Turk. J. Fish.& Aquat. Sci. 22(SI), TRJFAS20603
https://doi.org/10.4194/TRJFAS20603

RESEARCH PAPER

Turkish Journal of FISHERIES and AQUATIC SCIENCES

Microplastics in Turkish Straits System: A Case Study of the Bays and Straits

Yaprak Gürkan[1,#,*], Ahsen Yüksek[1,#]

[1]İstanbul University, Institute of Marine Sciences and Management, Mollahüsrev Mah. Müşküle Sok. 34134 Fatih, İstanbul, Türkiye.
[#]These authors share the first authorship.

How to cite

Gürkan, Y., Yüksek, A. (2022). Microplastics in Turkish Straits System: A Case Study of the Bays and Straits. *Turkish Journal of Fisheries and Aquatic Sciences*, *22(SI)*, *TRJFAS20603.* https://doi.org/10.4194/TRJFAS20603

Article History
Received 12 September 2021
Accepted 13 April 2022
First Online 14 April 2022

Corresponding Author
Tel.: +902124400000
E-mail: yaprak.gurkan@istanbul.edu.tr

Keywords
TSS
Marine litter
Microplastics
The Sea of Marmara
Mediterranean Sea

Abstract

When plastics were first created as easy to create, long-lasting materials, there was no environmental foresight. Now all plastics pollute including land, water, groundwater have been penetrated all levels of the food chain. Plastic fragmentation into smaller-sized particles and their entering into various environments in directly small sizes created a new global issue of high concern known as microplastics. This study was undertaken for better understanding the microplastic abundance, type and size distribution in the most populous region of Turkey by analyzing surface water and water column properties in the Turkish straits system in 2016. Our results showed that surface water microplastics ranged between 0.17 and 2.52 item/m^3, while in water column abundance was between 4.12 to 34.90 items/m^3. The proportional concentration of fibers was higher in water column samples (between 100% and 59.49%) than in surface water samples (between 70.59% and 19.75%). Microplastics between 0.3 and 2.0 mm had a ratio of 76.80 %. Considering the straits' boundaries, the entrance of the İstanbul Strait had more than two fold of microplastics than that in the exit of Dardanelles in water column. Heavily industrialized/urbanized bays had higher microplastics concentration where point and non-point sources considered as disturbances.

Introduction

Microplastics in the environment are defined as plastic particles < 5 mm (Arthur et al., 2009; Barnes et al., 2009). Their existence depends on primary and secondary sources; as primary are entered directly into the environment as <5 mm particles (such as microbeads and pellets) and as secondary, they occur by the fragmentation of larger plastic litter in the environment (Barnes et al., 2009; Cole et al., 2011). Primary microplastics include cosmetics and cleaning products and raw materials that are used in industry (Cole et al., 2011; Duis and Coors, 2016). Secondary microplastics constitute the majority, and unfortunately fragmentation is a continuous process (Andrady, 2011; Jang et al., 2014; Song et al., 2015). Photo-oxidation, photo-thermal oxidation, mechanical abrasion, hydrolysis and biodegradation (Song et al., 2017; Alimi et al., 2018; Julienne et al., 2019) and even digestion processes by some organisms (Mateos-Cárdenas et al., 2020) are responsible for the fragmentation pathways and almost unpreventable. Plastic litter is persistent, durable (Jambeck et al., 2015) and tends to create smaller magnitudes (Cózar et al., 2014), a certain temporal pattern in the quantity of microplastics is not clear (Galgani et al., 2021). Rivers are considered as the main carriers for microplastics, they transport the microplastics to the marine environment (Lebreton et al. 2017; Simon-Sanchez et al. 2019). Areas with intense urbanization and poor waste management are mostly responsible as hotspots for high quantities of microplastics entering in the marine realm (Derraik, 2002; Barnes et al., 2009). With the help of natural hydrodynamic processes, these particles are then spread and deposited elsewhere (Law et al., 2010) like offshore areas (de Lucia et al., 2014). They can also penetrate and accumulate in all regions of the oceans, from neuston to the seafloor and beaches by hydrographic, atmospheric, and physical conditions, as well as by bioaccumulation and biological processes (Hardesty et al., 2017). Thus, their bioavailability reaches different levels of the marine food web (e.g. Galloway et al., 2017). Due to their penetration to all aspects of costal and marine processes, and due to their sheer magnitude, microplastics have more recently became a global issue of concern (Lönnstedt & Eklov, 2016). Hence, it is important to understand their sources, accumulation, abundance and distribution in both marine environment and food chain (Moore et al., 2001; Collignon et al., 2012; Boerger et al., 2010; Kukulka et al., 2012; Frias et al., 2016; Aytan et al., 2016; Güven et al., 2017, 2022).

The Sea of Marmara is a permanently two-layered system with two narrow straits that consist of water exchange between the Black Sea and the Mediterranean Sea. The Sea of Marmara with both straits -Dardanelles and İstanbul Straits is named as Turkish Straits System (TSS). The upper layer water originated from the Black Sea is separated by a sharp pycnocline at almost 25 m depth with lower layer waters originated from Aegean Sea (Ünlüata et al. 1990, Beşiktepe et al., 1994). General circulation in the SOM's upper layer is from İstanbul Strait to Dardanelles. Semi-permanent anti-cyclonic eddy is the main characteristics of the upper layer circulation. The upper layer flow exit from the İstanbul Strait enters to the Sea of Marmara in the form of a jet. This jet like flow is stronger in winter and spring due to increase of wind stress and sea level differences. The jet like flow determines the speed and range of the anti-cyclonic eddy. Under certain circumstances, this eddy reaches the southern coasts (Gerin et al., 2013, pls. see p. 926, figure 8a). There are four important bays in the east and south coasts of the sea. Upper layer water circulation of the bays in the south and east coasts of the Sea of Marmara is changed due to general circulation of the sea and local conditions. Upper layer flows through inside of the bays in spring and summer and in winter it reverses (Müftüoğlu, 2008).

Given the importance of the TSS, cradling Istanbul is the most densely populated and economically important region of Turkey, the system was subjected to several microplastic studies recently. Tunçer et al., (2018) provided that the surface water microplastic data is with an average of 1.263 item/m^3 abundance across the Sea of Marmara. The coasts of İstanbul was research subject for Erkan et al. (2021) who ranked the surface microplastic in discharge areas to be in third order following the pier and stream station in terms of abundance per unit area. Çullu et al. (2021) studied microplastics in the surface waters of the Küçükçekmece lagoon and the adjacent shorelines (İstanbul) and found that the shorelines had excessive amounts of microplastics. Vardar et al. (2021) examined an advanced wastewater treatment plant in İstanbul in detail and indicated that fibers were the major microplastic type in effluent. Tan (2022) suggested a preliminary risk assessment index for microplastics in the coasts of the Sea of Marmara.

