation rather than occurrence, but were referred to in the "Discussion" section. These studies are presented in Table S2.

Risk assessment

Due to the absence of a standardized assessment methods to quantify the risk of MP exposure, we resort to the risk factor (Er^i) defined by Hakanson (1980) to assess the severity of MP pollution in each study. It should be noted that this method was initially developed to assess heavy metal pollution in soils and sediments. However, since it takes into consideration the content, environmental and ecological effects, and the toxicology of the material in the soil, it can be deemed as a good technique to evaluate microplastic pollution in the sediments (Li et al. 2021). Such an approach has been adopted more recently in studies assessing the risk posed by MPs in an environmental compartment (Li et al. 2021; Liu et al. 2022; Xu et al. 2018). Er^i is presented in Eq. (1).

$$Er^i = T_n \times C_f^i \tag{1}$$

T_n is a hazard score that evaluates the hazardous effect of a plastic polymer and is calculated as in Eq. (2) (Liu et al. 2022). C_f^i is the contamination factor calculated by dividing the MP concentration in one study (C_i) by the reference concentration (C_{oi}), as shown in Eq. (3) (Hakanson 1980; Liu et al. 2022).

$$T_n = \sum T_{ni} = \sum P_n \times S_n \tag{2}$$

where P_n is the percentage of polymer types detected in each study and S_n is a hazard score associated with each polymer type reported by Lithner et al. 2011.

$$C_f^i = \frac{C_i}{C_{oi}} \tag{3}$$

where C_{oi} is the reference concentration estimated as the minimum concentration of MPs reported for each compartment.

It should be noted that the hazard score (S_n) of each polymer was calculated by summing up the hazard scores of the monomers constituting each polymer. The hazard scores of the monomers depend on the classifications they belong to according to the Globally Harmonized System of Classification and Labelling of Chemicals and the Swedish Chemicals Agency (Lithner et al. 2011). Hazard grades increase by a factor of 10 to distinguish between the risks of the different categories.

The collected studies were divided by compartment (marine, freshwater, air, terrestrial). Due to environmental and hydrological differences, the marine compartment was divided into three zones each comprising a specific geographic area. Zone A considers the studies conducted on the southern and eastern parts of the Mediterranean as well as parts of the Atlantic Ocean on the Moroccan coast (Table S3). Zone B is made up of studies conducted in the Arab/Persian Gulf (Table S4). Lastly, zone C comprises the studies conducted on the southern coast of the Caspian Sea, with all studies in this zone were done in Iran (Table S5). Studies done in the Red Sea were excluded from this section as the data was not sufficient to compile a database and conduct a risk assessment. Each of the aforementioned zones had its individual C_{oi} depending on the matrix (water column or sediments). The same was done for the water column and sediments of the freshwater compartment (Table S6) as well as the air and terrestrial compartments (Table S7). The obtained risk factors, Er^i, are divided into the following risk degrees (Hakanson 1980):

- $Er^i < 40$ → low potential ecological risk.
- $40 \leq Er^i < 80$ → moderate potential ecological risk.
- $80 \leq Er^i < 160$ → considerable potential ecological risk.
- $160 \leq Er^i < 320$ → high potential ecological risk.
- $Er^i \geq 320$ → very high potential ecological risk.

That being said, the value of C_f^i is sensitive to the choice of C_{oi} which directly affects the value of Er^i. Hence, a sensitivity analysis is done by reconducting the same approach but using C_{oi} as the median concentration of MPs reported for each compartment (Tables S8 to S12).

Occurrence of MPs in MENA environmental compartments

This section reports the occurrence of MPs in the environmental compartments of the MENA region. "Literature review" section summarizes the results of the literature review in terms of the number of papers published, their geographic distribution, and the evolution of the number of publications with time. Thereafter, the concentrations, polymers, and sources of MPs are discussed for the marine, freshwater, terrestrial, and air compartments in "Marine compartment," "Freshwater compartment," "Terrestrial compartment," and "Air compartment" sections, respectively.

Literature review

A total of 97 studies were retrieved and comprehensively evaluated. Overall, Iran and Tunisia had the highest number of MP occurrence studies with 23 and 13 studies, respectively (Fig. 1a). No studies were conducted in Syria, Palestine, Jordan, Libya, Yemen, and Oman on the occurrence of MPs in the environmental compartments. The annual number of studies on MPs published in the MENA region evolved from one in 2016 to 40 in 2021 showing an increasing research interest in this topic in the region (Fig. 1b). Figure 1c shows that the marine compartment is a hotspot for MP research in the MENA region leading with 64 published studies while the air and terrestrial compartments seem to be lagging with 10 and 6 studies, respectively. Moreover, the distribution of polymers by compartment is displayed in Figure S1 while the distribution of MPs shapes by compartment is presented in Figure S2.

Marine compartment

The occurrence of MPs in the marine compartment is classified by water column ("Water column" section), sediments ("Sediments" section), and biota ("Biota" section).

Water column

Most of the occurrence studies of MPs in the water column of the MENA water bodies are located in the Mediterranean Sea and the Persian/Arab Gulf. Other studies are done in the Red Sea, Caspian Sea, and Atlantic Coast. The main findings of these studies are tabulated in Table 1.

The first occurrence study in the Mediterranean Sea was conducted in its Eastern part off the Israeli coast (van der Hal et al. 2017). Based on samples collected between July 2013 and May 2015, the mean concentration of MPs in the Israeli coastal waters was 7.68 ± 2.38 MPs/m^3 (van der Hal et al. 2017). Kazour et al. (2019) reported an average concentration of 4.3 ± 2.2 MPs/m^3 across the Lebanese coast. In a more recent study, the concentration nearly tripled to 12.13 MPs/m^3 (Jemaa et al. 2021). The results of these studies are comparable to a study done in Iskenderun Bay, Turkey, where the recorded concentration was 7.26 MPs/m^3 (Gündoğdu 2017). The aforementioned studies show MP concentration that is relatively high. Primarily, this could be attributed to the fact that sampling took place near the shore as opposed to the open ocean (Kazour et al. 2019; van der Hal et al. 2017). Other spatial factors include the rocky nature of the shore which acts as an accumulation site of MPs (van der Hal et al. 2017; Zhang 2017). Moreover, the results are influenced by the meteorological, hydrodynamic, and climatological conditions dominating during sampling. For instance, Jemaa et al. (2021) noticed a drop in MP concentration from 20.1 ± 21.8 MPs/m^3 in the spring season to 3.78 ± 5.2 MPs/m^3 in the fall season. This can be explained by the elevated surface runoff amounts due to rainfall events in the winter which increase the plastic load transported from land to the oceans (Jemaa et al. 2021; Setiti et al. 2021). However, this scenario was not observed in the Israeli coastal waters where the MP concentration was higher during the dry season (van der Hal et al. 2017). While the authors did not provide an explanation, one reason could be that the samples were taken from hotspots where the lower water levels during the dry season concentrate MPs that would otherwise be more dispersed in the water column (Malli et al. 2022). Also, the water currents in the Eastern Mediterranean basin act as attractors that accumulate MPs in the Lebanese and Israeli coastal waters (Jemaa et al. 2021; Kazour et al. 2019; van der Hal et al. 2017). Finally, it is worth mentioning that the concentration reported by Kazour et al. (2019) is high due to the usage of a 52-µm Manta trawl net. The latter collects more items compared to larger

