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RESEARCH ARTICLE

A review of plastic pollution in aquatic ecosystems of Turkey

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Abstract
Turkey is one of the major plastic pollution sources in the Mediterranean and the Black Sea. This review summarizes present information, data, and legislation on plastic pollution in Turkish aquatic ecosystems. According to results derived from reviewed studies, both macro- and microplastic pollutions were documented in Turkish aquatic ecosystems. Most of the studies on plastic pollution in Turkish waters were performed in the marine environment while only four were conducted in freshwater environments. Spatially, the majority of these studies, which were on levels in the marine environment, were conducted on the northeastern Mediterranean coasts of Turkey, especially Iskenderun and Mersin Bays. Additional studies were carried out on either the ingestion/presence/impact of microplastics by/to aquatic organisms or the entanglement of marine organisms in plastics. There were also studies assessing the microplastic content of commercial salt, and another has reported microplastic presence in traditional stuffed mussels sold in Turkish streets. Some studies were conducted on microplastic presence and/or their removal in wastewater treatment plants in Mersin, Adana, Mugla, and Istanbul cities. Macro- and microliter loading from a few Turkish rivers to the sea was also estimated. All these investigations indicate that Turkish aquatic environments have significant plastic pollution problems, which were also underlined by the legislative studies. The need for further studies in this field still exists, especially in freshwater environments.

Keywords Plastic pollution · Turkish Aquatic Ecosystems · Microplastics · Mediterranean Sea

Introduction

Enormous quantities of plastics are produced worldwide each year. In 2019, worldwide plastic production reached 368 million t (PlasticEurope 2020). When plastics produced by the textile industry are added, this amount increases to approximately 420 million t (Lebreton and Andrady 2019; The Fiber Year 2017). With the increase of the human population from 7.7 billion in 2019 to 9.2 million in 2040 (UN 2019), plastic production is estimated to be 589.3 million t by 2050 (Tisea 2021); hence, a significant increase in the amount of post-consumption plastic waste is also projected. As early as 2010, 4.8–12.7 million t of plastic waste were estimated to enter the ocean from land sources (Jambeck et al. 2015). Plastic pollution for the aquatic environments will nearly triple by 2030, from an annual 19–23 million t in 2016 under the business as usual scenario with the current production, consumption, and waste management practices (Borrelle et al., 2020). This means that currently (accumulated) plastic volume is higher than that of global fish capture (96.4 million t for 2018, FAO 2020).

The widespread use of plastics for numerous activities has resulted in extensive pollution on a global scale. The increase in plastic production and consumption has caused plastic pollution to become so widespread that it has now reached the deepest part of the ocean as well as to the poles (Bergmann et al. 2019; Barrett et al. 2020; Cincinelli et al. 2017; Dris et al. 2018). The ubiquity of plastics in environments produces various effects on the surrounding biota, classified mainly as colonization, ingestion, and entanglement (Tekman et al. 2021). The risks posed by these effects

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can be physical and chemical (Markic et al. 2019). Physical risk ultimately depends on the size of plastics ingested and the degree of entanglement, whereas chemical hazards can arise via additives or environmental pollutants absorbed by plastics (Rist et al., 2018).

Plastics are also already present in human food; from table salts (Gündoğdu 2018) to consumable seaweeds (Li et al. 2020), mussels (Li et al. 2019; Gündoğdu et al. 2020a), and many other fisheries products. Consequently, plastic pollution could have significant concerns for human health. The adverse effects of plastic pollution as an emerging environmental threat are expected to increase for the foreseeable future.

Studies conducted so far have also shown that plastic pollution is directly related to both waste management and geographic location. Countries that have inadequate waste management infrastructure struggles particularly with significant amounts of plastic pollution in their environment. Irrespective of such infrastructure, many countries whose marine areas are influenced by major currents of large/shared marine systems are likely to face severe plastic pollution from transboundary pollution.

Turkey is a developing country with a population of over 80 million and an average annual population growth rate of 1% (TURKSTAT 2020). More than half of this population (54.6%, approx. 45 million people) live in coastal areas. With its unique geographical location between the Black Sea and the Mediterranean, Turkey has access to the fish resources of these two water bodies. The country also has rich inland waters and river systems with significant fisheries and aquaculture potential. The entire coastline spans almost 8500 km (approximately 5000 miles) in length. Likewise, similar to the diversity in the marine ecosystem, Turkey has very important inland water resources to protect biological diversity, with its rivers and lakes covering approximately 10,000 km^2. In the studies carried out to date, 135 wetlands of international importance have been identified, and 12 have been designated as Ramsar sites. There are seven drainage basins in Turkey, 25 of which are river basins, and the groundwater is estimated to be 94 billion m^3.

Rapid economic growth, population, industry, technological development, production, and consumption patterns are significant pressures on the environment and natural resources in Turkey. One of the first environmental compartments affected by anthropogenic activities is aquatic ecosystems. Marine and freshwater ecosystems are under heavy pressure due to many different types of pollution, including plastics.

The first marine plastic pollution study in Turkish waters was conducted by Bingel et al. (1987) as early as in the 1980s. Most of the following years, plastic pollution related research focused on terrestrial solid waste and its management (Berkun et al. 2005; Metin et al. 2003). In parallel to rising global interest and efforts, the number of published studies investigating macro- and microplastics in Turkish waters has also increased during the last two decades. However, it is worth mentioning that the bulk of information on plastic pollution is obtained from marine ecosystems, while insufficient data exist from the freshwater ecosystems in Turkey.

This paper is the first to review the available published and grey literature on plastic pollution. It also aims to address the knowledge gaps by comprehensively reviewing reliable scientific data on all aspects of plastic pollution in Turkish marine and freshwaters to provide insight for the protection of Turkish territorial waters and freshwater environments. Hence, this review paper focuses on (I) sources of plastic pollution for the aquatic environment, (II) the current status and the effects of plastic pollutants over the Turkish coasts and freshwater environments, (III) an overview of the current policies, measures, and initiatives for controlling plastic pollution at the national level, and (IV) recommendations for various stakeholders such as politicians, decision-makers, researchers, industries, local environmental authorities, and the general public.

Sources of and pathways for plastic pollution to Turkish aquatic ecosystems

With a total production of 9.5 million t, Turkey is one of the major plastic producers in Europe (Figure 1). With a value of over 7 million t, the packaging sector has by far the largest share in total production.

Turkey does not constitute an exception in terms of the source of plastics that enter its aquatic ecosystems. Plastic waste entering the marine and freshwater ecosystems originates directly and indirectly from many different sources. Pathways of plastic waste, either from land or sea-based sources to aquatic ecosystems, are also critical in determining the quality and quantity of litter. Land-based plastics can enter the marine and freshwater environment, mainly by four pathways: (1) atmosphere, (2) run-off from land (either waterways or floods), (3) direct deposition to coasts (e.g., by beach users), and (4) wastewater treatment plants (WWTPs). The waterways (e.g., rivers, creeks, canals) can be considered as the main pathway for plastic pollution of the coastal environment. For instance, rivers receive plastic waste from different sources such as sewage water, soil run-off, rainfall, touristic activities, and transportation and carry them to the sea or lakes. In general, the density of plastic litter is lower than or similar to the water density, resulting in a significant portion of litter reaching the seas. Wind-driven plastics may be deposited on the sea surface also far from coastal areas. Soil-based plastic pollutants, such as agricultural films, single-use irrigation pipes, and plastic packaging materials for