The unique characteristics of the TSS has led us to search the instant status of microplastic abundance in particular locations. Thus, we conducted the study with the purposes of; i) understanding the levels of microplastic pollution in the bays that are exposed to different magnitudes of anthropogenic pressures, ii) comparison of the density of microplastics between surface waters and water column in the sampling sites, and iii) comparison the density of microplastics in northern entrance and southern exit boundaries of the TSS.

Materials and Methods

Study Area and Samplings

The present study was conducted in August 2016 in the bays of the TSS; İzmit, Gemlik, Bandırma, and Erdek Bays and the straits; north entrance of the Istanbul Strait (Bosphorus) and south exit of the Dardanelles (Çanakkale Strait) (Figure 1). Samplings were carried out via R/V Alemdar II during the cruise of Integrated Pollution Monitoring in Seas (T.C Ministry of Urbanization, Environment and Climate Change). The stations are part of the certain national pollution monitoring locations.

Surface water (SW) samples were collected by using 10 minutes of timed horizontal hauling with approximately 3 km/h, and the water column (WC) samples, as vertical hauling, from the depths of 10 m to the surface for WC to represent the upper layer. Samples for both SW and WC at each station were collected using a Nansen type plankton net with a 57 cm diameter and 333 µm mesh size. Samples were taken into glass sampling bottles that were washed with distilled water previously. Ethyl alcohol solution (96%) was added on the samples to have finally ~50% of alcohol-sea water solution. Then the bottles immediately were closed with its lid that was covered below with an aluminum sheet and stored in +4 °C until laboratory analyses.

Laboratory Studies (Collection, Morphological Identification and Size Measurements)

A sized of 26 µm of plankton mesh was used for final sieving in the laboratory. In order to eliminate the accumulated organic matter on the mesh, a 35% hydrogen peroxide solution was dripped on the samples, in amounts according to the organic matter density.

The samples were transferred to sterile petri dishes for identification of microplastics by using the Leica EZ4 stereomicroscope. Microplastic particles were classified into seven subgroups according to their morphological characteristics; fibers (FBR), foams (FM), fragments (FRG), sheets (SHT), microbeads (MB), pellets (PLL) (GESAMP, 2019), and paint particles (PNT). Paint particles as microplastics have been still issue of discussion. In this study, we distinguished them and further discussed the issue. Additionally, colors of the particles were identified in basic classes, such as black, white, blue, red, transparent, etc. Collected particles were transported to a pre-sterilized single-use GF/C filter containing petri dishes. Then, the size of the particles was measured under the Leica MZ125 stereomicroscope by using the Leica Application Suite (LAS) software program, where length was defined as the longest length of the particles. Lengths longer than 5 mm were excluded from this study, because these are too large to be characterized as microplastics. The smallest size used as a cutoff measure in this study was 0.3 mm (hauling mesh size) as the target minimum size. For graphical visualization and basic statistics the R 4.0.0 programming language (R Core Team, 2019) was used, and for mapping the Ocean Data View 4.5 software was used. Relative abundance is the percent composition of microplastic types (N), relative to the total number of microplastics were found in the study area. Microplastic abundance per unit volume (items/m^3) was calculated according to the volume of total filtered sea water; the height was 10 m for WC and the distance covered during hauling for SW when the diameter of the net were used for cylinder volume.

Non-parametric Kruskal-Wallis variance analysis was conducted in R to test if there is a statistically significant difference in microplastic sizes between SW and WC samples, also to test the size difference between stations.

Results

Microplastic Abundance and Type Distribution

Microplastic abundance per unit volume differed between SW and WC samples. For SW, the microplastic abundance ranged between 0.17 and 2.52 item/m^3 in SW samples Stations located in middle and outer Bandırma Bay, BB3 and BB2 had the highest values (2.52 and 1.72, respectively). İzmit Bay stations followed it as the second-highest microplastic amount per unit volume (Table 1). Gemlik and Erdek Bays had the lower contribution of SW microplastics.

WC microplastics had higher abundances of microplastics with values ranging from 4.12 items/m^3 (GB1) to 34.90 (BB2) items/m^3. Bandırma and İzmit Bays had the highest amounts (BB2, BB3, and IB1 with 34.90, 17.64, and 20.39 items/m^3, respectively). Erdek Bay also had a considerably high amount of microplastics ranging between 15.88 and 6.86 items/m^3.

Microplastic abundance per water volume was higher in the DS (0.39 item/m^3) than in the IS (0.17 item/m^3) in SW samples. We, however, recorded approximately twice the microplastic abundance in the