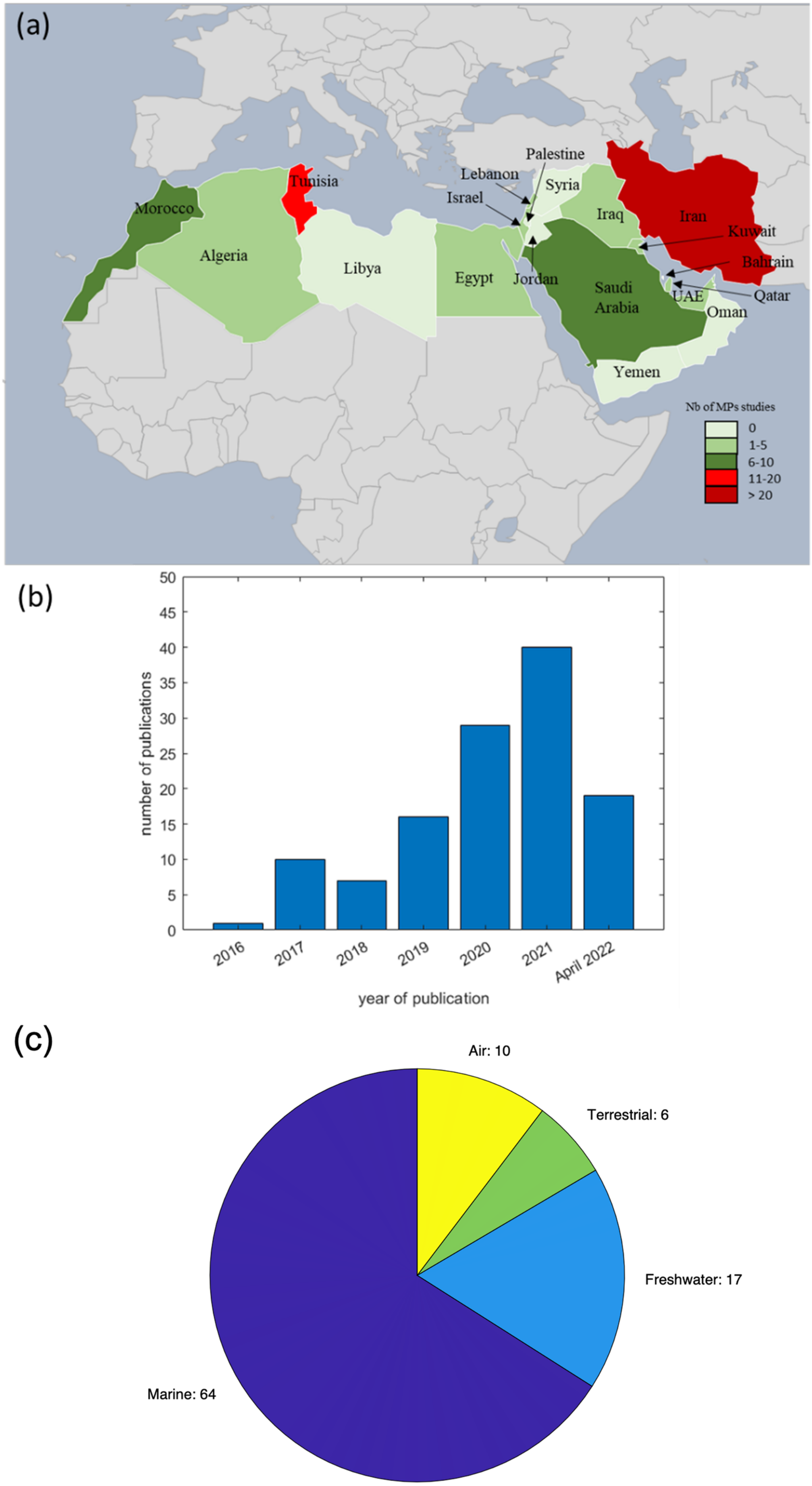

Fig. 1 Results of the literature search. **a** The variation of the number of published studies on MPs across MENA countries. **b** The evolution of the number of studies published on MPs in the MENA region between 2016 and 2022. **c** The number of studies published in each environmental compartment of the MENA region

Table 1 Abundance and characteristics of MPs detected in the marine water columns of the MENA region

Country	Area	Amount	Unit	Dominant			Reference
				Polymers	Colors	Shapes	
Algeria	Mediterranean Sea	0.86 ± 0.35	items/m^3	PE	-	Fibers, fragments	Setiti et al. (2021)
Egypt	Red Sea	50.66–66	items/100 mL	-	-	-	Sayed et al. (2021)
	Mediterranean Sea	40.66–69.3					
	Mediterranean Sea	-		PP	Transparent	Fragments	Shabaka et al. (2019)
Iran	Arab/Persian Gulf	9.28 ± 2.1	items/km^2	PP, PE	Black, red	Fibers	Agharokh et al. (2022)
		0.49 ± 0.43	items/m^3	PE, PP	White, blue	Fibers	Aliabad et al. (2019)
		0.218 ± 0.017	items/m^3	PE, PET, PA	Transparent, white	Fragments, films	Hosseini et al. (2020)
		18,000 ± 11,000	items/km^2	PE, PP	White, blue	Fibers	Kor and Mehdinia (2020)
	Caspian Sea	1.37 ± 0.47	items/m^3	PP	Black, blue	Fibers	Rasta et al. (2021a, b)
		1.25–1.77	items/m^3	PP, PE	Red, black	Fibers	Rasta et al. (2020)
		34,491 ± 18,827	items/km^2	LDPE, PP	White, red	Fragments	Mataji et al. (2020)
Israel	Mediterranean Sea	7.68 ± 2.38	items/m^3	-	White, transparent	Fragments	van der Hal et al. (2017)
Kuwait	Arab/Persian Gulf	1–4	Absolute	PP, PE	Blue, green	Filament	Saeed et al. (2020)
Lebanon	Mediterranean Sea	20.1 ± 21.8 (Spring)	items/m^3	PP, PE	Blue, black, white	Filaments	Jemaa et al. (2021a)
		3.78 ± 5.2 (Fall)	items/m^3			Fragments	
		4.3	items/m^3	PE	Blue, red	Fragments	Kazour et al. (2019)
Morocco	Atlantic Coast	10–168	items/m^3	-	White, blue	Fragments	Haddout et al. (2022)
Qatar	Arab/Persian Gulf	0.71	items/m^3	PP	Blue, white	Granules, fibers	Castillo et al. (2016)
		4.38×10^4–1.46×10^6	items/km^2	LDPE, PP	Blue	Fibers	Abayomi et al. (2017)
Tunisia	Mediterranean Sea	400 ± 200	items/m^3	PP, PE, CE	Transparent, black	Fibers, films	Wakkaf et al. (2020)
		63,739	items/km^2	PP, PE	White, blue	Fragments	Zayen et al. (2020)

PP polypropylene, *PE* polyethylene, *CE* cellophane, *PET* polyethylene terephthalate, *LDPE* low-density polyethylene, *PA* polyamide.

mesh sizes of 333 µm and 200 µm used by van der Hal et al. (2017) and Jemaa et al. (2021), respectively.

As for the Western Mediterranean, the water currents promote circulation (Jemaa et al. 2021) implying that the zone should have been less MPs compared to the Eastern Mediterranean (Cózar et al. 2015). For example, the recorded MP concentration in Bou-Ismail Bay, Algeria, was 0.86 ± 0.35 MPs/m^3 which is lower than the values recorded in the Eastern basin (Setiti et al. 2021). Moreover, the study by Setiti et al. (2021) shows a temporal variation in which the MP concentration drops from 1.26 MPs/m^3 in spring to 0.36 MPs/m^3 in fall. This is in accordance with the results discussed in the Eastern Mediterranean basin. However, a high concentration of 400 ± 200 MPs/m^3 in a semi-closed lagoon on the Tunisian coast was recorded (Wakkaf et al. 2020). The result could be explained by the fact that the lagoon is isolated from sea currents and is subject to land-based anthropogenic pressure (Wakkaf et al. 2020). Furthermore, Zayen et al. (2020) found a mean abundance of 63,739 MPs/km^2 of floating MPs in the Gulf of Gabes located in the southeast of Tunisia. As the results are reported in different units, comparison between studies is limited. Nevertheless, an interesting observation in this study is that the MP abundance increases offshore, as the samples are taken farther away from the coast (Zayen et al. 2020). This contradicts the claim by van der Hal et al. (2017) that MPs become scarcer in the open sea compared to the coast. An attempt to explain this discrepancy is that the offshore waters of the Western basin are under minimal dispersion and the circulation takes place from the shore inwards (Cózar et al. 2015; Zayen et al. 2020). On the contrary, the currents in the Eastern basin transport material from the Western part to accumulate on the coast (van der Hal et al. 2017).

The first study conducted in the Persian/Arab Gulf was in Qatar where a MP concentration of 0.71 MPs/m^3 was reported (Castillo et al. 2016). This is regarded as a low concentration given that the zone witnesses industrial and anthropogenic activities. The value is in accordance with other studies done in the coastal waters of Kuwait (Saeed et al. 2020) and the Gulf of Oman (Aliabad et al. 2019; Hosseini et al. 2020). Most of the studies reported a spatial variation in which MPs were more abundant in the vicinity of anthropogenic activity (Abayomi et al. 2017; Agharokh et al. 2022; Aliabad et al. 2019; Castillo et al. 2016; Hosseini et al. 2020). However, Abayomi et al. (2017) reported no seasonal variation in MP occurrence.

For the Red Sea, only one study was conducted in its water column specifying that the degree of MP pollution is lower than the values reported in the Mediterranean (Sayed et al. 2021).

In the Caspian Sea, mean concentrations ranged between 0.57 and 2.17 MPs/m^3 (Rasta et al. 2020; Rasta et al. 2021a, b). Meanwhile, Mataji et al. (2020) reported an abundance of 34,491 ± 18,827 MPs/km^2. The studies revealed a peak concentration during the summer season (Rasta et al. 2020; Rasta et al. 2021a, b), as opposed to the findings of the studies in the Mediterranean (Jemaa et al. 2021; Setiti et al. 2021). This was explained by the melting of snow which would increase the velocity of surface runoff from land to the marine compartment, potentially carrying more MPs with it (Rasta et al. 2020). Moreover, the Caspian Sea witnesses increased touristic activities during the summer which would increase the anthropogenic input into the basin (Rasta et al. 2020).

The most common polymers detected in the water column of MENA water bodies are polyethylene (PE) and polypropylene (PP). This is expected due to their extensive usage in packaging and fishing nets (Jemaa et al. 2021; Shabaka et al. 2019). Moreover, these polymers are less dense than water, so they float in the water column (Jemaa et al. 2021). PP breaks down relatively quickly, especially under conditions of warm temperatures and extensive sunlight exposure that are prevalent in the MENA (Castillo et al. 2016; Setiti et al. 2021). Hence, the main source of MPs in MENA water bodies is the degradation and fragmentation processes of macroplastics, making the MPs of secondary origin (Agharokh et al. 2022; Setiti et al. 2021; Zayen et al. 2020). For MP shape, fibers and fragments dominated. The source of fibers is mainly the washing of textiles and synthetic clothes. They are placed in the marine compartment through the effluents of wastewater treatment plants and domestic sewage (Abayomi et al. 2017; Aliabad et al. 2019; Bagheri et al. 2020; Kor and Mehdinia 2020; Mataji et al. 2020; Setiti et al. 2021; Shabaka et al. 2019). As for fragments, they mainly result from the fragmentation process and linger in the water column due to their surface-area-to-volume ratio that affects their settling (Haddout et al. 2022; Rasta et al. 2020).

Sediments

Similar to the water column, most of the occurrence studies in the marine sediments took place in the Persian/Arab Gulf and the Mediterranean Sea. A few other studies were conducted in the Red Sea, Caspian Sea, and the Atlantic Coast of Morocco. The results are presented in Table 2.