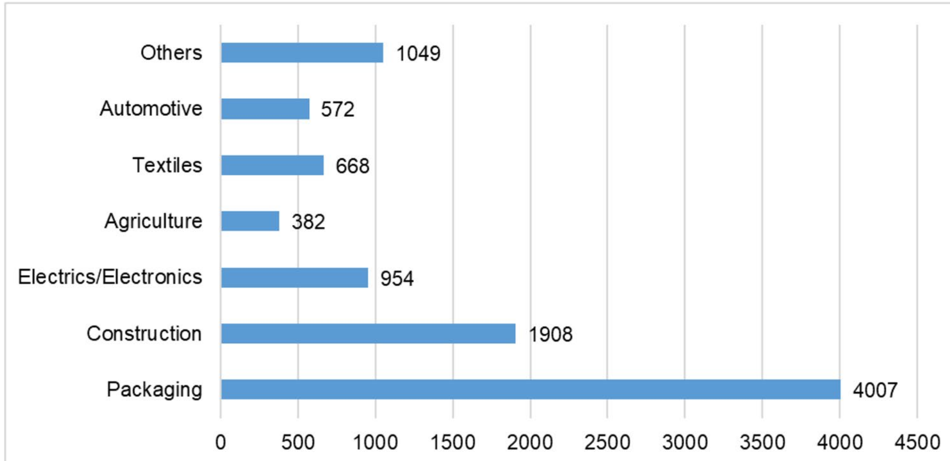

Fig. 1 Plastics production by subsectors—(1000 tonnes) in 2020 (source: PAGEV 2021)

Table 1 Disposal/recovery methods and volume of municipal waste in 2018 (TÜİK 2020)

Waste disposal and recovery methods	×1000 t	
	Amount	%
Waste delivered to municipality's dumping site	6521	20.2
Waste delivered to controlled landfill sites	21,644	67.2
Burning in an open area	6	0.019
Lake and river disposal	0.5	0.002
Burial	2	0.006
Other disposal methods(1)	65	0.20
Waste delivered to composting plants	123	0.38
Waste delivered to other recovery facilities(2)	3848	11.9
Total	**32,209**	**100**

(1) Data refers to disposals by burning in an open area, dumping into a river/onto land, and burying

(2) Data refers to wastes such as glass, metal, paper, and plastic that are collected separately by municipalities and sent to recovery facilities, and other wastes sent to biogas and composting facilities

pesticides and fertilizers, can enter the aquatic ecosystems via run-off and irrigation.

Besides the pathways discussed above for plastic pollution, it is necessary to refer to Turkey's inadequate waste management. According to the Turkish Statistical Institute (TÜİK, 2020), in 2018, around 90% of municipal waste produced in Turkey ended up in landfills (Table 1).

As shown in Table 1, municipal waste in Turkey is primarily sent to landfills. Additionally, uncontrolled illegal dumping activities have been frequently reported until recently (Figure 2; İHA 2019; İHA 2020; Gündoğdu and Walker 2021). Such dumping activities are reported to be mainly carried out directly or close to the aquatic ecosystems (Figure 2; Berkun et al. 2005; Tuncer et al. 1998; Yıldırım et al. 2004). Moreover, besides Turkey's local municipal waste, imported plastic waste is also subject to illegal dumping (Gündoğdu and Walker 2021).

The amount and characteristics of municipal solid wastes vary by country and region as well as neighborhoods. This

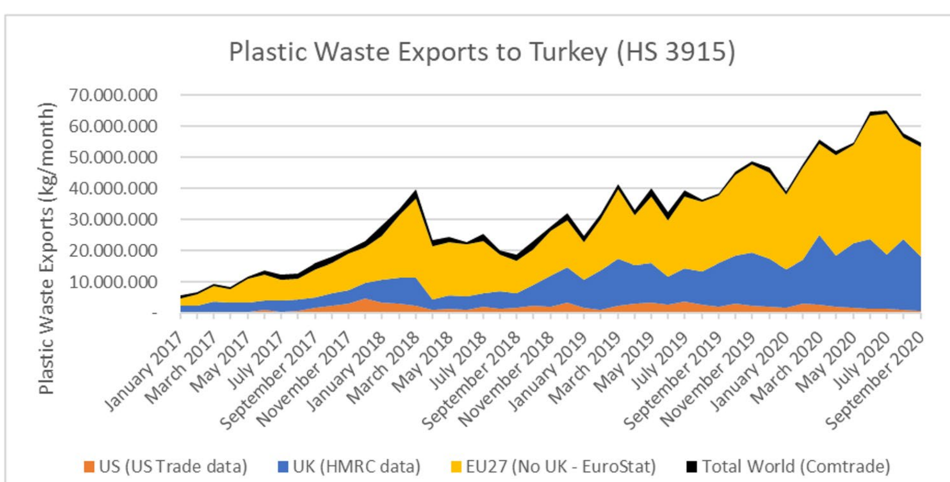

Fig. 2 Plastic waste export to Turkey per month and per country (January 2017–September 2020) (source: https://www.lastbeachcleanup.org/ and https://www.ban.org/)

difference is due to the socio-economic structures of the societies and consumption habits. Although it varies according to the socio-economic development levels of the countries/regions, the percentage of plastic in household solid waste is considered to be 10% (Lebreton and Andrady 2019). Although there is no published data on the plastic content of the total municipal waste in Turkey, there are some local studies (Yildiz et al. 2013; Özcan et al. 2016). For example, Yildiz et al. (2013) reported the percentage of plastic in municipal waste as 13.7% for Istanbul (the largest city in the country). When the value reported by Yildiz et al. (2013) is accepted as a reference, considering the volume of municipal waste, approximately 4.2 million tons of plastic waste could be calculated to be produced in 2018. This is a reasonable figure considering the very high share of packaging (and other single used) materials in plastic production in Turkey, supplemented by the imported waste with a higher share of plastics.

Rivers as a source/pathway of macro- and microplastic pollution for Turkish aquatic ecosystems

As a result of insufficient waste management, litter loads in the terrestrial environment are increasing, large quantities of which will be transported to aquatic ecosystems by various means, most notably riverine. González-Fernández et al. (2021) found that a major portion of the total litter loading (of which 82% plastics) is due to small-sized drainage basins (<100 km^2), indicating the relevance of small rivers, streams, and coastal run-off. That is why macrolitter flux was among the highest (mean 325,776 items $year^{-1}$) for the Göksu creek (near Istanbul, with a basin size of only 89.11 km^2) among 42 rivers in Europe. González-Fernández et al. (2021) estimated that among the 32 European countries, Turkey had the highest share (16.8%) of the total floating macrolitter loading to the marine environment. In a recent study, Özgüler et al. (2022) estimated total microlitter loading from 8 rivers in Mersin as 1.2×10^{12} items annually. This value is equivalent to twice the total stock of microplastics within the water column in Mersin Bay and hence shows the importance of rivers and transporting plastics to the sea. The importance of extreme rainfall events is also observed: Gündoğdu et al. (2018a) stated that the flash floods resulting from substantial rainfall in 2017 increased quantities of microplastics in Mersin Bay by approximately 14-fold.

WWTPs as a source/pathway of microplastic pollution for Turkish aquatic ecosystems

Waste Water Treatment Plants (WWTPs) are also known to be one of the main sources of plastics in the aquatic ecosystem in Turkey. Plastic particles originating from domestic/industrial wastewater, rainwater, and landfills enter WWTPs cumulatively (Okoffo et al. 2019). It has been reported in many studies that some of the plastic particles entering WWTPs are trapped in sewage sludge, while a proportion is discharged into aquatic ecosystems via effluent. WWTPs are considered one of the major sources of microplastics (<5 mm) that enter the aquatic ecosystem. Thus, most of the studies carried out for the WWTPs have focused on microplastics. The number of wastewater treatment plants in Turkey was 881 in 2016 (ÇŞB 2021). Approximately 5% of these treatment facilities discharge their treated effluent to lakes and dams, 65% to rivers, and 30% to seas (ÇŞB 2010). Although the number of treatment facilities is relatively high and the vast majority of these treatment plant effluents are discharged into aquatic ecosystems, many studies reveal the plastic pollution in treatment plants is very few.