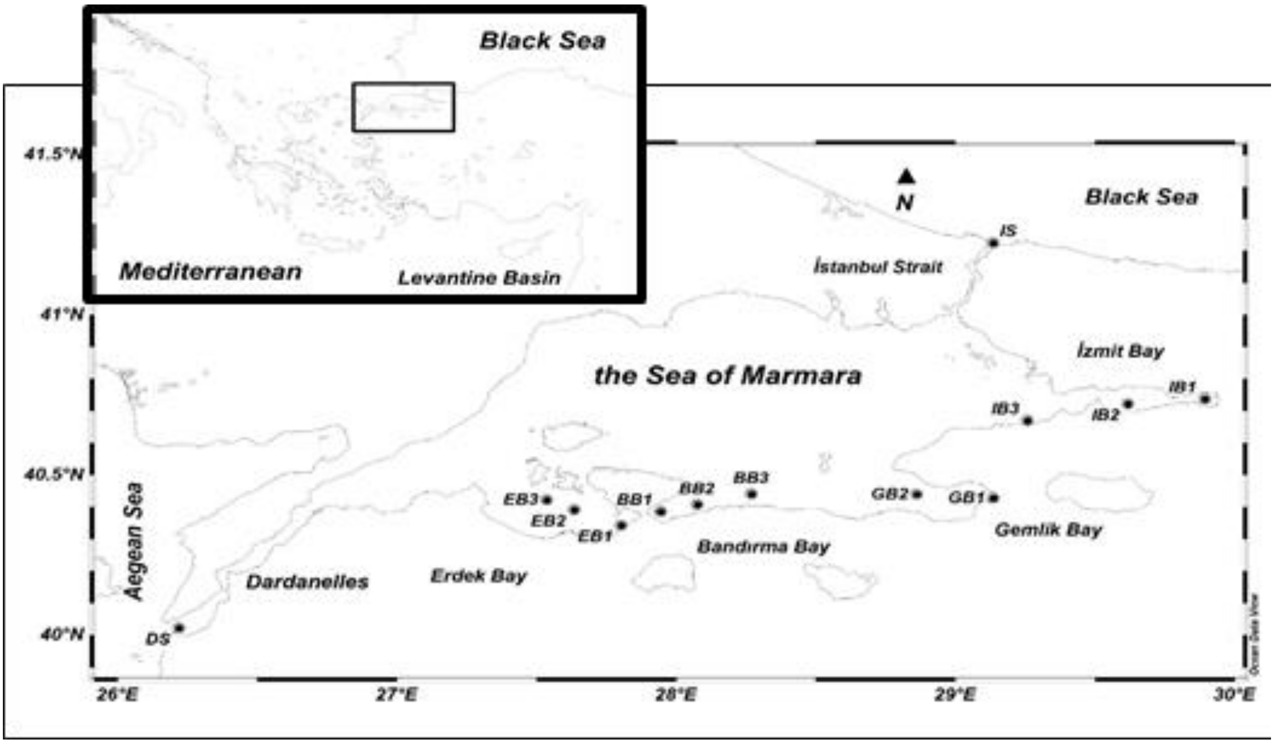

Figure 1. Study area and sampling stations in TSS.

IS (15.49 item /m^3) compared to DS (6.67 item /m^3) in WC samples (Table 1).

All seven types of microplastics were present in the study area (Figure 2 and 3). The ratios however differed in SW and WC samples. Regarding the SWs, from greatest to least ratios in percentages are as follows; 51.94% for fibers, 28.82% for fragments, 13.18% for paint particles, 3.60% for sheets, 2.14% for foams, 0.18% for pellets, 0.14% for microbeads. Microbeads and pellets were absent in WC samples. The ratios of the fibers, fragments, paint particles, foams, and sheets in percentages are; 79.28%, 6.29%, 9.78%, 1.16%, and 3.49%, respectively in WC samples (Figure 4).

The proportional concentration of fibers was higher in WC samples (between 100% and 59.49%) than in SW samples (between 70.59% and 19.75%) (Table 1 and Figure 4). Fragments in SW had the higher proportions (54.25% and 8.93%) in SW than in WC, except for the stations IS and EB2 (Table 1). There was no such pattern for the paint particles, sheets, and foams. The paint particles had 12% contribution to the total 3052 microplastics. Microbeads and pellets existed only in surface water samples by comprising only 0.23% of total 3052 microplastics.

Size Distribution

Altogether 3052 microplastics were measured. The average length of microplastics found in SW samples was 1.55 mm. At station base, the average length ranged between 1.00 ±0.63 and 2.06±0.93 mm (Table 1). The average length of the WC samples was 1.21±0.85 mm and again at station base, it ranged between 0.81±0.6 and 2.06±0.93 mm (Table 1). The Kruskal-Wallis test result using a 95% confidence interval showed that there was a significant difference in microplastic sizes

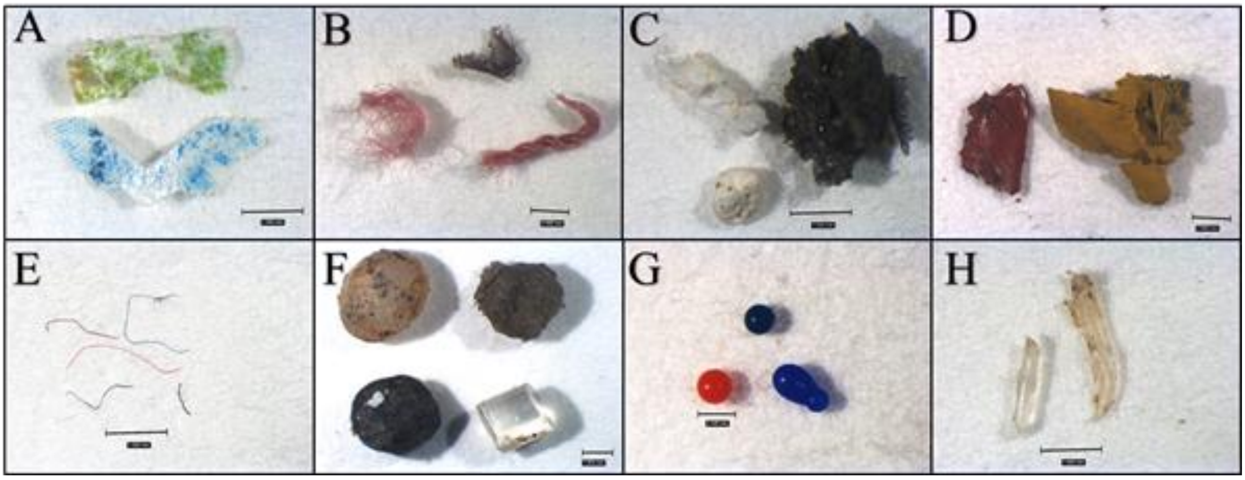

Figure 2. Microplastic type classification; A) sheets (SHT), B) fragments (FRG), C) foams (FM), D) paint particles (PNT), E) fibers (FBR), F) pellets (PLL), G) microbeads (MB), H) fragments (FBR). Scales are 1 mm.

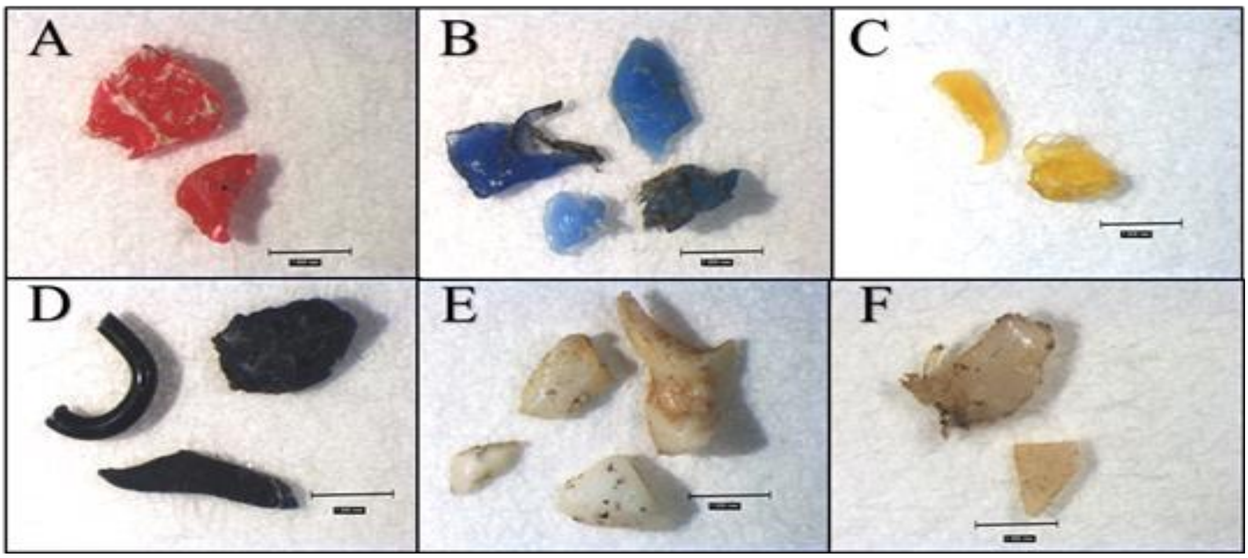

Figure 3. Fragments presented according to main color classification: A) red; B) blue; C) yellow; D) black; E) white; and F) transparent. Scales are 1 mm.