The number of studies in the Eastern Mediterranean sediments is lower than its central and western counterparts. In the eastern Mediterranean, a high concentration of MPs of 2433 ± 2000 MPs/kg was reported in the Lebanese sediments (Kazour et al. 2019). The latter is well-above concentrations found in sediments sampled off the Egyptian coast ranging between 330 and 766 MPs/kg (Sayed et al. 2021; Shabaka et al. 2019). This can be attributed to the well-documented solid waste mismanagement along the Lebanese coast that acts as a source of plastics into the marine compartment (Jemaa et al. 2021; Kazour et al. 2019). Thereafter, these plastics are prone to degradation and fragmentation processes to form MPs (Shabaka et al. 2019). Moreover, the concentration of MPs in the Lebanese sediments increases northwards and peaks in Tripoli, which is in accordance with the general circulation pattern in the area (Kazour et al. 2019). In the Western Mediterranean, the concentrations were generally lower than the eastern areas. For example, Tata et al. (2020) stated that the concentration of MPs in the Algerian sediments ranged between 183 and 649 MPs/kg. Similarly, Abidli et al. (2018) reported a concentration range between 141 and 461 MPs/kg in Tunisian sediments. Other studies conducted in Algeria and Tunisia presented their results in MPs/m^2 of sediments (Chouchene et al. 2019, 2021a, 2021b; Taïbi et al. 2021), which hindered comparison with the aforementioned studies. A spatial variation was observed in the occurrence of MPs in the sediments. For instance, industrial areas where water is discharged without prior treatment showed higher abundance of MPs (Abidli et al. 2019; Chouchene et al. 2019; Missawi et al. 2020; Tata et al. 2020), and harbors and areas where fishing activities are frequent witnessed elevated concentrations (Abidli et al. 2017; Chouchene et al. 2021a).

Table 2 Abundance and characteristics of MPs detected in the marine sediments of the MENA region

Country	Area	Amount	Unit	Dominant			Reference
				Polymers	Colors	Shapes	
Algeria	Mediterranean Sea	182.66–649.33	items/kg dry weight	PE	Blue, black	Fibers	Tata et al. (2020)
		7.6–66	items/m^2	-	White, transparent	Fragments, pellets	Taïbi et al. (2021)
Egypt	Red Sea	38.6–50.6	items/100 g	-	Green	Fragments	Sayed et al. (2021)
	Mediterranean Sea	48–76.6	items/100 g	-	Green, white	Fibers	Shabaka et al. (2019)
		33–174	items/100 g	PET	Transparent	Fragments	
Iran	Arab/Persian Gulf	3252 ± 2766	items/m^2	EPS, PET, PE	-	Foams	Nabizadeh et al. (2019)
		3.5–170	items/kg dry weight	PS, PP, PET	White, blue	Fibers, fragments	Maghsodian et al. (2021)
		138.3–930.3	items/kg dry weight	PP, PE, PA	White, blue	Fibers, fragments	Kor et al. 2020)
		262 ± 17	items/kg dry weight	PE, PET, PA	Black, transparent	Fragments, fibers	Hosseini et al. (2020)
		577	Absolute	-	White, black	Fibers	Abbasi et al. (2019a, b)
		295–1085	items/kg dry weight	-	Black, transparent	Fragments, fibers	Akhbarizadeh et al. (2017)
		61 ± 49	items/kg dry weight	PE, PA, PET	-	Fibers	Naji et al. (2017a, b)
		19.5–34.5	items/kg dry weight	PE	Black, blue	Fibers, fragments	Naji et al. (2019)
		190 ± 35.5	items/kg dry weight	PE, PP	Black, red	Fibers	Agharokh et al. (2022)
		3542–33,561	items/m^2	-	Blue, transparent	Filaments, fragments	Foshtomi et al. (2019)
		284–25,453	items/m^2	-	White, colorless	Fragment	Dobaradaran et al. (2018)
		2–1258	items/kg dry weight	PE, PA, PET	-	Fibers	Naji et al. (2017a, b)
	Caspian Sea	80–740	items/kg dry weight	PP, PE, PET	Black	Fibers	Bagheri et al. (2020)
		519.6–783.6	items/m^2	PP, PE	Red, black	Fibers	Rasta et al. (2020)
		210 ± 81	items/kg dry weight	PS, PP, PE	White, red	Foams, fragments	Mataji et al. (2020)
		107.6	items/kg dry weight	PS, PE	Black, blue	Fibers	Mehdinia et al. (2020)
Kuwait	Arab/Persian Gulf	1–5	Absolute	PP	Blue, white	Filament	Saeed et al. (2020)
Lebanon	Mediterranean Sea	2433 ± 2000	items/kg dry weight	PP	Blue, white	Fragments	Kazour et al. (2019)
Morocco	Atlantic Coast	15,720	items/kg dry weight	PE	-	Fibers	Abelouah et al. (2022)
		10–300	items/kg dry weight	-	White, blue	Fragments	Haddout et al. (2022)
		335.5	items/m^2	PP, PE, PET	-	Fragments, filaments	Velez et al. (2019)
Qatar	Arab/Persian Gulf	62 ± 141.8	items/kg dry weight	PE, PP	Black, blue	Pellets	Veerasingam et al. (2021)

Table 2 (continued)

Country	Area	Amount	Unit	Dominant			Reference
				Polymers	Colors	Shapes	
Saudi Arabia	Red Sea	0–119	items/kg dry weight	PET, PVC	-	Fragments, granules	Al-Lihaibi et al. (2019)
		160	items/m^2	PE	-	Fragments	Ruiz-Compean et al. (2017)
Tunisia	Mediterranean Sea	141.2–461.25	items/kg dry weight	PE, PP, PS	Black, transparent	Fibers, fragments	Abidli et al. (2018)
		7960 ± 6840	items/kg dry weight	-	Transparent, white	Fibers, fragments	Abidli et al. (2017)
		611 ± 514	items/m^2	PP, PE	White, transparent	Fibers, fragments	Chouchene et al. (2021a)
		2932 ± 63	items/m^2	PE, PP	White	Fragments, granules	Chouchene et al. (2019)
		611	items/m^2	PE, PP	White, transparent	Fiber, fragment	Chouchene et al. (2021b)
		129–606	items/kg dry weight	PE	-	-	Missawi et al. (2020)
UAE	Arab/Persian Gulf	59.71	items/kg dry weight	PE	Blue, green	Fibers	Aslam et al. (2020)

As for the sediments of the Persian/Arab Gulf, MPs were generally less abundant compared to those in the Mediterranean sediments. For example, the concentration of MPs in the beach sediments of Dubai, UAE, was 59.71 MPs/kg (Aslam et al. 2020). In Kuwait, only 37 MPs were detected in 15 beach samples (Saeed et al. 2020). On the Iranian coast, the presence of mangrove forests could increase the concentration of MPs due to vegetative trapping (Naji et al. 2017a, b). However, Maghsodian et al. (2021) reported a concentration range of 3.5 to 170 MPs/kg of mangrove sediments which is comparable to the aforementioned studies. Most of the studies found higher concentrations of MPs near sites with anthropogenic, tourist, and industrial activities (Akhbarizadeh et al. 2017; Hosseini et al. 2020; Saeed et al. 2020). The detected MPs are mostly of secondary origin resulting from the fragmentation of larger plastics (Agharokh et al. 2022; Kor et al. 2020; Naji et al. 2019; Veerasingam et al. 2021). This is attributed to the conditions of high salinity (exceeding 40 parts per thousand) and extended sunlight exposure in the Gulf, which promote the degradation process (Naji et al. 2017a, b). The dominance of fragments in the sediments increases their permeability which could potentially alter the temperature profile in the sediment layer and affect the reproductive life of biota there (Nabizadeh et al. 2019). As for fibers, they are mainly introduced via wastewater effluents through laundry where a single garment is reported to cause the emission of about 1900 fibers per wash (Kor et al. 2020; Maghsodian et al. 2021; Naji et al. 2017a, b). It is worth mentioning that Maghsodian et al. (2021) linked the abundance of MPs to sediment texture in which coarser and larger sediments trap more MPs. This contradicts the findings of other studies that found a positive relation between MP abundance and fine-grained sediments (Liebezeit & Dubaish 2012; Pazos et al. 2021). This could be explained by the fact that coarser sediments have a higher porosity creating local sites for MP accumulation (Malli et al. 2022). Typically, MPs in such sites are resuspended by turbulence, but given that the study was conducted in a mangrove forest, the presence of vegetation could have repressed turbulence and resuspension events implying higher abundance of MPs in coarse sediments (Maghsodian et al. 2021; Malli et al. 2022). Finally, Veerasingam et al. (2021) described a depth-dependent distribution of MPs in the sediments. Specifically, the highest concentration is localized in the top 0–5-cm surface sediments and no MPs are detected below 20 cm (Veerasingam et al. 2021); this could be attributed to the increased plastic use due to population growth (Porta 2021).

The results pertaining to the shape, type, sources, and spatial distribution of MPs in the sediments of the Red Sea, Caspian Sea, and Atlantic Coast are similar to what was reported in this section about MPs in the Mediterranean Sea and Persian/Arab Gulf. As for the abundance, the Red Sea appears to be less polluted with plastics compared to the Mediterranean Sea (Al-Lihaibi et al. 2019; Sayed et al. 2021). On the contrary, the Atlantic Coast of Morocco seems to be highly polluted with concentration similar to the ones reported on the Tunisian coast (Abelouah et al. 2022; Haddout et al. 2022). In fact, the Moroccan coast is considered one of the most polluted beaches worldwide (Abelouah et al. 2022; Jambeck et al. 2015; Velez et al. 2019). As for the Caspian Sea, the abundance of MPs varied temporally where more MPs were detected in June compared to January, coinciding with periods of heavy tourism (Mataji et al. 2020; Mehdinia et al. 2020; Rasta et al. 2020). Moreover, the enclosed nature of the Caspian Sea increases the likelihood of MP entrapment in the sediments due to the lack of water exchange with the open ocean (Mehdinia et al. 2020).