The first study on microplastics in influent and effluent waters of WWTPs in Turkey was carried out by Gündoğdu et al. (2018b). The researchers compared microplastic concentrations of the influent and secondary effluent water of two wastewater treatment plants in Turkey, and reported that the influent of the WWTP contained 1–6.5 million particles per day, while the effluent contained 220,000–1.5 million particles per day. The removal rates of microplastics were reported between 73 and 79%. The second study on microplastic load in WWTPs was carried out by Akarsu et al. (2020). These researchers reported an average of 180 million particles per day in the effluent waters and reported between 55 and 97% removal rate of microplastics for the three WWTPs in Mersin province. Despite such high removal rates, considering the large volumes of wastewater discharged from WWTPs into the aquatic ecosystems, the total load from the three WWTPs was calculated as $>100 \times 10^9$ particles $year^{-1}$ which is stated as a significant pathway for microplastics' transport to the northeastern Mediterranean Sea (Akarsu et al. 2020). In another recent study, Vardar et al. (2021) estimated a total of 107×10^{10} particles $year^{-1}$ microplastics' discharge load from the Ambarlı WWTP in Istanbul. All these studies confirm that WWTPs are an important source of plastic pollution of aquatic environments (Gündoğdu et al. 2018b, Ziajahromi et al. (2017) on the global scale. Akarsu et al. (2021) has also studied the removal of microplastics from the effluent of WWTPs and demonstrated the electrocoagulation-electrofloatation as a promising method.

The current state of plastic pollution in Turkish aquatic ecosystems

In Turkey, plastic pollution research in aquatic ecosystems began in the 1980s. The first plastic pollution study was carried out by Bingel et al. (1987) on the northeastern

Mediterranean coast of Turkey. In this study, which aimed primarily to determine the fish biomass in the northeastern Mediterranean coast of Turkey, the density of plastics accumulated on the seabed was also investigated by weighing plastics in the trawl net. It can be said that this study is one of the first seabed plastic pollution studies in the world. After this study, no other publication on plastic pollution in Turkish aquatic ecosystems appeared in the literature until 2002.

Plastic pollution in Turkish marine waters

Based on the Web of Science database (accessed on 13/04/2021) and other widely accessible published studies and grey literature to date, many studies have been conducted in Turkish seas and coastal areas (beach, lagoon, and wetland) (Table 2). Most of these were carried out on the Mediterranean coast, followed by the Black Sea, the Marmara Sea and connected straits, and the Aegean Sea (Table 2). A couple of studies were carried out on either the ingestion of microplastics by aquatic organisms, their presence in the digestive system, or the entanglement of marine organisms in plastics (Gündoğdu et al. 2019, 2020b; Güven et al. 2017; Isinibilir et al. 2020; Tunçer et al. 2019; Svetlichny et al. 2021). In addition, microplastic pollution studies were carried out on edible mussels collected from various coastal regions of Turkey (Gedik and Eryaşar 2020) and stuffed mussels collected from different coasts of Turkey (Gündoğdu et al. 2020a) and table salts (Fatih 2017; Gündoğdu 2018) produced from both marine and freshwater sources. Most of the published studies were carried out in Iskenderun, Mersin, and Antalya Bays (the northern Levantine coast of Turkey) by relevant research institutions in this region.

It is worth noting that the increase in the number of plastic pollution studies conducted after Bingel et al. (1987) in Turkey is not parallel to the increase in the number of plastic pollution studies conducted globally. However, there has been a notable increase in pollution studies since the mid-2010s. The reason for this increase in plastic pollution studies in Turkey, as a candidate country to the European Union (EU), is the calls from the two major directives requiring plastic pollution monitoring (i.e., the Water Framework Directive and the Marine Strategy Framework Directive) in aquatic environments. However, the number of researchers working on plastic pollution in Turkey is still quite limited. The monitoring of marine litter along with other major pollutants within the integrated monitoring studies initiated in 2014 by the Ministry of Environment and Urbanisation has also naturally led to an increase in the number of plastic pollution data for the Turkish marine environment (Polat-Beken et al. 2017a, 2017b; Tuğrul et al. 2015). However, despite these monitoring studies being carried out along all Turkish coastal waters, including reference stations, results are not yet conclusive to reflect the state and trends in the Turkish seas regarding plastic pollution. It is worth noting that floating macroplastics in river mouths and lagoons are not included in these monitoring studies.

Surface waters

To date, nine microplastic studies have been carried out in Turkish surface waters: two in the Black Sea, five in the northeastern Mediterranean, one in the Dardanelles Strait, and one in the Küçükçekmece lagoon lake (Table 2). For sampling, plankton nets were used in the Black Sea studies, manta nets in the Mediterranean and Çanakkale straits studies, and a water pump in Küçükçekmece lake due to the shallowness of the lake. The microplastic types found in the Black Sea were fibers (49.4%), films (30.6%), and fragments (20%) (Aytan et al. 2016). In this study, paint particles from ships, microbeads that are widely used in the cosmetics industry, and raw plastic pellets were not reported. However, another study reported that shipping paint particles (51.6%) are predominant in surface waters of the central Black Sea coasts (Öztekin and Bat 2017). Surprisingly, as reported for the Eastern Black Sea coast, microplastics such as paint particles, microbeads, granules, or pellets were also not reported for the Bulgarian coast (Berov and Klayn 2020). According to Berov and Klayn (2020), microplastic pollution on Bulgarian coasts is lower than in other regions of the Black Sea, the Baltic Sea, and the Mediterranean Sea. Pojar et al. (2021) stated that the Danube River mouth contains significantly more microplastics than the Bulgarian and Romanian coasts.

All studies carried out in surface waters of the Turkish Mediterranean coasts were located in its northeastern region. The most frequently reported plastic particle types in studies conducted on the northeast Mediterranean coasts were fragments, fibers, and films (Table 2). Similarly, the distribution of plastic type in the Marmara Sea was also reported as fragments, films, foam, granules, and filaments, respectively (Tunçer et al. 2018).

Considering that lagoons act as a transition medium between freshwater and marine environments raises the possibility that microplastic types are similar due to their exchange. In support of this statement, the only study conducted in a lagoon environment reported a similar microplastic pattern to studies undertaken in the marine environment (Çullu et al., 2020). This similarity of microplastic types between transition and marine waters suggests that the plastic source originated in terrestrial environments. The microplastic formation process then continued in lagoons and marine environments, respectively.

Studies of surface waters in other regions of the Mediterranean Sea report relatively lower levels (between 0.15–7.68

items/m^3) of microplastics than reported for Turkish coasts (Table 3; Lefebvre et al. 2019; Fossi et al. 2016; Baini et al. 2018; de Lucia et al. 2014).

Benthic habitats including sediment

The quality of benthic habitats reflects seafloor characteristics, particularly the structure and functionality of benthos. Disturbance of the seabed caused by plastics may change the benthic community, damaging sensitive species and causing biodiversity loss. Plastic pollution, which also affects benthic biodiversity, is recognized worldwide as one of the most severe environmental problems on benthic ecosystems (Haegerbaeumer et al. 2019). In order to understand the changes in benthic habitats caused by plastic pollution, it is necessary to reveal the presence of plastic in these ecosystems.

Macroplastic pollution studies in the benthic habitats of Turkish coasts are mostly carried out using the trawl net, and most of them were conducted on the Northeast Mediterranean coasts (Table 2). The first of these studies was conducted by Bingel et al. (1987) in the Northeast Mediterranean through a sampling study by trawl in areas up to 100 m depth in Iskenderun and Mersin Bays, reporting 6200 g/h plastic. After this initial study, no further investigation was performed until 2002. In 2002, Yılmaz et al. (2002) reported a volume of 16,400 g/km^2 plastic debris in Iskenderun Bay. Following this second study, various concentrations of plastic litter have been reported by multiple researchers for the NE Mediterranean coasts (Güven et al. 2013; Eryaşar et al. 2014; Gündoğdu et al. 2017). It is understood from studies conducted in other regions that plastics are the most dominant litter type on the sea bottom (Table 2; Topçu and Öztürk 2010; Büyükdeveci and Gündoğdu 2021).