Table 1. Sampling area, stations, matrices (SW: surface water, WC: water column), total number of microplastic analyzed, microplastic abundance (items/m³), percentage of microplastic types, length of microplastics (mm, Mean, SD: standard deviation, Median: Med., minimum: min, maximum: max.)

					Type [abundance %]							Length [mm]				
Area	Station	Matrix	Items/m³	Tot.	FBR	FRG	PNT	FM	SHT	MB	PLL	Mean	SD	Med.	Min.	Max.
Istanbul Strait	IS	SW	0.17	42	57.14	7.14	26.19	2.38	7.14	-	-	1.22	0.93	0.86	0.3	4.33
		WC	15.49	79	59.49	16.46	3.80	7.59	12.66	-	-	1	0.63	0.85	0.3	3.54
Dardanelles	DS	SW	0.39	91	30.77	41.76	23.08	-	4.40	-	-	1.46	0.97	1.26	0.34	4.55
		WC	6.67	34	70.59	2.94	5.88	-	20.59	-	-	1.17	0.6	1.12	0.43	3.11
İzmit Bay	IB1	SW	0.92	218	40.83	39.45	16.06	-	3.67	-	-	1.45	0.96	1.28	0.31	4.86
		WC	20.39	104	76.92	8.65	14.42	-	-	-	-	1.19	0.87	0.91	0.3	4.64
	IB2	SW	0.9	212	38.68	54.25	4.25	0.47	2.36	-	-	2.06	0.93	2.01	0.35	5
		WC	8.82	45	86.67	2.22	11.11	-	-	-	-	1.37	1.02	1.19	0.32	4.99
	IB3	SW	0.47	112	62.50	15.18	19.64	-	2.68	-	-	1.47	0.99	1.17	0.3	4.74
		WC	5.88	30	83.33	-	13.33	-	3.33	-	-	1.1	0.7	0.83	0.31	2.78
Bandırma Bay	BB1	SW	0.66	155	34.19	30.97	28.39	-	6.45	-	-	1.6	1.23	1.12	0.34	4.96
		WC	10.78	55	78.18	16.36	3.64	1.82	-	-	-	1.32	0.77	1.14	0.33	3.15
	BB2	SW	1.27	299	70.57	15.38	11.71	0.67	1.67	-	-	1.26	0.8	1.04	0.3	4.61
		WC	34.9	178	97.19	2.81	-	-	-	-	-	1.37	0.88	1.15	0.3	4.61
	BB3	SW	2.52	595	68.24	20.34	2.18	4.71	3.70	0.50	0.34	1.76	0.95	1.53	0.32	4.98
		WC	17.64	90	81.11	6.67	8.89	2.22	1.11	-	-	1.18	0.71	1.01	0.3	3.56
Gemlik Bay	GB1	SW	0.39	93	53.76	37.63	4.30	2.15	2.15	-	-	1.25	0.94	0.88	0.3	4.21
		WC	4.12	21	100.00	-	-	-	-	-	-	0.93	0.73	0.58	0.3	2.89
	GB2	SW	0.66	157	19.75	52.87	11.46	8.28	6.37	-	1.27	1.53	0.94	1.33	0.31	4.75
		WC	9.02	46	71.74	-	19.57	2.17	6.52	-	-	1.21	0.85	0.99	0.35	3.92
Erdek Bay	EB1	SW	0.24	56	48.21	8.93	35.71	-	7.14	-	-	1.43	1.05	1.14	0.33	4.57
		WC	15.88	81	75.31	1.23	16.05	-	7.41	-	-	1.41	1.15	0.89	0.3	4.9
	EB2	SW	0.36	86	38.37	18.60	39.53	-	3.49	-	-	1	0.67	0.85	0.35	3.44
		WC	6.86	35	60.00	22.86	11.43	-	5.71	-	-	1.12	0.86	0.81	0.3	3.84
	EB3	SW	0.33	77	45.45	24.68	29.87	-	-	-	-	1.12	0.84	0.81	0.31	4.55
		WC	11.96	61	67.21	1.64	31.15	-	-	-	-	0.81	0.66	0.7	0.3	4.78

between SW samples of the stations (P<0.01), and we did not observe a certain pattern yet. Also for the WC, we did not find statistically significant test results between stations (P>0.05). When we consider every single microplastic sample found and collected from both matrixes, particles between 0.3 and 2 mm were found to have a ratio of 76.80 % (Figure 5).

In terms of the size distribution of microplastic types, the WC microplastics had lower size variation than SW samples, with most samples being < 2 mm. Regarding the SW samples, fragments, sheets and foams had a wider range of length distribution, however, median values were still < 2 mm (Figure 6). Notable results of this box-plot data visualization are that in the SW matrix, sheet components had the longest length class, and paint materials had generally shorter sizes in both matrixes. In addition, foams in WC were shorter and had a lower range of length values than the SW samples (Figure 6).

According to the Kruskal-Wallis non-parametric test, no significant difference was found between matrixes (P>0.05).

Colors of Microplastics

Black and blue were the dominant colors for both matrixes when we consider all the stations, 38% of the microplastics in SW samples is black and 17.7% of them is blue. Similarly, the proportions of black and blue in WC samples were 46% and 22.8%, respectively (Figure 7). White was the third most abundant color for SW with a ratio of 10.3%, however, it was in sixth place with a ratio of 3.0 % in WC samples. Proportions of the classified colors are demonstrated in Figure 7.

Discussion

Plastics enter the marine environment mainly from highly urbanized land use (Derraik, 2002; Jambeck et al., 2015). Wastewater treatments (Murphy et al., 2016; Baucher and Friot, 2017; Vardar et al., 2021) and rivers (Schimidt et al., 2018; Simon-Sanchez et al., 2019) are thought as key transport sources of microplastic loads to the marine environment. Additionally, microplastic concentrations is higher in more polluted rivers, according to Katoka (2019). Mansui et al. (2015) correlated the distribution of microplastics to anthropogenic sources (harbors, population in coastal areas, riverine inputs, maritime activities, and tourism).