High-density plastics such as polyamide (PA) are found in the sediments (Table 2). However, low-density MPs such as PP and PE were also present despite their positively buoyant nature. These could have reached the sediments due to biofouling, aging, and aggregation processes that alter their density (Al-Lihaibi et al. 2019; Chouchene et al. 2021b; Haddout et al. 2022; Mehdinia et al. 2020; Naji et al. 2019; Saeed et al. 2020; Veerasingam et al. 2021). Other lightweight MPs could have been transported by strong winds to shallow downwind sites (Chouchene et al. 2021a; Tata et al. 2020). This could imply that the marine sediments are a sink for microplastics (Missawi et al. 2020). However, surface sediments are prone to remobilization by strong currents, dredging, and trawling activities (Abidli et al. 2017, 2018; Haddout et al. 2022).

Biota

The presence of MPs in the marine water column and sediments implies the exposure of marine biota to such particles. The most likely uptake route when biota incidentally ingest MPs mistaking them for prey (Al-Salem et al. 2020; Baalkhuyur et al. 2020). Moreover, a passive, but less frequent, uptake route exists in fish manifested by gill water filtration (Al-Salem et al. 2020). Once MPs are present in biota, they can potentially propagate across the trophic levels of the food web through biomagnification (Abidli et al. 2019; Miller et al. 2020). Twenty-six studies spanning eight MENA countries investigated the occurrence of MPs in marine species including fish, shrimps, gastropods, seaworms, and bivalves (Table 3). Specifically, most studies focused on commercial fish (18 studies) and mollusks (8 studies). This could be attributed to the economic and cultural aspects of seafood trade and consumption especially in the coastal regions of the MENA, making these species of particular interest when studying MP exposure (Baalkhuyur et al. 2020). Comparison between studies is limited as there are differences in units (MPs/individual, MPs/mass of cell, or absolute) and organs investigated (gastrointestinal tract, liver, muscle cells, whole organism). Nevertheless, the results are used to assess the level of pollution in the corresponding marine compartments.

The highest number of MPs in biota was retrieved from a fish collected from the Mediterranean coast of Egypt (Shabaka et al. 2020). The authors recovered 7525 MPs which is one of the highest amounts of MPs found in fish globally (Alimi et al. 2021). In general, biota from the Eastern Mediterranean seem to have more MPs than the western zone. To elaborate, Kazour et al. (2019) reported a concentration of 2.9 ± 1.9 MPs/individual in anchovies. This is well-above concentrations found in anchovies from the Spanish coast ranging between 0.11 and 0.18 MPs/individual (Compa et al. 2018). Moreover, the proportion of MPs retrieved from biota's digestive tracts in the area is increasing with time. For example, the proportion of a species of rabbitfish, *Siganus rivulatus*, that ingested MPs increased from 10 to 80% in Israeli waters over the past 60 years (van der Hal et al. 2018). Shabaka et al. (2020) also reported the presence of more than 1000 MPs/individual in *S. rivulatus* in Egypt. This was attributed to the sampling site being a highly polluted harbor that favors the fragmentation processes of plastics into brittle and easily ingested MPs (Shabaka et al. 2020). It is worth mentioning that *S. rivulatus* is a herbivorous fish that feeds on seaweed; the latter acts as a trap for microplastics that attach to the plants through biofilms promoting incidental ingestion (Abidli et al. 2021; Shabaka et al. 2020). The amount of MPs ingested by the said species was higher in fish collected from the Mediterranean Sea when compared with those collected from the Red Sea (Sayed et al. 2021). It was also higher than herbivorous fish (e.g., *S. Salpa*) collected from the Western Mediterranean (66.4 MPs/individual) (Abidli et al. 2021). Overall, it seems that this trend could be attributed to the higher degree of MP pollution in the Eastern Mediterranean as the region acts as an accumulation zone of MPs transported from the Western Mediterranean by water currents (Jemaa et al. 2021; van der Hal et al. 2017).

For other species such as bivalves, several studies found comparable results of MP concentrations between the Eastern and Western Mediterranean. For example, oysters had, on average, 7.2 ± 1.4 MPs/individual in Lebanon (Kazour et al. 2019) while mussels had around 7.7 ± 3.8 MPs/individual in Tunisia (Wakkaf et al. 2020). Bivalves are filter feeders; this means that they can incidentally trap MPs found in their surroundings via filtering large volumes of water (Abidli et al. 2019). Shellfish can be used as pollution biomonitors or bioindicators for a certain area as they accumulate high levels of pollution (Abidli et al. 2019; Said et al. 2022). In fact, some studies reported a positive correlation between the presence of fibrous MPs in the water column and their presence in biota (Wakkaf et al. 2020). For example, Abidli et al. (2019) found 1482.82 ± 19.20 MPs/kg of mussels' cells in a Tunisian lagoon where they previously reported a concentration of 7960 ± 6840 MPs/kg in its sediments (Abidli et al. 2017, 2019). Similarly, Missawi et al. (2020) found a positive correlation between the presence of MPs in sediments and seaworms. They reported a

Table 3 Abundance and characteristics of MPs detected in the marine biota of the MENA region

Country	Area	Species	Amount	Unit	Dominant		Reference
					Polymers	Shapes	
Egypt	Mediterranean Sea	*A. noae*	1.65 ± 0.28	items/individual	PE, PP, PS	-	Said et al. (2022)
	Mediterranean Sea	Fish (8 species)	28–7525	items/individual	PP, PE, PEVA	Filaments, foams	Shabaka et al. (2020)
	Mediterranean Sea	*C. crysos* *L. aurata* *S. rivulatus* *E. caninus*	2–8.6	items/individual	Rayon	Fragments	Sayed et al. (2021)
	Red Sea	*S. rivulatus* *L. obsoletus* *L. Ehrenberg* *C. crenidens*	2.33–5.66	items/individual	Rayon	Fibers	
Iran	Caspian Sea	*R. frisii*	11.4 ± 1.68	items/individual	-	Fragments, fibers, Beads	Taghizadeh Rahmat Abadi et al. (2021)
		Carnivorous fish (3 species)	2.26 ± 2.93	items/individual	PE	Fibers	Rasta et al. (2021a, b)
		Omnivorous fish (6 species)	1.10 ± 1.10	items/individual			
		N. melanostomus	39	items/g cell	PP, PE, PET, PA	Fibers	Bagheri et al. 2020)
		C. lamarcki	19.8	items/g cell			
	Arab/Persian Gulf	*P. waltoni*	15	Absolute	PS, PE, PET, PA	Fibers	Maghsodian et al. (2021)
		M. affinis	1.02	items/g cell	PET, PP, PS	Fibers, films	Keshavarzifard et al. (2021)
		Molluscs (5 species)	3.7–17.7	items/individual	PE, PET, PA	Fibers, fragments	Naji et al. (2018)
		O. ruber *L. abu* *S. forsteri* *C. arel*	0.33 ± 0.05	items/individual	PP, PE	Fiber	Agharokh et al. (2022)
		T. tonggol	2.85 ± 1.57	items/individual	-	Fibers, fragments	Hosseinpour et al. (2021)
		S. putnamiae	2.46 ± 1.46	items/individual			
		P. indicus *E. coioides* *A. djedaba* *S. jello*	0.57–1.85	items/individual	-	Fibers, fragments	Akhbarizadeh et al. (2018)
		P. indicus *S. tumbil* *S. sihama* *C. abbreviates*	21.8	items/individual	-	Fibers	Abbasi et al. (2018)
		P. semisulcatus	7.8	items/individual			
Israel	Mediterranean Sea	*S. rivulatus*	59.7	items/individual	-	Fragments, fibers	van der Hal et al. (2018)
Kuwait	Arab/Persian Gulf	Fish (8 species)	3	Absolute	PE	Fragments	Al-Salem et al. (2020)
		E. coiodes *S. hasta* *A. latus* *L. kluzingr*	3	Absolute	PP, PE	Fragments	Saeed et al. (2020)
Lebanon	Mediterranean Sea	*E. encrasicolus*	2.5 ± 0.3	items/individual	PS	Fragments	Kazour et al. (2019)
		S. spinosus	7.2 ± 1.4	items/individual			

Table 3 (continued)

Country	Area	Species	Amount	Unit	Dominant		Reference
					Polymers	Shapes	
Morocco	Atlantic Coast	*Scomber spp.* *T. truchurus* *S. pilchardus*	26% positive detection	-	PA, PC, PS	-	Maaghloud et al. (2020)
		T. trachurus	0.46 ± 1.29	items/individual	PA, PC	Fibers, fragments	Maaghloud et al. (2021)
Saudi Arabia	Red Sea	Fish (6 species)	0–30	items/individual	PS, PE, PES	Foam, fragments	Al-Lihaibi et al. (2019)
		Fish (26 species)	0–3	Absolute	PP, PE	Films, fibers	Baalkhuyur et al. (2018)
	Arab/Persian Gulf	*S. canaliculatus* *R. kanagurta*	0.057 ± 0.019	items/individual	PE, PP	Fibers, fragments	Baalkhuyur et al. (2020)
Tunisia	Mediterranean Sea	*L. aurata*	42–65.33	items/individual	PP, PE	Fibers, fragments, films	Abidli et al. (2021)
		S. salpa	22.4–66.4	items/individual			
		H trunculus	703.95 ± 109.80	items/kg cell	PP, PE	Fibers, fragments, films	Abidli et al. (2019)
		C. gigas	1482.82 ± 19.20	items/kg cell			
		H. diversicolor	500–3700	items/kg cell	PE	-	Missawi et al. (2020)
		M. galloprovincialis	7.7 ± 3.8	items/individual	PP, PE, CE	Fibers, fragments	Wakkaf et al. (2020)
		S. scriba	3630–6110	items/kg cell	PEVA, HDPE	Fragments	Zitouni et al. (2020)

concentration ranging between 0.5 and 3.7 MPs/g of cell (Missawi et al. 2020). The aforementioned MPs were of small size capable of causing oxidative stress to seaworms and other marine animals (Missawi et al. 2020; Zitouni et al. 2020). Finally, Maaghloud et al. (2021) reported a significant positive correlation between MP content and growth where mature individuals contained more MPs.