Microplastic pollution studies in sediment were carried out in the northeast Mediterranean Sea and Marmara Sea (Golden Horn in the Bosphorus). Güven et al. (2017) reported that 70% of microplastics detected in the sediment were fibers, 28% were hard plastic, and 2% were nylon. However, no information was given about the mean concentration of microplastics. Another study conducted in the Marmara Sea stated a 0.3–85.6 g/kg microplastic concentration in sediment (Baysal et al. 2020). The most common polymer types were reported as acrylonitrile butadiene styrene (ABS), ethylene vinyl acetate (EVA), and polystyrene (PS) (Baysal et al. 2020). However, not all studies give such precise details. For instance, Doğruyol (2019) reported 566 particles/kg of micro- and macroplastics in the Golden Horn, but no further information (e.g., shape, type, and polymer composition of plastics) were provided. The usage of NaCl as a density separator raises concerns about the chosen method of microplastic extraction. Doğruyol (2019) stated that the NaCl they used as a density separator was adjusted to 140 g/L density (probably mistyped), suggesting that plastics with a high density such as PET and PVC cannot be separated. This shows that the results obtained do not reveal the full extent of microplastic contamination.

In order to understand the true extent of microplastic pollution on Turkish coasts, it is necessary to compare it with studies carried out on other coasts. For instance, Cincinelli et al. (2021) reported an average of 106.7 microplastic particles/kg for Bulgarian coasts. This concentration is high for the Marmara Sea but significantly lower than for the Golden Horn. Similarly, significant differences were found in the amounts of benthic microplastics reported (1.70 to 2175 items/kg) in studies conducted in other Mediterranean regions (Table 3; Abidli et al. 2018; Filgueiras et al. 2019; Vianello et al. 2013). However, the lack of available studies and methodological differences make comparison difficult.

Beach litter

Coastal areas, namely the intersection of land and sea, are extremely complex environments shaped by the interactions between terrestrial, marine, and atmospheric phenomena. These complex and fragile structures include coves, wetlands, estuaries, mangroves, and near-shore reef systems. Regardless of fragility, ten percent of the world's population is dependent on coastal fishing activities for their livelihoods due to the high biological production capacities (FAO 2018). Despite the environmental/social importance of coastal regions and their vulnerability, pollution caused by anthropogenic activities presents a major threat to these areas globally. The most important of these pollutants are plastics. Plastics are found in coastal regions all over the world, not only near densely populated city centers but also in the waters around Antarctica (Barnes et al. 2009; Suaria et al. 2020), Arctic beaches (Bergmann et al. 2017), and uninhabited islands in all ocean basins (Lavers et al. 2019; Lavers and Bond 2017; Ryan et al. 2019). Marine debris stranded on coasts and floating in nearby waters creates environmental threats to numerous species living in coastal environments (Gündoğdu et al. 2019) and safety hazards caused by broken items or syringes. Plastics littered on beaches are also aesthetically unappealing, negatively affecting local incomes from tourism and entertainment activities (Krelling et al. 2017).

As in other parts of the world, it has been reported in many studies that there is severe plastic pollution in the Turkish coastal environment. At least twelve studies have been undertaken in Turkish coastal environments, mainly examining macroscale marine debris on beaches. Seven of these studies on beaches were carried out in the Northeastern Mediterranean coasts, six on the Black Sea coasts, and one on the Aegean Sea coasts. The first of these studies was carried out by Gabrielides et al. (1991), who reported that approximately 70% of the litter found on Erdemli beach consisted of plastics. It has been reported by various researchers that the majority of debris found on sandy beaches consists of plastics and that a significant amount of beach waste originates from other countries (Özdilek et al. 2006; Özhan et al. 2016; Gündoğdu et al. 2019; Gündoğdu et al. 2020a). It is also well known that plastic litter on sandy beaches can harm organisms (e.g., sea turtles, ghost crabs) that use this area as a habitat. For instance, a negative correlation between the amount of litter and the green turtle (*Chelonia mydas*) hatchlings has been reported for Hatay/Samandağ beach (Özdilek et al. 2006; Gündoğdu et al. 2019).

Many studies have reported on coastal areas highly polluted by marine litter, including plastics. For example, Aydin et al. (2016) and Gündoğdu and Çevik (2019) reported pollution as 0.92 items/m^2 and 12 items/m^2 on beaches in İskenderun and Mersin bays, respectively, with both studies indicating that especially Dörtyol beach was highly polluted. In addition, studies conducted on other Turkish coastal areas (Table 2; Terzi and Seyhan 2017; Aytan et al. 2020; Öztekin et al. 2020; Yabanlı et al. 2019; Kideys and Aydın 2020) have reported higher levels of pollution compared to results from studies carried out in different regions of the Mediterranean coastline.

It is well known that the structure and direction of the beaches, winds, waves, and the proximity of beaches to estuaries are important factors affecting the amount of litter accumulation. On the other hand, as stated in almost all of the studies, inadequate and ineffective waste management (direct dumping of waste into the sea or to river beds) is another important source of the existing pollution. Moreover, excess urbanization, industrialization, agricultural activities, single-use plastics disposal, cigarette butts, waste discarded by beach users, and fishing activities are also important factors. In addition to the land-based plastic waste inputs, another important source of plastic waste is transported plastics from other countries through currents. This can be clearly seen in studies conducted on the Turkish Mediterranean and the Black Sea coasts. The most important vector carrying non-native litter to Mediterranean coasts is the cyclonic Central Mediterranean current system which flows from Libya, Egypt, Israel, Lebanon, and Syria to the southern Turkish Mediterranean coastline. The Levantine Sea is estimated as one of the most important plastic waste accumulation areas of the Mediterranean in modeling studies (Liubartseva et al. 2018). Although it is assumed that the transportation of litter from the countries mentioned above further accelerates pollution in the Levantine Sea, there is no data to support this assumption yet. Further monitoring studies are needed to understand this situation better.

Effects of plastics on marine biota

It is clear that large volumes of plastics in aquatic ecosystems threaten aquatic life, a well-known and ever-increasing global issue. However, it is also important to note that all litter, not only plastics, affects aquatic life (Carney-Almroth et al. 2019). It is currently estimated that 3488 marine species globally are directly under threat due to marine litter (Tekman et al. 2021). Tekman et al. (2021) demonstrated through the Litterbase database that the organisms most affected by marine litter are fish (22.3%), followed by sea birds (16.4%), crustaceans-arthropods (10.9%), and bacteria (10.4%). The detrimental effects of marine litter were categorized according to the numbers of cases reported as follows: ingestion (37.4%), colonization on litter (36.5%), and entanglement (20.9%) (Tekman et al. 2021). Moreover, many previous studies have also reported that various aquatic organisms are affected by plastics, including fulmars, clams, mussels, and fish (Foley et al. 2018; Gündoğdu et al. 2020b; Gündoğdu et al. 2020a). Even microscopic organisms such as zooplankton (Aytan et al. 2021) and fish larvae can directly ingest small plastics during feeding (Lusher 2015). When plastics degrade to micro- and nano-size plastics in environments, they can even more easily enter the aquatic food web (Piccardo et al. 2020).

Although the effects of plastics on aquatic organisms are widely known and a matter of concern, only eight studies have been conducted on this subject (Table 2; Jovanović et al. 2018; Tunçer et al. 2019; Isinibilir et al. 2020; Svetlichny et al. 2021).