Altogether 3052 items were collected (size range between 0.3 mm- 5.0 mm) from both the SW and WC samples in the TSS. Our results revealed that fibers were the most abundant microplastics types (59.63 %) followed by fragments (22.48%). Aytan et al. (2016) found that fibers comprises 49% of all microplastics in the Black Sea, while Güven et al. (2017) reported that fibers and hard plastics were the most abundant microplastic types found in both water samples and fish samples. The percentage of fibers contributed about 70% to the microplastic composition along the Turkish

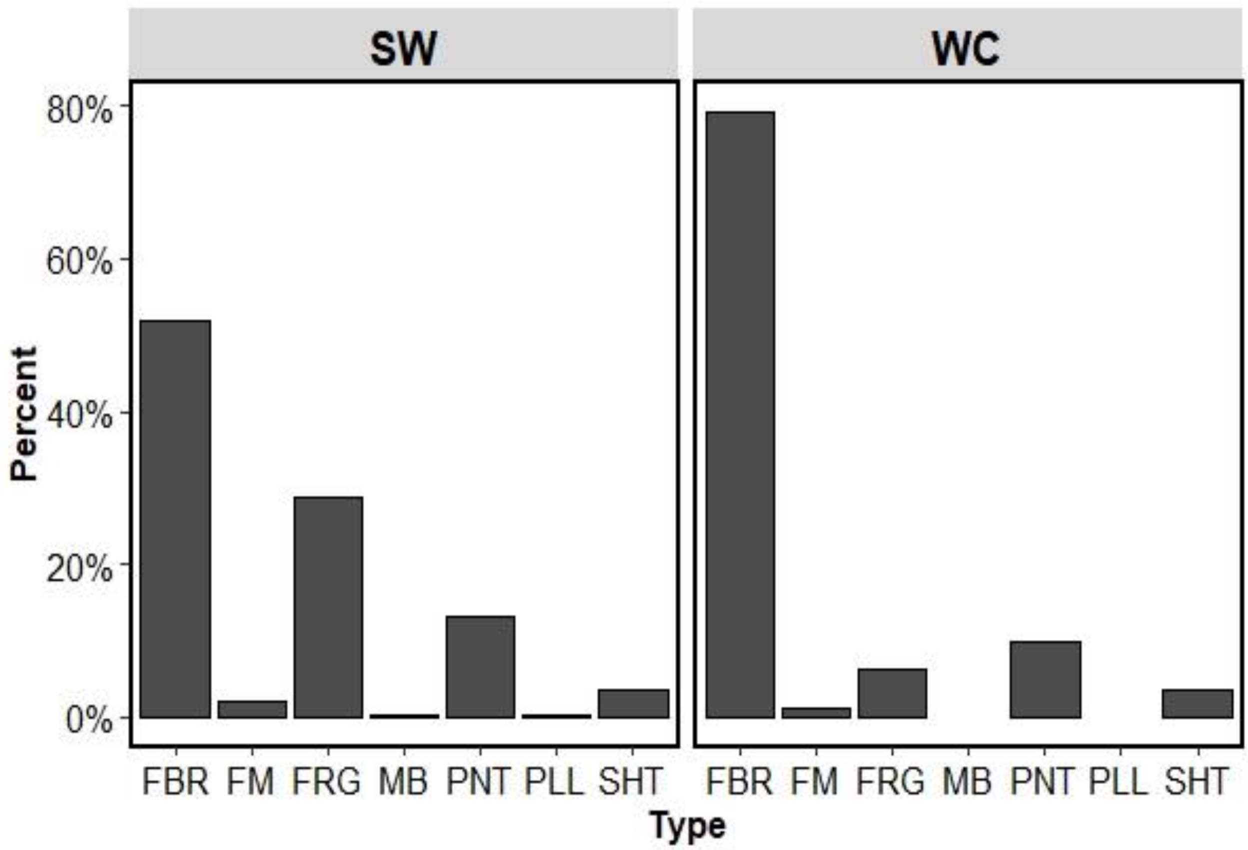

Figure 4. Type distribution of microplastics among matrixes according to SW: surface water and WC: water column.

Mediterranean coasts (Güven et al., 2018), slightly higher than our findings. Fibers and fragments constituted respectively 31.92% and 33.23% of the microplastics found on the north coast of İstanbul (Çullu et al., 2021). Contrary, Erkan et al. (2021) reported that the fragments were rationally high in all stations when filaments increased the abundance in the areas closer to discharges. Tunçer et al. (2018) observed the amorphous particles as the most abundant type in the Sea of Marmara.

The primary source of synthetic fibers is domestic washing (Brown et al., 2008; Sundt et al., 2014). Vardar et al. (2021) studied an advanced wastewater treatment plant in İstanbul and reported that above 94% of the microplastics discharged to the marine environment was fibers. As this region hosts the highest population in the country (over 23,000,000 TUIK, 2022), an extremely high amount of domestic washing and its waste are discharged into the Sea of Marmara's ecosystem, and this high load percentage is indeed worrisome for both the environment and the biota. These results support the high score of fibers in our study area. Although Bangaev et al. (2017) challenged the concentrations of fibers based on the current methodologies, they acknowledged that fibers were extensive in the marine environment. In addition to this, we found fibers to have more frequency in water column (WC) samples. According to Bangaev et al. (2017), fibers sink in time because of their polymer densities, bio-fouling, and the mass of the suspended matter around them, and