In the Arabian/Persian Gulf, the proportion of biota with MPs in a selected sample was relatively lower than the Mediterranean samples. For instance, only 37.5% of commercial fish spanning eight species contained MPs in Kuwait (Al-Salem et al. 2020). Similarly, 30% of hamour fish and none of the mussel samples showed MP content in another study conducted in Kuwait (Saeed et al. 2020). Biota in the Red Sea showed three times more MPs in their bodies compared to those collected from the Gulf (Baalkhuyur et al. 2018, 2020). Moreover, MPs were recorded in the livers of fish samples collected from the Gulf (Abbasi et al. 2018; Akhbarizadeh et al. 2018). Nevertheless, Hosseinpour et al. (2021) attributed the presence of MPs in liver tissues to procedural uncertainties rather than fish uptake. Similar to the studies conducted in the Mediterranean, Agharokh et al. (2022) showed a positive correlation between fish size, gastrointestinal tract weight, and MP presence for some species. Furthermore, shrimps closer to the shore, and hence closer to anthropogenic areas, had more MPs than those collected offshore (Keshavarzifard et al. 2021). As for the Caspian Sea, the amounts of MPs in its biota were comparable to those found in the Gulf (Bagheri et al. 2020; Taghizadeh Rahmat Abadi et al. 2021).

Regarding the shapes of the retrieved MPs, fragments and fibers dominated. This is expected for fragments, given that the majority of MPs in the MENA marine compartments are of secondary nature. As for fibers, it could be that their shape resembles algae which is consumed by herbivorous fish as well as shrimps (Keshavarzifard et al. 2021). Moreover, the variation in the dominant colors present signifies that the MPs are of different sources. It could be that the recorded colors of MPs mimic those of the prey of the studied species which explains the recurrence of the blue, black, and transparent colors (Kazour et al. 2019; Keshavarzifard et al. 2021; Maghsodian et al. 2021).

Freshwater compartment

The abundance of microplastics in the freshwater compartment has been studied in different countries across the MENA region with the majority of studies being collected from Iran. Studies were retrieved from five countries out of the nineteen countries in the MENA region. It is worth mentioning that this compartment includes matrices such as rivers and lakes. However, studies conducted in treated wastewater effluents (Naji et al. 2021) or drinking water (Adib et al. 2021; Almaiman et al. 2021) were included as well as the former is typically discharged to flowing water while the latter is directly consumed by the public. The use of different measurement units and the relative scarcity of studies make it difficult to compare the abundance of MPs in different freshwater surfaces across the region. The collected data and findings have been summarized in Table 4. The highest MP abundance in water columns (surfaces) was recorded in Iran (Abbasi 2021) which was 6000 items/m^3 at a maximal level especially near the roads and tourist sites. However, MP abundance was higher in sediments than it was in water. This high abundance recorded is not unusually high for a wetland (here, Hashilan Wetland) as the values obtained were compared with other locations worldwide (Tampa Bay, Florida) and similar values were obtained. The highest MP abundance in biota (12 ± 11.31 items/organism) was recorded in the Ghazanchi River in Iran (Heshmati et al. 2021) among the studies available, and this is probably due to the presence of more industrialized areas and higher

Table 4 Abundance and characteristics of MPs detected in the freshwater matrices of the MENA region

Country	Matrix	Amount	Unit	Dominant			References
				Shapes	Colors	Polymers	
Egypt	Biota (Nile Tilapia)	7.5 ± 4.9	items/organism	Fibers	Black, red, blue	PE, PET, PP	Khan et al. (2020)
	Biota (catfish)	4.7 ± 1.7	items/organism	Fibers	Black, red, blue	PE, PET, PP	
Iran	Treated wastewater	971 ± 103–1401 ± 86	items/m^3	Fibers, fragments, spheres	-	PP, PET, PE	Adib et al. (2021)
	Sediment	0–40	items/kg dw	Fibers	Black, gray, blue, green	PE, PP, PS	Abbasi (2021)
	Water column	2000–6000	items/m^3	Fibers	Blue, green, red, pink	PE, PP, PS	
	Sediments	350.6 ± 232.6	items/kg dw	Fibers	-	PE	Ghayebzadeh et al. (2021)
	Water column	1860	items/m^3	Fibers, fragments	Black, white/transparent, red	-	Hajiouni et al. (2022)
	Biota (fish)	4.20 ± 3.32–12 ± 11.31	items/organism	Fibers, fragments, foam, films, microbead	Black, green	PS, PE, PA	Heshmati et al. (2021)
	Biota (riverine fish–guts)	8.12 ± 4.26	items/organism	Fibers, fragments	-	PA, PE, PS	Makhdoumi et al. (2021a, b)
	Biota (riverine fish–muscles)	850 ± 380	items/kg cell	Fibers, fragments	-	PE, PP, PS	
	WWTP effluent	2018.85 ± 403.43	items/m^3	Fibers, film, fragment	Black, white, yellow	PE, PP	Naji et al. (2021)
	WWTP effluent	0.84	items/L	Fibers, films, granules	Clear, green, blue, red	-	Takdastan et al. (2021)
	Water column	170	items/m^3	Spheres	Black	-	Pashaei et al. (2021)
Iraq	Water column	2600–6500	items/km^2	-	Transparent	PE, PS, PP	Abed and Alasady (2022)
	Water column	1900–2800	items/km^2	-	Transparent	PP, PS, PE	Abed et al. (2021)
	Sediments	86.7	items/kg dw	Fibers	-	PE, PET, Nylon	Kadhum et al. (2020)
Saudi Arabia	Drinking water	2100 ± 5000	items/m^3	-	-	PE, PS, PET	Almaiman et al. (2021)
	Water column	200–3200	items/m^3	Fibers	White, red, blue	PP, PE	Picó et al. (2021)
	Water column	3200	items/m^3	Fibers	Blue, red, transparent	-	Picó et al. (2020)
Tunisia	Sediments	2340 ± 227.15 (min)	items/kg dw	Fibers, fragments, films	White, transparent, blue, black, red	PP, PE	Toumi et al. (2019)
		6920 ± 395.98 (max)	items/kg dw				

populations near the river. The highest MP abundance in sediments was recorded in Tunisia at 6920 ± 395.98 items/kg dw (Toumi et al. 2019) from a stream that receives industrial and domestic wastes. In general, polyethylene (PE) and polypropylene (PP) were the most dominant polymer types in all samples taken.

Terrestrial compartment

Studies retrieved from the soil compartment were from two countries in the MENA region: Iran and Tunisia, with the majority of studies being from Iran. Samples were collected from soil although some samples were also collected from snow and sand. Most studies used items/kg dw as a measurement unit. Table 5 summarizes the collected data and findings. The highest MP abundance was recorded in Tunisia at 852.24 items/kg dw (Boughattas et al. 2021). This MP concentration was obtained in a medium where soil was irrigated with treated wastewater. MP shapes were mostly fibrous, and PET and nylon were recorded more frequently when compared to the other compartments. According to a study by Nematollahi et al. (2022a, b), MP abundance in urban soil samples (619 items/kg dw) was approximately double that of industrialized samples (390 items/kg dw). Population density plays a major factor in affecting the MP concentration where MPs may originate from people's clothing, bags, and plastics released (Periyasamy & Tehrani-Bagha 2022). In addition, the wind direction affects the movement and consequently abundance of MPs in a particular geographical location.

Air compartment

Studies conducted on MPs in the air compartment were only found in two countries in the MENA region: Kuwait and Iran with the majority of studies being conducted in Iran. The most commonly used measurement unit of MP abundance in air is items/g of dust. MPs in air are mostly monitored in dust or in indoor spaces. The highest concentration was recorded inside a school in Iran at around 56,000 items/g of dust. This infers that a change in indoors activities results in a variation in MP abundance. For example, the presence of school uniforms, rubber toys, packaging, paper, and artwork would all lead to an increase in MP abundance in schools (Abbasi et al. 2022d). Other values recorded are summarized below in Table 6. Fibrous microplastics were more abundant than others, and white and transparent colors of MPs were predominant contrary to the other compartments where other colors were detected more frequently. It is worth noting that during dust storms, MPs are more likely to move from one country to another in semi-arid and arid environments (Abbasi et al. 2022a). For example, even if a certain geographical area is not industrialized, MPs could still be detected as a result of the movement of MPs from neighboring industrialized areas based on the prevailing wind direction (Abbasi et al. 2022a; Browne et al. 2010; Rezaei et al. 2019). In general, what affects MP concentration in air is the population density and geographical location in addition to the wind speed and direction.

Risk assessment

The results of the risk assessment are broken down by environmental compartments. Due to the nature of the approach used, results for compartments with a higher number of studies (e.g., marine) are more reliable than those with fewer studies (e.g., terrestrial).

Marine compartment

Figure 2 summarizes the results of the risk assessment conducted in the marine compartment. A log-scale format was applied on the Er_i values on the *y*-axis for a better visualization of the collected data.