Plastics are known to interact with aquatic organisms in the form of colonization (Tekman et al. 2021). It has been found that various taxa commonly colonize on plastics in coastal areas (Gündoğdu et al. 2017). In addition, the entanglement of fish in plastics was the subject of a case report (Tunçer et al. 2019). Plastics may also indirectly affect organisms. For instance, Gündoğdu et al. (2019) determined that the concentration of plastic pollution present on beaches at Samandağ poses a significant risk towards green sea turtles that use the area for nesting.

Turkey has the second-longest coastal zone (8333 km) in the Mediterranean region after Greece. Turkish coasts possess ecosystems of richness and diversity, covering long and wide beaches with a total of 86 wetlands, 14 of which are RAMSAR sites. Studies have shown that there is severe plastic pollution pressure on these areas. However, as the number of research publications on plastic pollution in Turkish seas and coastal regions is deficient, plastic pollution may be more widespread than predicted.

Plastic pollution in Turkish inland waters

According to the General Directorate of Nature Conservation and National Parks, there are 25 river basins, 320 natural lakes, and 861 dams in operation identified in Turkey. Some lakes are seasonal, filling with winter rains and drying due to the lack of rainfall in the summer period. Freshwater ecosystems in Turkey are subject to falling water levels due to excessive irrigation methods, drought, and increasing pollution loads. Plastic pollution has become one of the threatening problems of our era, among many human pressures on aquatic ecosystems (Wagner et al., 2014). There are major gaps in current knowledge concerning microplastic pollution in freshwater ecosystems, especially amounts, sources, and ecological effects (Eerkes-Medrano et al. 2015; Horton et al. 2017).

Plastics can enter lakes and rivers via several pathways such as tributaries, improper plastic waste dumping within catchment areas, recreational water activities, storm events, flooding, and from the atmosphere (Kataoka et al. 2019). It is estimated that between 4.8 and 12.7 million tonnes of plastic enter the oceans each year through rivers and lakes, particularly during extreme floods (Bertoldi et al. 2021; Bläsing and Amelung 2018). González-Fernández et al. (2021) analyzed data collected from 42 rivers of 11 European and neighboring countries between September 2016 to September 2017, and estimated that between 307 and 925 million macrolitter items (82% plastics) are released annually from Europe to the ocean. This study also included two Turkish rivers (Lamas River-Mersin and Göksu River-İstanbul) from which floating marine macrolitter loads were determined as 17,423 and 314,908 items/year, respectively. These are the only data on the riverine transport of macroplastics for Turkey.

Rivers and lakes showed a similar pattern to the marine environment, where secondary microplastic production occurs via macroplastic fragmentation due to physical factors (Vethaak 2021). The abundance of microplastics in lakes is strongly linked to water residence time, surface area, proximity to waste management facilities, and amount of sewage outflow (Eerkes-Medrano et al. 2015). Human population densities and proximity to the urban areas are also important influencing factors for MP inputs to waters (Bellasi et al. 2020). For example, the microplastic concentration on the southern shores of Lake Garda was observed at 100 items/m^2, while in northern sediments, around 110 items/m^2 (Imhof et al. 2013). Regional differences in socioeconomic characteristics and environmental forces such as wind trigger variation in MP abundances in lakes (Barnes et al. 2009; Browne et al. 2011).

Microplastic pollution research in freshwater ecosystems differs significantly between developed and developing countries (Yao et al., 2020). For freshwater ecosystems, only five plastic pollution studies are available in Turkey which was undertaken from a crater lake, a pond, a ditch/puddle, and two reservoirs (Çomaklı et al. 2020; Erdoğan 2020; Tavşanoğlu et al. 2020; Karaoğlu and Gül 2020; Turhan 2022). Instead of freshwater ecosystems, microplastic ingestion was reported from a fish species from Lake Van, an endorheic soda lake (Atıcı et al. 2021). The types and sources of microplastic pollution were reported in the Crater Lake at 2380 m altitude in Erzurum (Çomaklı et al. 2020). In this study, the chemical composition of the microplastics was determined as either polyethylene or polypropylene. A study on microplastic pollution in Süreyya Bey Dam lake evaluated microplastics' types, mesh size effect of nets, and biofilm composition on the microplastic surface in the freshwater ecosystem (Tavşanoğlu et al. 2020). In this study, fibers were the most abundant microplastic type in different size mesh nets. The plastic components of the microplastics were mainly PET, PVC, PS, PE, and PP. Accordingly, the researchers stated that microplastics are the vector for potentially pathogenic strains such as *Escherichia coli*, *Enterococcus faecalis*, and *Acinetobacter baumanii* complex. Another study from a dam lake was conducted in Sürgü Dam Lake in Malatya (Turhan 2022). The microplastic concentrations were investigated in three compartments from surface water, sediment, and fish gastrointestinal tracts by Turhan (2022). The most common polymer type was polyethylene terephthalate and polypropylene. The study stated that the MP pollution in the dam lake is relatively moderate in sediment compared to fish and surface water.

The microplastic pollution was also investigated in a pond in the nature reserve at Yozgat (Erdoğan 2020). This study investigated surface water microplastic pollution from five different stations (Erdoğan 2020). Accordingly, a study investigated the microplastic pollution in surface water, sediment, and tadpoles of *Pelophylax ridibundus* and *Rana macrocnemis* from the small pond, ditches, and puddles in Rize province (Karaoğlu and Gül 2020). The General Directorate of Water Management has undertaken a new project related to microplastic surveillance of inland waters, which commenced in October 2020 (tarimorman.gov.tr), which has not been completed.

Several research projects have been conducted in different parts of the world related to microplastic loads of rivers. However, these studies are still very limited (Castro et al. 2016; Horton et al. 2017; Zhang et al. 2018). From the published data, microplastic pollution is reported mostly from North America and Europe (Li et al. 2021). Considering the location of Turkey, the Danube River, which is the second-largest river in Europe, was estimated to discharge around 4.2 tons of microplastics per day into the Black Sea (Lechner et al. 2014). Even though there are 25 river basins in Turkey, there is no published information on microplastic loads from rivers to the sea. Resembling the global trend, there are currently increasing efforts to investigate microplastic pollution in freshwater ecosystems in Turkey considering new ongoing projects. A study from the river is obtaining the microplastic presence from the three most dominant fish species (*Squalis cephalus*, *Cyprinus carpio*, and *Alburnus mossulensis*) in the Karasu River (Atamanalp et al. 2021). The major microplastics were fiber in the intestinal contents, and the amount of microplastics for *S. cephalus, C. carpio*, and *A. mossulensis* was found to be 6.18 items, 7.0 items, and 6.0 items, respectively. The most common polymer type was PE, PVC, PET/polyesters, PP, and cellulose. In addition, there is also one study that investigates microplastic pollution in Lake Tuz between 2015 and 2016 in Turkey. Results show variation among the sampling seasons regarding the microplastics pollution in the lake. Furthermore, fibers were the dominant microplastics type in the lake, a similar pattern observed for freshwater (Fatih 2017).

Policies relevant to plastic pollution in Turkey

Similar to scientific studies, first policy actions on discarded litter for aquatic ecosystems were elaborated for the marine environment, as about 97% of Earth's water is in the ocean. Marine litter is a truly transboundary issue requiring an international effort to manage. One of the initial large-scale policy developments on marine litter at the international level, as a dedicated issue, was the setup of the Regional Activity on Marine Litter, supported by UNEP in 2005. Most of the 18 Regional Sea Programmes action plans were drafted within the Global Partnership framework on Marine Litter (GPML) launched by the June 2012 UN Conference on Sustainable Development (Rio+20).