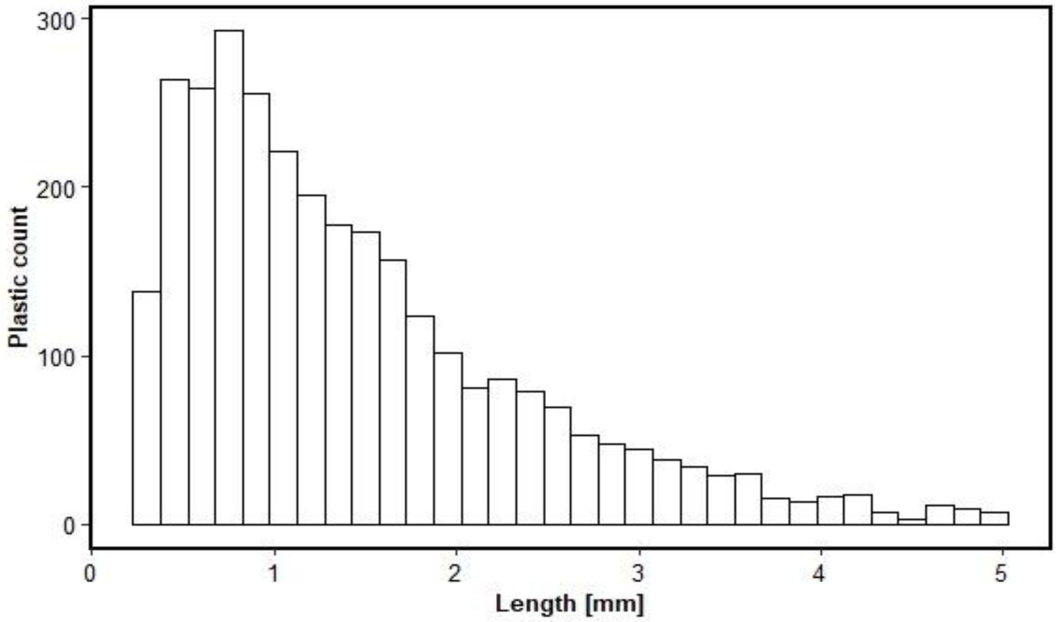

Figure 5. Size distribution of microplastics in the TSS.

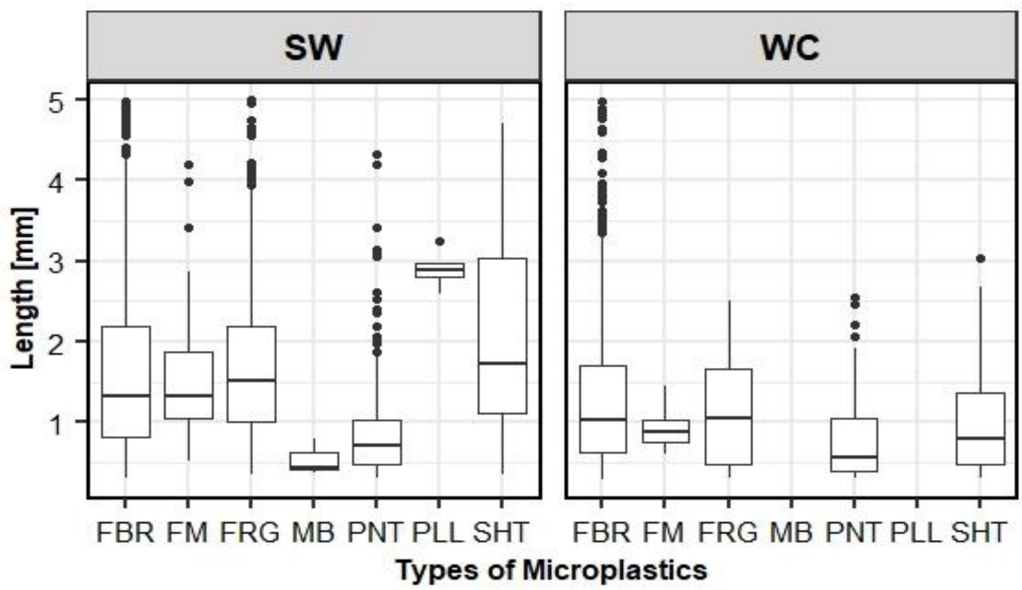

Figure 6. Size distribution of microplastic types in surface water (SW) and water column (WC).

afterward, they can re-accumulate on the surface by water turbulent. The higher concentrations of fibers in WC samples may be derived from this sinking mechanism.

Our results showed that the microplastic abundance in the WC (4.12-34.90 items/m3) was much higher than the microplastic abundance in SW (0.17-2.52 items/ m3) in the strait junctions and bays of the TSS in August 2016. In our case, 10 m was the maximum limit for collecting the water column samples representing the upper layer, to have consistency and comparability between stations. Baini et al. (2018) reported the concentration of microplastics in the water column in Tuscany (Italy) with an average of 0.26 items/m3 that is lesser than our abundance range. Microplastic abundance in the WC was between 0.014 and 12.5 items/m3 in the East Asian seas, according to the review by Hidalgo-Ruz et al. (2012). Fibers in our WC samples had almost 80% of total microplastics and this distribution of abundance may be linked to the sinking characteristics of fibers. Nevertheless, sinking of the plastic particles is a very complex mechanism and based on the polymer type, biofouling, and catches of suspended matter (Chubarenko et al., 2016; Kaiser et al., 2017; Bangaev et al., 2017) and their transportation to the sub-surface due to mixing of the upper layer by wind-driven circulations (Zhang, 2017).

Primary microplastics (microbeads and pellets) contributed minimal (0. 23%) to the total. The only station they were presented simultaneously was the outer part of the Bandırma Bay (Table 1, pls. see BB3) close to the Susurluk River mouth. Primary microplastics, such as microbeads, are generally sourced from personal care/cleaning products (PCCPs) (Wang et al., 2019); thus, they contribute the microplastic pollution via wastewaters (Murphy et al., 2016). Baucher and Friot (2017) summarized the abundance of primary microplastics is been "equivalent to" or "outweigh" the secondary sources from "mismanaged wastes," and they also include fibers in primary sources. When we consider PCCPs, their original sizes entering the aquatic systems are considerably small (Wang et al., 2019). Due to their original shapes, when they are not spherical, it was stated that distinguishing the microbeads is challenging (Isobe, 2016). Murphy et al. (2016) reported that no microbeads in the wastewater treatment are plant's effluent; therefore, they suggested that microbeads resulting from washing might not be a "major issue for the receiving environments" even when the treatment plant was efficient. Microbeads alone are not the only microplastics in PCCPs that can have glitters widely, and the products can generally be used as rinse-off materials (Anagnosti et al., 2021). Once again, regular-shaped microplastics or microbeads were not mentioned as issues in the effluent of an advanced wastewater treatment plant in İstanbul when the effluent carried fibers extensively in a ratio over 92% (Vardar et al., 2021). Even in the highest abundance, primary microplastics (microbeads and industrial pellets) contributed to Istanbul's microplastic pollution at level of 3.93% at locations that interacted with physically treated discharges (Erkan et al., 2021). Nevertheless, in the light of the knowledge that the only station including