In the Mediterranean sediments, studies done in Lebanon and Morocco showed very high risks. In Lebanon,

Table 5 Abundance and characteristics of MPs detected in the terrestrial matrices of the MENA region

Country	Matrix	Abundance	Unit	Shapes	Colors	Polymers	References
Iran	Sand (Desert)	20	items/kg dw	Fibers	Black, gray	PET, PA	Abbasi et al. (2021)
	Snow	20	items/L	Fibers	Black, gray	Nylon	Abbasi et al. (2022d, a, b, c)
	Soil	50	items/kg dw	Fibers	Black, gray, red, pink	PET, nylon, PS, PP	Amiri et al. (2022)
	Soil (urban)	619	items/kg dw	Fibers	White, transparent	PET, nylon	Nematollahi et al. (2022a, b)
	Soil (industrial)	390	items/kg dw	Fibers	White, transparent	PET, nylon	
	Soil	67–400	items/kg dw	-	-	LDPE	Rezaei et al. (2019)
Tunisia	Soil	13.21 ± 0.89–852.24 ± 124.2	items/kg dw	Fibers, fragments	Black, blue, red, yellow, grey	PE, PBAT	Boughattas et al. (2021)

Table 6 Abundance and characteristics of MPs detected in the air matrices of the MENA region

Country	Matrix	Amount	Unit	Dominant			References
				Shapes	Colors	Polymers	
Kuwait	Indoor	3.2–27.1	items/m^3	Fibers	Black, transparent, blue, red	PES, PA	Uddin et al. (2022)
Iran	Dust	21–165.8	items/g of dust	Fibers	Red, pink, black, gray	PA, PET, PP	Abbasi et al. (2017)
	Urban	0.3–1.1	items/m^3	Fibers	White, transparent	-	Abbasi et al. (2019a, b)
	Dust	60	items/g of dust	Granules, films	White, transparent	-	
	Dust	26.4	items/g of dust	Fibers	-	PP, PE, PS, PET	Abbasi and Turner (2021)
	Dust	0.32	items/g of dust	Fibers	White, transparent	Nylon, PP, PET	Abbasi et al. (2022a)
	Indoor/Dust	80–56,000	items/g of dust	Fibers	White, transparent, black, gray	PET, PP	Abbasi et al. (2022d, a, b, c)
	Urban/Outdoor	5.2	items/m^3	Fragments	Transparent, white, black, red	PET	Akhbarizadeh et al. (2021a, b, c)
	Dust	2.93–20.17	items/g of dust	Granules	Black, yellow	-	Dehghani et al. (2017)
	Indoor	195	items/g of dust	Fibers	White, transparent	PET, PP	Nematollahi et al. (2022a, b)
	Dust	0.067–1.133	items/g of dust	-	-	LDPE	Rezaei et al. (2019)

the accumulation of MPs explains the high risk due to the aforementioned water circulation pattern in the Mediterranean Sea (Kazour et al. 2019). Moreover, the presence of polyurethane (PUR) contributes to the risk as it has a hazard score S_n of 7384 (Lithner et al. 2011). The same applies for Morocco where polyvinyl chloride (PVC) was reported in the sediments with an S_n of 10,551 (Abelouah et al. 2022; Lithner et al. 2011). Other studies in Tunisia, Algeria, and Egypt showed low to considerable risk (Missawi et al. 2020; Shabaka et al. 2019; Tata et al. 2020). In the water column, the studies showed a similar trend. A very high risk is observed off the Lebanese coast mainly attributed to the high concentrations reported. Furthermore, it seems that the risk increases in the spring season as compared to the fall season as the Er_i dropped from 527 (very high risk) to 99 (considerable risk) (Jemaa et al., 2021a). This explained by the temporal variation in the concentration of MPs between the two seasons (Jemaa et al., 2021a).

In the Arab/Persian Gulf, the studies conducted in the water column of Iran showed a low potential risk where the Er_i ranged between 10.6 and 19.3 (Agharokh et al. 2022; Aliabad et al. 2019; Hosseini et al. 2020). However, the sediments off the Iranian coast posed very high risks (> 1000) (Agharokh et al. 2022; Hosseini et al. 2020; Kor et al. 2020; Naji et al. 2017a, b). Given that the identified polymers are the same in the sediments and water column, the reason for the high risk in the sediments is attributed to the high MP concentrations, rather than the hazard score of the polymers. It could be that the water circulation off the Persian coast promotes sedimentation (Rasta et al. 2021a, b). Other reasons include elevated biofouling activities, due to the presence of nutrients and sunlight, that increase the density of MPs (Naji et al. 2019). Other studies in the Gulf showed a high risk in the sediments as well with an Er_i of 192 in Qatar (Veerasingam et al. 2021) and 197 in the United Arab Emirates (Aslam et al. 2020).

The closed nature of the Caspian Sea enhances the sedimentation of MPs leading to very high risks in the sediments (Er_i > 1500) (Bagheri et al. 2020; Rasta et al. 2020). This is also attributed to the presence of polymers with very high hazard scores such as polyester (S_n of 1117) and polynitrile (S_n of 11,521). Moreover, the risk in the water column of the Caspian Sea ranged from considerable to high risk because of the presence of these polymers as well (Rasta et al. 2020; Rasta et al. 2021a, b). Finally, the low number of studies for the individual matrices of the Red Sea as well as the variation in the units used to report the results hindered conducting a risk assessment for this zone.

Freshwater compartment

The samples obtained were divided by matrix, as previously mentioned, i.e., sediments or water column. Studies retrieved were distributed between three countries: Iraq, Iran, and Saudi Arabia. The risk factors are presented in Fig. 3c. For the case of sediments, the reference concentration C_{oi} was 4.43 items/kg dw (Abbasi 2021) despite excluding the study from which this value was taken due to the absence of data on polymer composition. The presence of PVC, which has a high hazard score S_n (Lithner et al. 2011), in one of the studies (Ghayebzadeh et al. 2021) has led to very high-risk factor, Er_i, of 17,696 i.e., a very high potential risk level. As

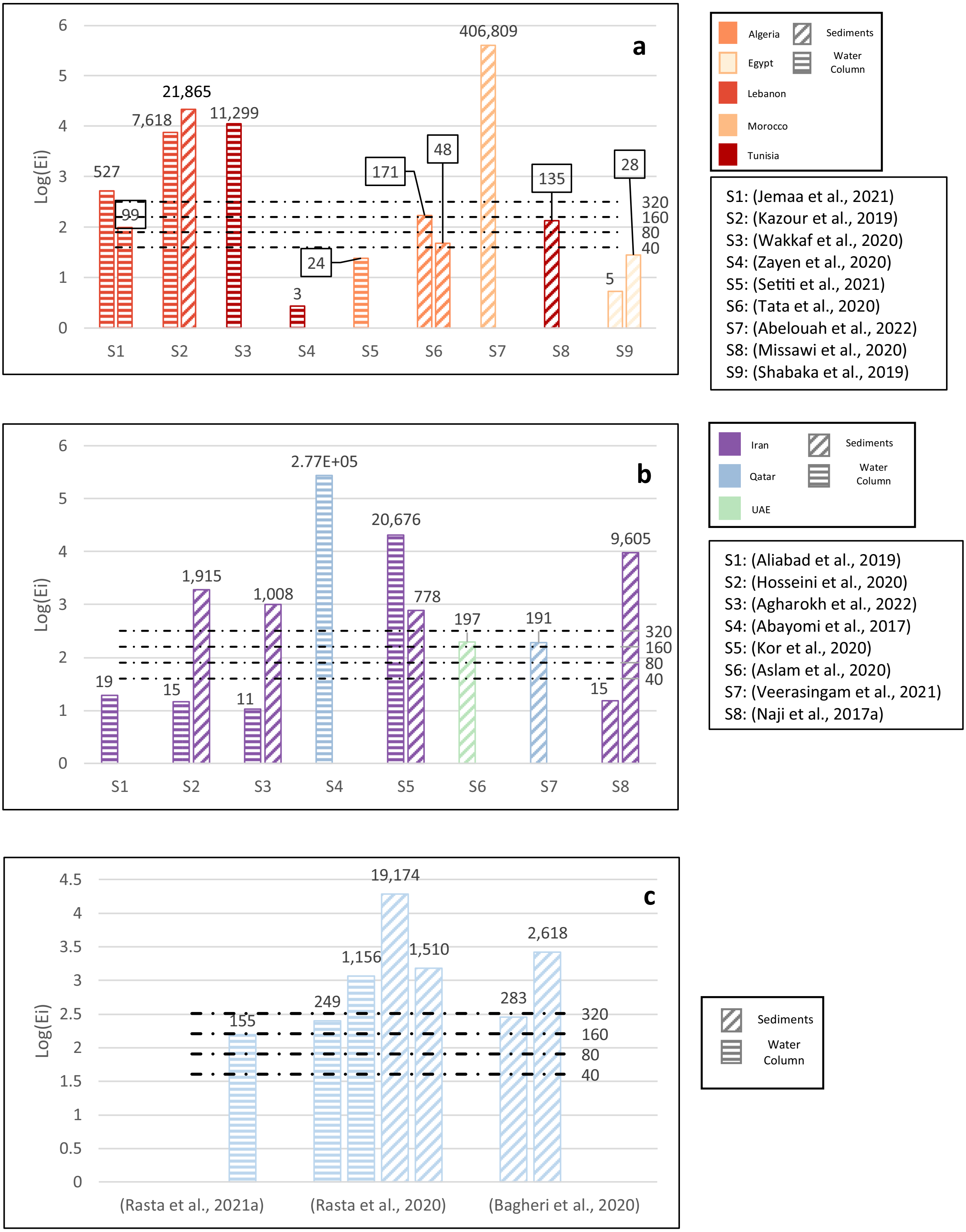

Fig. 2 Risk factors of the studies conducted in the marine compartment of the MENA region classified as zones: **a** Mediterranean, **b** Arab/Persian Gulf, and **c** Caspian Sea. The dotted lines represent the different ranges of risk with the values being mentioned on the right of each graph