Turkey is a member of two regional Sea Programmes; (1) UNEP administered Mediterranean Action Plan (UNEP/MAP), otherwise known as the Barcelona Convention, and (2) non-UNEP administered Commission on the Protection of the Black Sea Against Pollution (BSC), otherwise known as the Bucharest Convention. Consequently, Turkey actively contributes to and applies joint measures developed by these regional seas organizations. Similarly, the European Commission also closely cooperates with the joint activities for marine litter in the Mediterranean (since almost all northern Mediterranean countries belong to the EU) and the Black Sea (due to EU member states Bulgaria and Romania).

With the financial and expert support of UNEP, the Permanent Secretariat (of the BSC, which is mainly responsible for the international environmental management of the Black Sea) produced the publication entitled "Report on Marine Litter in the Black Sea," as early as 2009 (BSC 2009). Following this report, some of the suggested activities (methodologies, monitoring, and assessment, increased public awareness on marine litter) were also immediately included in the Strategic Action Plan for the Environmental Protection and Rehabilitation of the Black Sea, adopted in Sofia, Bulgaria, on 17 April 2009. Later, in 2018, the Regional Action Plan on marine litter management for the Black Sea basin was adopted. However, despite clearly outlined strategies for developing harmonized methodology, data collection, the setting up of baselines, and threshold values for different compartments of the Black Sea, successful implementation of this plan by the riparian countries, including Turkey, has yet to be materialized (Makarenko 2020).

Turkey is also a candidate member state for the European Union and hence is committed to harmonization with EU legislation, which includes regulations on marine litter. The major EU directive on the marine environment is the Marine Strategy Framework Directive (MSFD) which includes marine litter issues among ten descriptors that aim to achieve Good Environmental Status (GES). It requires the EU Member States to ensure that "properties and quantities of marine litter do not cause harm to the coastal and marine environment." Descriptor Ten: Marine Litter comprises two primary and two secondary criteria to reach this goal. The first two criteria concern macro- and microplastic quantities and establishing thresholds for the coasts, surface waters, and seabed. The two remaining criteria relate to levels and thresholds and the impact of plastics on marine organisms. A specific setup group (i.e., MFSD TG-ML, Task Group on Marine Litter) is responsible for supporting the implementation of the MFSD directive focusing on harmonization/analysis of data, determination of baselines, thresholds, and evaluation policy impact for Descriptor 10.

The "Turkish Marine Research Strategy" (TUDAS), which was signed and approved by the Ministerial cabinet on 2 October 2014, is the first official document referring to the MFSD (Eyüboğlu and Eyüboğlu 2021). TUDAS emphasizes the monitoring of water quality and ecosystem status (including marine litter) in addition to many other MFSD related activities (e.g., increase in capacity for marine research, studying the impact of climate change, sustainable management of marine resources, marine protected areas, and data sharing).

Several projects have been or are being coordinated by the Turkish Ministry of Environment and Urbanization towards implementing the MFSD (ref: https://eppanetwork.eu/wp-content/uploads/2019/12/Workshop-Report-WFD-MSFD.pdf). "Marine and Coastal Waters Quality Status Determination and Classification" project (DEKOS), undertaken during 2011–2013, sought to obtain the necessary information and application tools to support the ecosystem-based management principle for transitional-coastal and coastal-marine waters (as in the MSFD and Water Framework Directive WFD). DEKOS identified 12 marine assessment areas for coastal waters for the evaluation of good environmental status (Eyüboğlu and Eyüboğlu 2021). "Updating the National Action Plan for Protecting the Marine Environment Against Land-Based Sources" project (2016–2017) focused on baselines for eutrophication, contaminants, and marine litter. Evaluation of existing pollution control measures and legislative frame and revision of policies and strategies based on river basins were finalized within the scope of this project. The project entitled "Capacity Building on Marine Strategy Framework Directive" (MARinTURK) (2016–2018) targeted the future harmonization and implementation processes of the MFSD in Turkey. "Development of Turkish Marine Environmental Strategy" project (2018–2020) was a significant step towards developing a Marine Environmental Strategy and National Marine Environmental Action Plan (Eyüboğlu and Eyüboğlu 2021), taking into account not only the EU objectives, but also the United Nations Sustainable Development Goals in line with the Blue Economy strategy. The Integrated Pollution Monitoring of Turkish Seas program running since 2013 is an important activity for the collection of data on marine litter (beach, seafloor, and microplastics) from the Mediterranean, Aegean, Marmara, and the Black Sea coasts of Turkey. Data from this program is also made available through UNEP/MAP and BSC. To support this program, the "Standardisation of Marine Monitoring project (DISSP 2015–2017) provided monitoring guidelines, including on marine litter.

The First Circular Economy Action Plan (2015), Strategy for Plastics (2018) and the New Circular Economy Action Plan (2020), and Zero Pollution Action Plan (2021), which are among the main blocks of the European Green Deal, are other main European Commission (EC) policy instruments to deal with marine litter among other topics (all these directives are accessible through the link https://ec.europa.eu/environment/topics/plastics_en). These recent legislations also reiterate that pollution of the seas by plastics and microplastics is one of the major problems and propose actions directly or indirectly related to marine litter, including its international dimension. In line with the First Circular Economy Plan, the EU Commission declared another goal of ensuring all plastic packaging will be recyclable by 2030. One of the flagship initiatives against plastic pollution of the oceans, aligned to the Strategy for Plastics, is the Directive on Single-Use Plastics and Fishing Gear (SUPs) which introduces a set of ambitious measures to curb ten major litter items. Among these, cotton bud sticks, plastic cutlery, plates, straws, stirrers, and sticks for balloons will be banned from 3 July 2021. For the other single-use plastic items in the list, measures for limiting their use will be put into action, which includes awareness-raising, design modification (e.g., connecting caps to bottles), explanatory labeling (to show environmental harm), and Extended Producer Responsibility (EPR) schemes.

Although Turkey does not have a SUP specific legislation (Aydın 2021), the current Turkish regulations relevant to marine litter and related waste management are compatible to a certain extent with those of the European Union (Table 4; Angı 2019). For instance, similar to the EU Directive on Reducing the Consumption of Lightweight Plastic Carrier Bags, lightweight plastic bags have also been discouraged in Turkey by a compulsory fee for customers, a regulation that came into force in 2018. One of the most significant recent policies to decrease Turkish marine litter is the Zero Waste regulation that came into force in 2019. The Zero Waste regulation paves the way for an improved waste management system, more efficient recycling, decreased waste production, and data collection on a non-industrial litter by institutions, municipalities, and the general public. The responsibilities of municipalities and stakeholders are very well defined in this regulation, including activities for waste management, more efficient use of resources, prevention or minimization of waste generation, waste collection at the source, recycling, and increasing public awareness. In order to gather support, the Zero Waste Blue Action initiative was started in 2019 with a specific action plan to manage marine litter in all coastal areas of Turkey (https://webdosya.csb.gov.tr/db/cygm/icerikler/samav%2D%2D20200914212036-20200925151356.pdf). All coastal municipalities are now developing their action plans for cleaning, monitoring, data collection, risk mapping, hot points, and awareness-raising activities of marine litter.

Research gaps and needs

Evaluation of macro- and microplastic pollution in aquatic ecosystems is very urgent. The lack of quantitative data makes it difficult to assess the hazard dimensions of plastic pollution on aquatic biota (Horton et al. 2017). One of the best indicators for marine litter is on beach litter. Hence, regular (possible at seasonal intervals) monitoring of beaches from different regions of Turkey should be set up. For this monitoring, involvement and support of NGOs (such as the Blue Flag Turkey) and citizens could also be encouraged. Besides ongoing monitoring of macro- and microplastics in coastal and marine environments, regular monitoring (minimum at seasonal intervals) of riverine loads should also be planned for determining baselines and thresholds of plastic pollution towards the evaluation of the success of the relevant policies (e.g., reduction of lightweight plastic bags, zero waste). In addition to the central government organizing a regular monitoring program for Turkish seas, the monitoring and development of reduction measures for riverine and other freshwater sourced litter should be organized by the

Fig. 3 Knowledge gaps relating to plastic pollution of Turkish aquatic ecosystems

greater city municipalities for the coastal cities of Turkey (Figure 3).