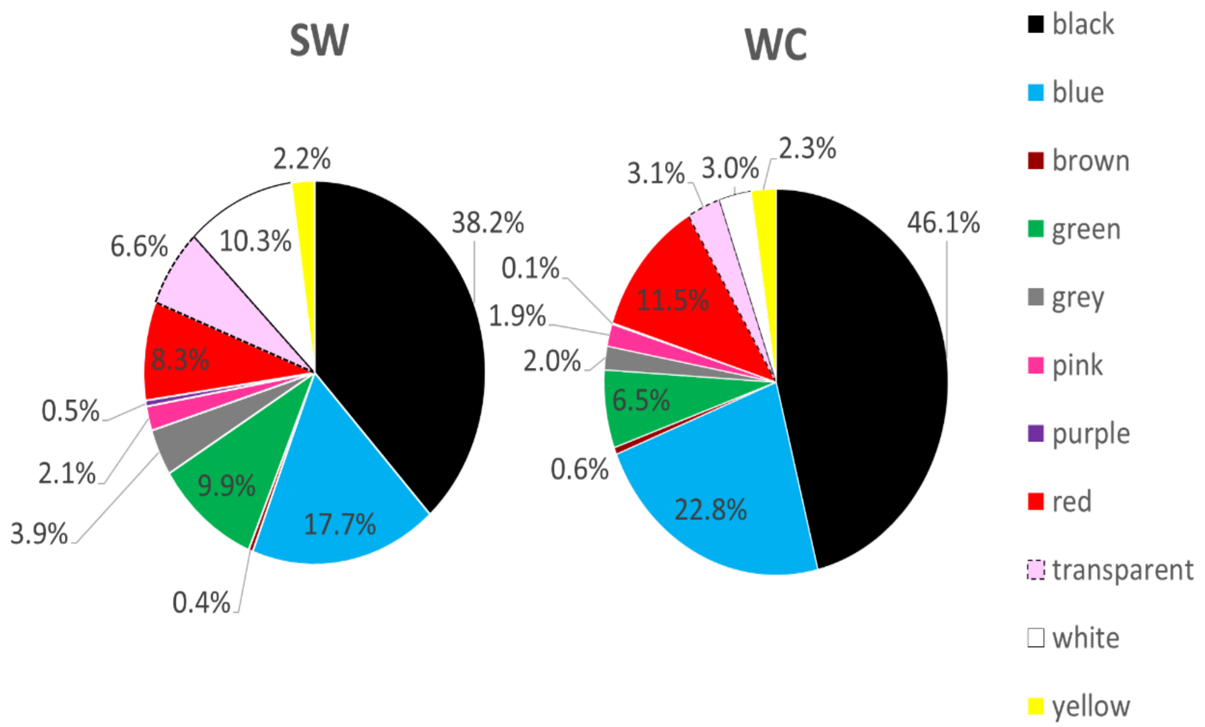

Figure 7. The proportion of microplastics according to color compared between the two matrixes- SW surface water and WC Water Column.

microbeads was the outer of Bandırma Bay, we may alternatively consider the effects of physically treated discharges into the Susurluk river basin since the river carries discharges form a highly urbanized and industrialized area (MAR-AAT, 2021). The sampling site is affected by the inflow of the river under certain currents (Gerin et al., 2013).

Paint particles constitute 12% of total microplastics and this ratio has high importance since they are the third most abundant microplastic type. Wang et al. (2019) considered the paint material is primary microplastics and listed the sources as architectural coating, marine coating, and vehicle paint. Gaylerde et al. (2021) also highlighted the importance of including paint particles into microplastics. We found the collected paint particles in the form of paint chips and three-dimensional single-colored particles to be very brittle that particles could break easily if they were not handled delicately. Turner (2021) explained their brittleness due to their chemical proportion as having more additives than polymers and opposed the idea of their being identified as microplastics. Some of the co-polymers in non-aqueous and water-based acrylic paints are polyesters, polyurethanes, polyacrylates, and polystyrenes (Zhou, 2015; Gaylerde et al., 2021), and three of those four polymers are common types of marine microplastics (Smith et al., 2018). As Horton et al. (2017) notified that there is no threshold of polymer content between a pigmented polymer and polymer-containing paint. There is one common idea that simplifies the significance of identifying the paint particles as either microplastics or micro litter is that the paints are heavily laden with chemicals and, even in small concentrations, can have adverse effects on the environment and food chain; therefore, they must be distinguished (Turner, 2021; Gaylerde et al., 2021). We acknowledged the paint particles as microplastics and treated them accordingly. The size distribution of these is very short and narrow (Figure box-plot) (~75% of paint particles ≤ 1 mm). We suggest that this size distribution is a result of their brittleness. The studies by Imhof et al. (2016) and Song et al. (2014) support the outcome of higher abundances in smaller size classes. We expected to find the paint particles to have higher concentrations at the locations that have higher port/maritime activities; instead, we observed that they frequently and considerably existed throughout the sampling sites. Therefore, we suggest that the paint particles should be recognized in extensively urbanized coastal areas.

The size distribution of all microplastic particles found in the area presents an almost exponential distribution with more abundancy (76.80 %) in sizes 0.30-2.00 mm, consistent with Shimidt et al. (2018). On the contrary, Cózar et al. (2014) presented a different size distribution in the open ocean surface, a peak around 2 mm and a gradual decrease in the frequency towards 0.2 mm. Our mean lengths differed between 1.00-2.06 mm and 0.81-1.41 mm for SW and WC samples, respectively. Güven et al. (2017) stated that the collected particles frequently ranged between 0.1 and 2.5 mm in the Mediterranean coasts of Turkey, which are similar to our findings. The size-frequency differed in the Adriatic Sea, Zeri et al. (2018) found that 64% of the microplastics was in the size range of 1.00 - ≤ 5.00 mm. Moreover, La Daana et al. (2018) detected a very similar result in the Arctic central basin that the 1.0 –5.0 mm class has a 64 % ratio. Tunçer et al. (2018) reported a range in sizes between 0.8 and 65 mm, with a mean size as 6.159 ± 8.39 mm in the Sea of Marmara. Since the definition of microplastics is for particles <5 mm, we could not compare our results with their findings. In return, the research conducted in İstanbul highlighted that the surface waters of the sampling sites had microplastics in sizes within the 1-5 mm size range with a majority (Erkan et al., 2021). The frequency of the microplastics between 1.0 and 5.0 mm was 59.34% in our study. These results seem to have compliancy. There is an essential contribution to the size spectrum for literature stated by Pedrotti et al. (2016) that the small-sized microplastics were more abundant around the coastline; however, we did not identify such a pattern. Nevertheless, larger particle averages were detected in more polluted areas such as İzmit and Bandırma Bays which supports the findings of Isobe et al. (2015) and Schimidt et al. (2018), which suggested that the larger size frequencies remain close to pollution sources. Fragmentation of plastics is due to many natural and manufactural causes, and size-frequency could be significantly relevant with the fractal process (Cózar et al., 2014; Alimi et al., 2018; Julienne et al., 2019; Mateos-Cárdenas et al., 2020). These discrepancies in size distribution may be linked to the cut-off sizes, the sampling and collecting tools, and even the sampling sites and periods.