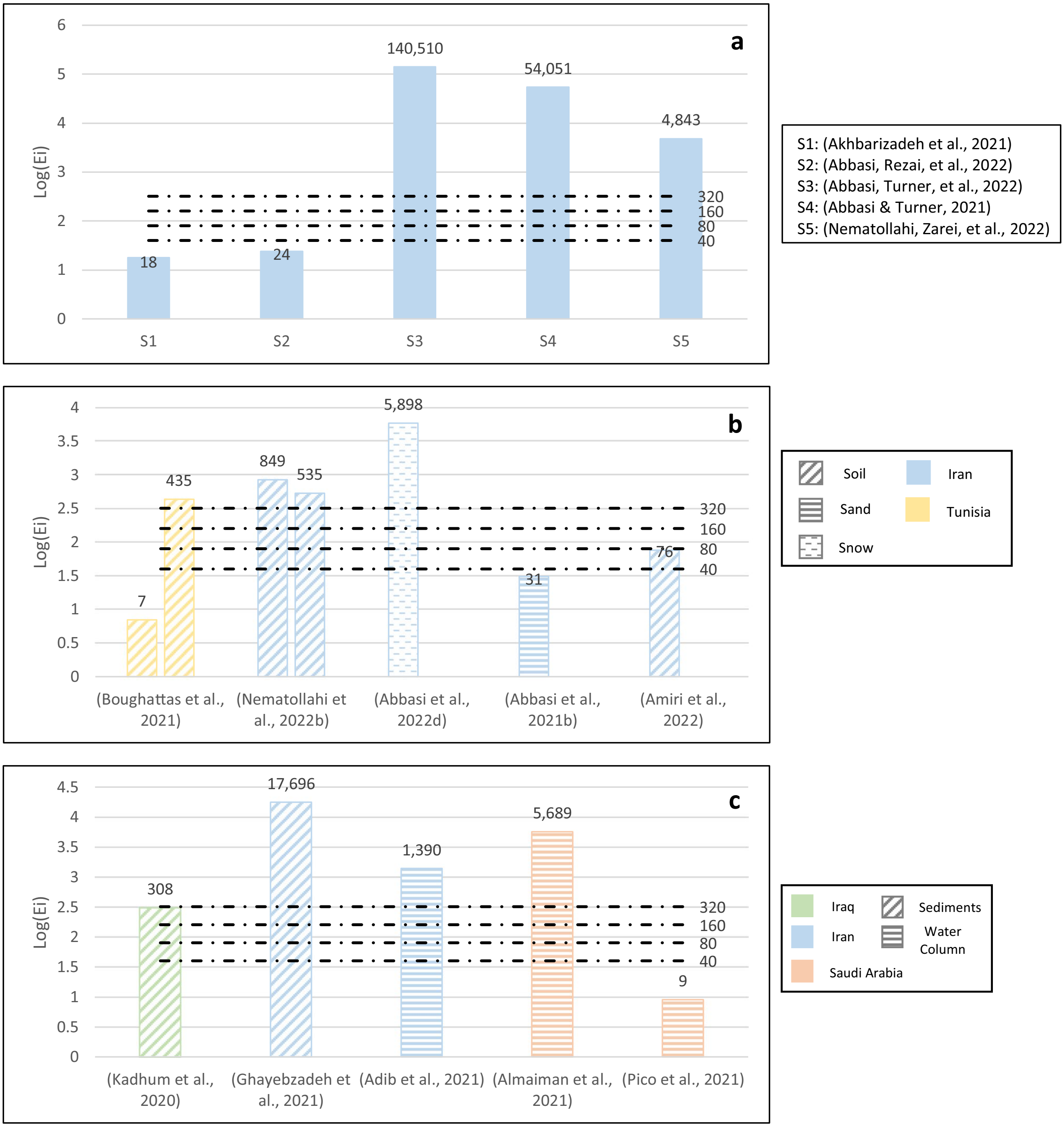

Fig. 3 Risk factors of the studies conducted in (a) air, (b) terrestrial, and (c) freshwater compartments of the MENA region

for the water column samples, the reference concentration was found to be 27 items/m^3 from a study that was excluded due to indetermined polymer composition (Picó et al. 2021). The presence of polyurethane (PU) in the studies has led to extremely high-risk factors, > 40,000, due to the polymer's high S_n, 13,844 (Adib et al. 2021; Almaiman et al. 2021).

Terrestrial compartment

In the terrestrial compartment, most samples were collected from soil. A base concentration (C_{oi}) of 13.21 items/kg dw was chosen similar to what was done in other compartments. All the studies retrieved were from Iran. Recording polyurethane in snow, in one of the studies, has led to very high-risk factor and consequently very high potential risk level (Abbasi et al. 2022b). Studies with compositions of more frequent polymers that usually have a low S_n score had low and moderate potential risk levels. However, a high initial MP concentration (C_i) will lead to a high or very high potential risk level regardless of what the polymer composition is. These results are highlighted in Fig. 3b.

Air compartment

Most samples in the air compartment were collected through dust while differentiating between indoor and outdoor environments. Studies excluded were those lacking details on polymer compositions. All the studies left were from Iran. Due to the presence of two measurement units in this compartment, two reference concentrations were chosen corresponding to each respective unit. The results are presented in Fig. 3a. Most studies used items/g of dust as a measurement unit with a C_{oi} of 0.31 (Abbasi et al. 2022a). One study had a high initial MP concentration, C_i, at 6500 which led to a very high risk factor of around 140,510 i.e., a very high potential risk level (Abbasi et al. 2022d). This might be attributed to the fact that samples were collected from indoor spaces (school classrooms). The high concentration is due to the presence of materials that generate MPs such as school uniforms and stationery (Abbasi et al. 2022d. It is also dependent on the ventilation and the cleaning habits of the school (Abbasi et al. 2022d).

Discussion

Table 7 summarizes the occurrence of MPs in different compartments and matrices. For the purpose of uniformity, the most commonly used units were the ones presented while reporting the concentration ranges. There were differences in reporting the concentrations of MPs in surface water (e.g., mg/L, items/m^3, and items/km^2), sediments (e.g., items/kg and items/m^2), biota (e.g., items/individual and items/g of cell), air (e.g., items/m^3 and items/g of dust), and soil (e.g., items/kg and items/km^2). These variations hinder comparison between studies, especially when conducting risk assessments and priority studies as in this work. Studies suggesting conversion methods between these units are emerging (Leusch & Ziajahromi 2021). Nevertheless, additional differences in sampling methods, treatment procedures, and detection techniques lead to unreliable comparisons between the different studies. Therefore, a standardized framework for sampling, analyzing, and reporting MP occurrence research is urgently needed for more accurate prioritization studies.

To put the concentrations provided in Table 7 in a global context, they should be compared with MP concentrations from other regions around the world. For instance, the concentration of MPs in the water column off the coast of Argentina reached 33,373 items/m^3 (Orona-Návar et al. 2022a, b), which is much higher than the highest concentration recorded in MENA water bodies. However, only 1.31 to 11.5 items/m^3 were detected in the Arctic waters in Norway (Auta et al. 2017). This could be attributed to differences in the degree of anthropogenic stress and the efficiency of waste management techniques between the regions. Similarly, in soil, the concentration of MPs ranged between 1430 and 3410 items/kg in Shaanxi Province, China (Chang et al. 2022), but around 217.8 items/kg in Northern Germany (Harms et al. 2021). These results are comparable to the range recorded in the MENA region. It is important to reiterate that such comparisons should be interpreted with caution due to possible differences in sampling methods. Moreover, comparison between compartments is essential due to possible interactions. An alarming concentration in one compartment can impose an influx of MPs into another compartment. To elaborate, the concentration of MPs in air could increase after a dust storm occurs in an area where MPs are abundant in soil (Abbasi et al. 2022a). Likewise, an increase of MPs might be observed in freshwater and marine compartments during the wet season when surface runoff inputs MPs from the terrestrial to the aquatic compartments (Jemaa et al. 2021).

Overall, the MENA region is responsible for 8.3% of the global mismanaged plastic (Geyer et al. 2017). Moreover,

Table 7 Concentration ranges of MPs detected in MENA environmental compartments reported in the most commonly used units of measurements