Inland waters face several difficulties, such as reductions in groundwater levels and surface area, salinization, or eutrophication. Considering the increase of anthropogenic activity, the amounts and characteristics of plastics entering the environment from past to present should be documented. A few studies have investigated the microplastic accumulation throughout history in freshwaters from other regions (Turner et al., 2019; Dong et al., 2020), but no data exists for Turkish inland water bodies. It is crucial to determine the Anthropocene period in which humans became a significant component affecting the environment and earth processes (Dong et al., 2020). It is also important to use a paleolimnological approach for understanding the microplastic states of inland waters as a potential indicator of the Anthropocene period.

Another gap and issue for inland waters is the lack of a standard protocol in sampling and analyses of microplastics (Horton et al. 2017; Lu et al., 2021, Razeghi et al., 2021). It is important to apply standard protocols to determine regional, national, and global distributions in microplastics' pollution to produce comparable data. The lack of standard methodology and quantitative assessment of MP investigation, especially in the freshwater environment, makes it complicated to understand the variation across studies

Table 2 Plastics pollution levels from some of the studies in Turkish marine ecosystems

Study area	Sample type	Sampling method	Litter type	Litter concentration and plastic concentration (if reported)	Source
NE Mediterranean (İskenderun and Mersin Bay	Benthic sediment	Trawl net	Benthic plastics	88 kg/km^2	Bingel et al. (1987)
NE Mediterranean (Mersin bay, Erdemli)	Sandy beaches	Transect	Plastics, wood, Styrofoam, fishing gear, glass, metal and others	Plastics (49–71%), Styrofoam (3.5–9.3%)	Gabrielides et al. (1991)
NE Mediterranean (İskenderun bay)	Benthic sediment	Trawl net	Benthic plastic litter	15,583 gr/month	Yılmaz et al. (2002)
Mediterranean Sea (Antalya Bay)	Sandy beaches	Transect	Beach litter	18–743 items/100 m	Balas et al. (2004)
NE Mediterranean (Samandağ)	Sandy beaches	Transect	Beach litter	8.403–135.120 gr/57.9 m	Özdilek et al. (2006)
Black Sea	Benthic sediment	Trawl net	Benthic litter	128 items/km^2 to 1320 items/km^2; soft plastic 79.6%, hard plastic 10.3%	Topçu and Öztürk (2010)
Mediterranean Sea (Antalya Bay)	Benthic sediment	Trawl net	Benthic litter	18.5 to 2186 kg/km; plastic 81.1%	Güven et al. (2013)
Black Sea	Sandy beaches	Transect	Beach litter	0.085 to 5.058 items/m^2; 62.7% hard plastic, 15.8% soft plastic, 4.4% synthetic fibers, 4.3% styrofoam, 3.9% polyurethane	Topçu et al. (2013)
NE Mediterranean Sea (Mersin Bay)	Benthic sediment	Trawl net	Benthic litter	0.01 and 5.85 kg/h; plastic 73%	Eryaşar et al. (2014)
Black Sea	Surface water and water column	WP2 net with 200 mm mesh	Microplastics	1200 items/m^3–600 items/m^3	Aytan et al. (2016)
NE Mediterranean (İskenderun and Mersin Bay)	Sandy beaches	Transect	Beach litter	0.92 items/m^2, and 7.43 g/m^2; plastic 80%	Aydin et al. (2016)
NE Mediterranean (Mersin Bay)	Sandy beaches	Transect	Beach litter	0.031–0.473 items/m^2; plastics: 78.8–98.1%	Kideys et al. (2017)
Western Black Sea (Sinop-Sarıkum)	Sandy beaches	Transect	Beach plastic litter	Macroplastics 1.0807–4.5054 items/m^2, microplastic 0.5567–1.5684 items/m^2	Visne and Bat (2016)
SE Black Sea	Sandy beaches	Transect	Beach litter	0.03–0.58 (0.16 ± 0.02); plastics 61.2%	Terzi and Seyhan (2017)
Western Black Sea (Sinop-Sarıkum)	Surface water and water column	Neuston net (300 µm) and cylindro-conical plankton net	Microlitter	2.667–2.325 items/m^3 for sea surface and 24.475–26.153 items/m^3 for water column	Öztekin and Bat et al. (2017)
NE Mediterranean (İskenderun and Mersin Bay)	Surface water	Manta net	Micro- and mesoplastics	Iskenderun Bay:0.2254 item/m^2; Mersin Bay 0.6827 item/m^2	Gündoğdu and Çevik (2017)

Table 2 (continued)

Study area	Sample type	Sampling method	Litter type	Litter concentration and plastic concentration (if reported)	Source
NE Mediterranean Sea (İskenderun Bay)	Surface water	Manta net	Microplastics	1,067,120 items/km^2	Gündoğdu (2017)
NE Mediterranean (İskenderun and Mersin Bay)	Surface water, water column, and benthic sediment and biota	Surface water: Manta net; water column: WP2 net; sediment: Van Veen Grab	Microplastics	Water: 16,339 to 520,213 items/km^2; biota: 1.80 item/individual	Güven et al. (2017)
NE Mediterranean Sea (Mersin Bay)	Benthic sediment	Trawl net	Benthic plastic litter	2670 item/km^2; 86.3 kg/km^2	Gündoğdu et al. (2017)
NE Mediterranean Sea (Mersin Bay)	Surface water	Manta net	Microplastics	539,189–769,9716 items/km^2	Gündoğdu et al. (2018b)
NE Mediterranean Sea (Antalya Bay)	Benthic sediment	Trawl	Benthic litter	13.3–651.1 items/km^2, 0.02–559 kg/km^2; plastics: 73%	Olguner et al. (2018)
Marmara Sea (Dardanelles)	Surface water	Manta net	Microplastics	1263 items/m^2	Tunçer et al. (2018)
South Aegean Sea (Datça)	Sandy beaches	Transect	Microplastics	1154.4 items/kg d.w.	Yabanlı et al. (2019)
NE Mediterranean (İskenderun Bay)	Sandy beaches	Quadrats	Beach plastic litter	Meso- and macroplastics 12.2 items/m^2 and 12.3 items/m^2	Gündoğdu and Çevik (2019)
NE Mediterranean (Samandağ)	Sandy beaches	Quadrats	Beach plastic litter	19.5 ± 1.2 items/m^2	Gündoğdu et al. (2019)
Golden Horn (Marmara Sea)	Benthic sediment	Van Veen Grab	Microparticles	566 items/kg d.w.	Doğruyol (2019)
Black Sea Rize Coast	Sandy beaches	Transect	Beach litter	1.22–4.17 items/m^2; 84–91% plastic	Aytan et al. (2020)
Black Sea Sarıkum/Sinop	Sandy beaches	Transect	Beach litter	1.512 items/m^2; 95.6% plastic	Öztekin et al. (2020)
Marmara Sea	Benthic sediment	Van Veen Grab	Microplastics	0.3–85.6 g/kg	Baysal et al. (2020)
Mediterranean Sea (Antalya and Muğla)	Benthic sediment	Trawl	Benthic litter	19 items/km^2 and 18 kg/km^2; plastics: 40%	Mutlu et al. (2020)
SE Black Sea (Trabzon)	Sandy beaches	Transect	Beach litter	22 items/m^2; plastics: 79.7%	Terzi et al. (2020)
Marmara Sea (Küçükçekmece Lagoon)	Surface waters	10 L of bulk surface water	Microplastics	33 items/L	Çullu et al. (2021)
Marmara Sea	Sandy beaches	Quadrats	Beach litter	66.2 items/m^2; plastics: 76%	Artüz et al. (2021)