	Unit	Marine				Freshwater	Terrestrial	Air
		Mediterranean Sea	Red Sea	Caspian Sea	Arab/Persian Gulf			
Water column	items/m^3	0.86–400	-	1.25–1.77	0.22–0.71	170–6000	-	-
Biota	items/individual	1.65–7525	0–30	1.10–11.4	0.06–21.8	4.2–12	-	-
Sediment	items/kg of dry weight	129–7960	0–119	80–740	2–1258	0–6920	13.21–852.24	-
Dust	items/g of dust	-	-	-	-	-	-	0.067–56,000

the region contributes to 1.4% of the global plastic emitted to the oceans (Meijer et al. 2021). Specifically, Algeria and Egypt have a share of 0.6% and 0.3% of the global plastic emitted to the oceans, respectively (Meijer et al. 2021). Schmidt et al. (2017) reported that the Nile River is among the top ten plastic polluting rivers worldwide. In general, the presence of plastic debris in the water column is positively related to the amount of mismanaged plastic waste generated in river catchments (Schmidt et al. 2017). Moreover, the study found that larger rivers and rivers with population-rich catchments had higher plastic loads. In fact, Schmidt et al. (2017) estimated that the Nile River transports around 84,792 tons/year of MPs. Despite the above, only one study is done in the Nile sampling fish from the river (Khan et al. 2020). While more recent studies do not classify the Nile as a priority river (Meijer et al. 2021), it is still important to conduct more occurrence studies in the water column and the sediments of the river given the high anthropogenic pressure in its surrounding. Besides rivers, estuaries are conduits that transport MPs from the freshwater compartment to the marine compartment (Pinheiro et al. 2021). However, the transport mechanisms and the fate of these MPs in estuarine compartments are still unclear (Malli et al. 2022). Factors such as salinity, windage, rainfall, sedimentation, and biofouling determine whether MPs are trapped within the estuary or expelled to the marine compartment (Browne et al. 2010; Malli et al. 2022; Pinheiro et al. 2021; Stead et al. 2020). Hence, Malli et al. (2022) suggested the regionalization of MP studies as the aforementioned properties differ between estuaries. Only four studies have been conducted in MENA estuaries, three of which took place in Iran (Abbasi et al. 2018; Ghayebzadeh et al. 2021; Naeeji et al. 2020) and one in Morocco (Haddout et al. 2022). Hence, more studies are needed to better understand the role of estuaries in MP transport in the MENA region. Moreover, all of the studies sampled estuarine waters and sediments, except for Abbasi et al. (2018) who investigated MPs in estuarine fish and prawns. It is necessary to conduct more studies on the occurrence of MPs in estuarine biota to investigate their biomagnification along the river-estuary-sea continuum (Malli et al. 2022). It is worth mentioning that most of the occurrence studies done in the MENA region took place in the marine compartment. However, 80% of ocean plastic comes from land-based sources (Jambeck et al. 2015).

Amid the COVID-19 pandemic, the amount of plastic waste generated on land is set to increase due to the disposal of personal protective equipment such as face masks (Al-Salem et al. 2020). In fact, several studies have already investigated the occurrence of face masks on MENA beaches and reported early signs of degradation to ultimately end up as MPs (Akhbarizadeh et al 2021a; Haddad et al. 2021; Mghili et al. 2022). On the coastline of Agadir (Morocco), the personal protective equipment density (PPE) increased after lockdown with the majority of which being face masks (Haddad et al. 2021). This shows that the increase in PPE usage during COVID-19 likely had its effects on the environment after the lockdown was over and before all COVID-19 restrictions were lifted. In another study, PPE samples were collected from selected sites at the Bushehr port in Iran with more than 10% being partly degraded which might be a source of secondary MP generation (Akhbarizadeh et al. 2021b). It should also be noted that poor infrastructure and waste management, which was worse during COVID-19, led to an increase in PPE contamination on beaches in other parts of the world (De-la-Torre et al. 2022b). A study by Dioses-Salinas et al. (2022) shows that some protected areas in Peru were contaminated with PPE like facial masks and KN95 respirator wrappers. The FTIR spectroscopy done concluded that the material was poorly degraded meaning that it is recent and most likely from the COVID-19 indirect environmental drawbacks. Phthalate esters, in addition to MPs, are released due to the degradation of face masks and gloves, yet a higher concentration was recorded from face masks (De-la-Torre et al. 2022). The effect of face masks on the different aquatic and terrestrial organisms is surrounded by uncertainties, but it is likely that face masks have endocrine-disrupting and behavioral effects (Cabrejos-Cardeña et al. 2023). The long-term impact resulting from PPE contamination during COVID -19 will be observed as more studies are conducted in both the marine and terrestrial compartments.

Therefore, more studies are needed in the terrestrial compartment to form a more comprehensive view of the sources of MPs. Also, there is a dearth of studies on MPs in groundwater in the MENA region. Such studies also serve as an indicator for areas with mismanaged plastic waste and unregulated landfilling activities. More studies are needed in the freshwater compartment as it acts as a link between the terrestrial and marine environments.

As previously mentioned, there are issues with using metrics as the PLI and HI for MP risk assessment. The wide variety of units used in the retrieved studies hinders direct comparison of the risks. Moreover, differences in environmental conditions within the same zone (e.g., East and West Mediterranean) increase the uncertainty associated with the risks given by the PLI. As for the HI, the hazard scores reported by Lithner et al. (2011) do not cover all types of MPs that have been detected in the MENA environmental compartments. The sensitivity analysis provided evidence that the risk factor approach adopted in this study carries some uncertainty as well. Switching from the minimum reported concentration to the median reported concentration caused some sites to shift from a very high risk categories to lower risky categories. For example, the concentration reported by Jemaa et al. (2021) in Lebanon dropped from a very high risk (Er^i of 527) to moderate risk

(Er^i of 41). Other studies such as Wakkaf et al. (2020) in Tunisia remained in the very high risk category regardless (Er^i dropped from 11,300 to 891). This could be mainly attributed to the small number of data entries available which causes a dramatic shift between the minimum and median concentrations, in some cases reaching two orders of magnitude. To elaborate, C_{0i} for the air compartment was 0.31 items/g of dust using the minimum concentration approach and increased to 50.44 items/g of dust using the median concentration. A promising alternative approach lies in assessing the ecological risk of MPs based on PNEC data (Adam et al. 2021; Jung et al. 2021; Koelmans & Ruijter 2022). Accordingly, more ecotoxicological studies are needed to compile toxicology databases that could be utilized in conducting such risk assessments for MPs. In the MENA region, two ecotoxicology studies have been done on mussels in Israel (Hamm et al. 2022) and clams in Saudi Arabia (Arossa et al. 2019). Moreover, Abbasi and Turner (2021) investigated dermal human exposure to MPs by sampling head hair, hand skin, face skin, and saliva for 4265 individuals in Iran. Similarly, human exposure through ingestion was investigated by sampling water bottles (Makhdoumi, Naghshbandi, et al. 2021a, b), canned tuna (Akhbarizadeh, Dobaradaran, Nabipour, et al., 2020), and vinegar (Makhdoumi, Naghshbandi, et al. 2021a, b) as well as through inhalation (Abbasi, Keshavarzi, Moore, Turner, et al. 2019a, b; Uddin et al. 2022). That being said, toxicology studies on MPs are still in their early stages implying that limited quantified data is available on their adverse health effects on humans. Available data conducted on animals and in vitro studies may not necessarily reflect the actual effect on humans. As previously mentioned, the wide variety of shapes, sizes, and compositions of MPs makes it challenging to establish a database of acceptable daily intakes or reference doses. To overcome this, a set of long-term exposure, mechanistic, and epidemiological studies are needed to investigate the chronic effects, interactions, and association between MPs and human health, respectively. Finally, more research is needed on the interactions of MPs with metals, persistent organic pollutants, and pharmaceuticals to unveil any synergetic toxic effect between these emerging contaminants (Álvarez-Ruiz et al. 2020; Foshtomi et al. 2019; Ouda et al. 2021; Picó et al. 2020; Ruiz-Compean et al. 2017).

This review surveyed occurrence studies in the MENA region. It is worth mentioning that none of these studies investigated removal techniques of MPs from the environmental compartment, with the exception of Petroody et al. (2020) who studied the MP removal efficiency of a wastewater treatment plant on the southern coast of the Caspian Sea. Several studies mentioned that the main source of MPs fibers is domestic wastewater (Abidli et al. 2018; Rasta et al. 2021a, b). The issue lies in the fact that the extent of treating wastewater and the efficiency of wastewater treatment plants significantly varies between countries (Karam et al. 2013; Naji et al. 2021; Petroody et al. 2020). Hence, more research and applications of end-of-pipe capture techniques are needed to reduce the emissions of MPs from wastewater to the freshwater and marine compartments. Furthermore, countries in the vicinity of the Arab/Persian Gulf as well as Israel, Egypt, and Algeria are increasingly relying on desalination technologies to secure their needs of drinking water (Maftouh et al. 2022; Ouda et al. 2021). Membrane-based reverse osmosis plants can potentially concentrate microplastics on the membrane and in the retentate reducing the risk of ingestion through drinking water (Tang & Hadibarata 2021). However, this increases the risk of membrane fouling which would decrease the permeate flux and reduce the overall productivity of the reverse osmosis plant (Maftouh et al. 2022). Consequently, research efforts are needed to minimize the number of MPs in the permeate while simultaneously prolonging the lifespan of the membrane and maintaining the efficiency of membrane-based desalination systems.

Conclusion

This review provides an overview of the occurrence of MPs in different environmental compartments across the MENA region. Overall, there has been an appreciable increase in the number of publications on the subject, especially in Iran and Tunisia. However, most of the research focuses on the occurrence of MPs in the marine compartment leaving the air, terrestrial, and freshwater environments understudied. In the Mediterranean Sea, the eastern coasts were under a higher environmental risk of MPs due to the general circulation pattern in the water body that promotes the accumulation of MPs on the coasts of Lebanon and Israel. The sediments of the Arab/Persian Gulf and the Caspian Sea also showed high risk attributed to their closed or semi-closed nature that promotes the sedimentation of MPs. As for the atmospheric compartment, riskier concentrations were recorded in studies conducted indoors (e.g., Er^i of 140,510 in a school classroom). In the freshwater compartment, the high risks of MPs (e.g., Er^i of 17,700 in river estuaries in Iran) were attributed to the presence of more toxic polymers (high hazard score S_n) such as polyurethane and polyvinyl chloride. Despite the growing research on MPs in the MENA, more studies are needed in countries such as Jordan, Oman, and Syria as well as in the terrestrial and freshwater compartments. A standardized framework to report results is urgently needed to provide reliable comparisons between the finding of the different studies. After all, the availability of data on the occurrence and accumulation of MPs in the environmental compartments on the MENA region is key to ensure effective policy legislation and environmental remediation plans.

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Availability of data and materials The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical approval Not applicable.

Consent to participate The study does not involve any human participants, human data, or human tissues.

Consent for publication All authors have read and approved the final draft of this manuscript.

Conflict of interest The authors declare no competing interests.

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