Table 3 Plastic concentrations reported for different regions of the Mediterranean and Black Sea by various researchers

Sample type	Study area	Concentration	Source
Surface Water/Water Column	Mediterranean, surface (Cretan Sea)	0.119 item/m^2	Kornilios et al. (1998)
	NW Mediterranean	0.116 item/m^2	Collignon et al. (2012)
	Mediterranean (Ligurian/Sardinian Sea)	0.310 item/m^2	Fossi et al. (2012)
	Mediterranean, surface	0.250 item/m^2	Cozar et al. (2015)
	Mediterranean, surface (Central and Western Regions	0.147 item/m^2	Ruiz-Orejon et al. (2016)
	Mediterranean, surface (Central/Western Part)	0.400 item/m^2	Suaria et al. (2020)
	Western Black Sea Romania	7 particles/m^3	Pojar et al. (2021)
	South Eastern Mediterranean Sea (Israeli surface waters)	7.68 ± 2.38 items/m^3	van der Hal et al. (2017)
	Lebanese coast	4.3 ± 2.2 items/m^3	Kazour et al. (2019)
	Tunisia Bizerte lagoon, Southern Mediterranean Sea	453.0 ± 335.2 items/m^3	Wakkaf et al. (2020)
	Ligurian and Tyrrhenian Seas	255,865 ± 841,221 items/km^2, or 394.19 ± 760.87 g/km^2;	Caldwell et al. (2020)
	Gulf of Gabes (Tunisia)	25,471–111,821 items/km^2	Zayen et al. (2020)
	Western Black Sea	4.62 × 10^4 items/km^2)	Berov and Klayn (2020)
Beach Sediment	Israel	0.04–2.09 (items/kg)	Lots et al. (2017)
	Lion Bay (France)	North: 166 ± 205 items/kg ve South; 58 ± 53 items/kg	Constant et al. (2019)
	Barcelona (Spain):	148 ± 23 items/kg d.w	Lots et al. (2017)
	Tel Aviv (İsrael)	168 ± 16 items/kg d.w	Lots et al. (2017)
	Dikili (Turkey)	248 ± 47 items/kg d.w	Lots et al. (2017)
	Greece (Kea Island)	10–977 items/m^2	Kaberi et al. (2013)
	Portugal	185.1 items/m^2, 36.4 g/m^2	Martins and Sobral (2011)
	Romania	1000–5500	Popa et al. (2014)
	Cyprus	45,497 ± 11,456 items/m^3	Duncan et al. (2018)
	Italy (Pelagos sanctuary)	1.05 (items/kg)	Giovacchini et al. (2018)
	NW Adriatic	0.11–0.51 (items/kg)	Munari et al. (2016)
	Sicily (Italy)	160 ± 31 items /kg d.w	Lots et al. (2017)
	Madeira (Portugal)	92 ± 15 items /kg d.w	Lots et al. (2017)
Benthic Sediment	Black Sea	106.7 items/kg %83 plastics	Cincinelli et al. (2021)
	North African coasts of Mediterranean Sea	182.66±27.32 and 649.33±184.02 items/kg[1]	Tata et al. (2020)
	Italy Venice lagoon	672–2175 items/kg d.w.	Vianello et al. (2013)
	Netherlands (North Sea coast)	6.0 ± 5.7 items/kg d.w.	Van Cauwenberghe et al. (2015)
	Spain	900 ± 100 items/kg d.w.	Alomar et al. (2016)
	Belgium	390 items/kg d.w.	Claessens et al. (2011)
	South of Portugal	10 ± 1.0 items/kg d.w.	Fastelli et al. (2016)
	Tunisia	141.20 ± 25.98–461.25 ± 29.74 items/kg d.w.	Abidli et al. (2018)
	Central Adriatic (eastern sector)	190–790 items/kg d.w.	Palatinus et al. (2019)
	Spanish continental shelf (western Medit.)	113.2 ± 88.9 items/kg d.w.	Filgueiras et al. (2019)
	The northern Tyrrhenian Sea/Italy	1.70 ± 0.93 items/kg d.w.;244.5 ± 122.3 particles/m^2	Mistri et al. (2020)

Table 4 Turkish and EU plastic packaging waste management regulations (modified from Angı 2019)

Turkish regulations	Latest version	EU regulations	Latest version
The Environmental Law	1983	There is no one specific Environmental Law but whole legislations related to Environmental policies entitled Environmental laws	
Regulation on the Waste Management	2017	Directive on Waste and Repealing Certain Directives (EU Waste Management Law)	2008
Regulation on the Management of Packaging Waste	2017	Directive on Packaging and Packaging Waste	2018
Regulation on Plastic bags	2018	Directive on Reducing the Consumption of Lightweight Plastic Carrier Bags	2015
Regulation on the Landfill of Waste	2015	Directive on the Landfill of Waste	1999
NA		New Circular Economy Action Plan	2020
NA		Directive on Single Use Plastics and Fishing Gear	2018
National Marine Environment Strategy	In preparation*	Marine Strategy Framework Directive	2011
Zero waste strategy	2019	Strategy for Plastics	2018
Zero Waste Blue Action	2019		

*Eyüboğlu and Eyüboğlu (2021)

and emphasize gaps in the knowledge (Lu et al., 2021). For instance, according to the literature, most of the studies were conducted using 330 micron mesh size in Manta/Neuston net for rivers and lakes; however, rivers are the main pathway for microplastic transport, so an optimum mesh size should be strongly defined for future works. Development of research methodology should be undertaken jointly with the relevant task groups of the EU on litter.

The monitoring of microplastics in seas, lakes, and rivers should be combined with the ecotoxicological parameters. In evaluating the effects of microplastics on the food chain, it is critical to design laboratory experiments by considering their amounts in the aquatic ecosystem. Another important pathway for microplastics to enter the aquatic ecosystem is the atmospheric. No Turkish study has so far focused on this topic, which should be addressed urgently as research conducted in Paris found that atmospheric fallout contributed significant quantities of fibers to aquatic systems (Dris et al. 2018).

Concluding remarks

Turkey is considered one of the most polluters of the Mediterranean and Black Sea. By reviewing the scientific literature about plastic litter in Turkish aquatic ecosystems, we identify an urgent need to expand the research area, especially in freshwater systems. We could confirm that plastic pollution studies in marine environments are quantitatively higher than freshwater environments in Turkey. Both macro- and microplastic pollution sources and levels from aquatic environments should be monitored regularly in syncronized manner. There are currently a few studies evaluating plastic pollution's impact on freshwater or marine fauna. Considering the significance of marine and freshwater systems for many people in Turkey, there is also an urgent need to expand the plastic pollution study through public and environmental health perspectives. By extending the studies to look at comparable countries in terms of GDP and mismanaged waste per capita will provide a broader outlook to the decision-makers. Future studies that pay more attention to building international collaborations and capacity to address this research gap will be helpful to Turkey in following the objectives of the UN Decade of Ocean Science for Sustainable Development.

Turkey has the ambition to participate in the global process of aligning the Sustainable Development Goals (SDG) agenda with its national plans and strengthening actions. Mitigation of plastic pollution is essential to achieving many of the SDG targets. This is closely linked with municipal waste management and aquatic plastic pollution. Thus, in addition to the researches reviewed here, further monitoring and evaluation studies can support the progress of SDGs. Educational and awareness-raising campaigns successfully transformed into long-term behavior change can be a powerful tool to reduce plastic pollution in the Turkish aquatic environment.

Turkey has recently restricted the import of most plastic waste to support its national zero waste strategy (Gündoğdu and Walker 2021). If this decision is supported by a solid effort to implement 5R (Refuse, Reduce, Reuse, Repair, and Recycle) strategies, it will be allowed to be a country that manages its plastic waste before reaching the aquatic environment.

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