In SW samples, the highest amounts of microplastics were found in the outer and mouth of Bandırma Bay and from the inner and middle parts of İzmit Bay. In WC samples, the highest values were found in the mouth of Bandırma Bay, inner İzmit Bay, outer Bandırma Bay, and inner Erdek Bay, respectively. Tan et al. (2022) suggested that the İzmit (inner) and Bandırma (inner) Bays had highest microplastic index (MPI) values according to preliminary risk assessment study. İzmit Bay was well defined as a "receiving body for most of the region's treated and untreated domestic-industrial wastewaters" (Tolun et al., 2012). Riverine and channel inflows, particularly Dil Stream, mainly from the bay's northern coasts, carry pollutants and industrial discharges (Tolun et al., 2012; Pekey, 2006). When we attempt to explain the high concentrations around Bandırma Bay, we find that similar effectual occasions exist in the bay regarding anthropogenic pressures. Moreover, the Susurluk River is accepted as a nonpoint source of contaminants and nutrients for the southern coasts of the sea (Tan et al., 2017). As the river is the largest freshwater basin for the Sea of Marmara, many industrial and domestic land use and their discharges (by carrying 29.7% of the discharges) (MAR-AAT) are also present around it (Sarı, 2008; Küçükali, 2013; Tan et al., 2017). Considering the relatively high microplastic concentrations in Erdek Bay, particularly in the inner part, the population and industrialization are not as dense as former bays. Agricultural and fishing activities and tourism in summer are some of the human actives that affect the bay's ecosystem (Mülayim et al., 2012). However, two primary freshwater inflows, Gönen and Karabiga Rivers, carry municipal waste into the bay (Balkıs & Çağatay, 2001) and are also considered as affecting factors (Tan et al., 2017). Gemlik Bay, on the other hand, has the lowest abundance value in WC in the inner part, yet, the outer part still contained a notable amount of microplastic litter. Gemlik Bay is not rich in freshwater sources, yet the Karsak Creek is the short runnel assumed as the most crucial pollution source (Ünlü and Alpar, 2006). However, the creek is not as large and heavily urbanized/industrialized as former rivers, though industrial wastewaters are pollution sources for the creek (Solmaz, 2000). The mainly northern coast of the bay is a hotspot for tourism (Ünlü and Alpar, 2006), and agricultural activities around the bay are widespread.

A notable finding of this study is that microplastics in the SW of the bays were more abundant than in the straits. In the WC samples, however, the entrance of the Black Sea (IB) in the İstanbul Strait had more than two-fold the microplastics than that of the Dardanelles exit, and the abundance in the Strait of İstanbul (IS) is considerable. These two location were selected to sustain us a comparison between north entrance and the south exit of the TSS, since the surface water flows from Black Sea to Aegean Sea (Beşiktepe et al., 1994). In light of our preliminary results that suggested discrepancy in microplastic abundance, it is a priority to better estimate the most systematic data on the microplastic content of the waters entering and exiting through the TSS.

Conclusion

We sampled microplastics in surface water and water column at 13 station in the TSS in august 2016. The bays had considerable amount of microplastics in the areas where point and nonpoint sources are subjects of pollutants and pressures. Fibers, fragments and paint particles were the most three abundant microplastic types, respectively within the sampling area. In all stations, water column had higher microplastic abundance. The north entrance of the TSS had higher microplastic abundance than that of south exit in water column samples. 76.80% of total microplastics was in sizes between 0.3 and 2 mm.

The Sea of Marmara, similar to other coastal seas under anthropogenic influence, has had its share of microplastic pollution, which should be recognized in long-term monitoring plans. Our study emphasizes that the sensitivity of the TSS on plastic pollution is very important due to its unique hydrographic structure. Although it is not about identifying the certain pollution sources, this study may facilitate us to understand the potential microplastic distribution and the abundance capacities of the Turkish Straits System.

Ethical Statement

Not applicable.

Funding Information

This study was funded by the Scientific and Technological Research Council of Turkey (TUBITAK); project number 117Y270 reported in 2019, and the field studies were conducted during the project “Integrated Marine Pollution Monitoring Program” of Ministry of Environment and Urbanization in 2016.

Author Contribution

Yaprak Gürkan and Ahsen Yüksek conducted the fieldwork. Yaprak Gürkan accomplished the laboratory studies. Yaprak Gürkan and Ahsen Yüksek designed the structure of the manuscript and analyzed the data. Yaprak Gürkan and Ahsen Yüksek wrote the manuscript.

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal-conflicts that could have appeared to influence.

Acknowledgements

The authors would like to thank Dalida Bedikoğlu, Sefa Marangoz, and Esma Gölbaşı for their valuable help during laboratory studies. And finally, the authors wish to thank Dr. Olgaç Güven for his being an extreme teacher about the topic.

References

Albayrak, S., Caglar, S., Mulayim, A., Kurt-Sahin, G., Balkis, H., Cinar, N. F., Atabay, H., Tutak, B., Bahceci, H. (2019). A case study: ecological quality status of Susurluk river basin (Marmara Sea). *Fresenius Environmental Bulletin*, 28(2), 769-776.

Alimi, O. S., Farner Budarz, J., Hernandez, L. M., & Tufenkji, N. (2018). Microplastics and nanoplastics in aquatic environments: aggregation, deposition, and enhanced contaminant transport. *Environmental science & technology,* 52(4), 1704-1724. https://doi.org/10.1021/acs.est.7b05559

Anagnosti, L., Varvaresou, A., Pavlou, P., Protopapa, E., & Carayanni, V. (2021). Worldwide actions against plastic pollution from microbeads and microplastics in cosmetics focusing on European policies. Has the issue been handled effectively? *Marine Pollution Bulletin*, 162, 111883. https://doi.org/10.1016/j.marpolbul.2020.111883

Andrady, A. L. (2011). Microplastics in the marine environment. *Marine pollution bulletin*, 62(8), 1596-1605. https://doi.org/10.1016/j.marpolbul.2011.05.030

Arthur, C., Baker, J.E., & Bamford, H.A. (2009). *Proceedings of the International Research Workshop on the Occurrence, Effects, and Fate of Microplastic Marine Debris*. National Oceanic and Atmospheric Administration (NOAA) Technical Memorandum, NOS-OR&R 30.

Aytan, U., Valente, A., Senturk, Y., Usta, R., Sahin, F. B. E., Mazlum, R. E., & Agirbas, E, (2016). First evaluation of neustonic microplastics in Black Sea waters. *Marine environmental research*, 119, 22-30. https://doi.org/10.1016/j.marenvres.2016.05.009

Aytan, U., Esensoy, F. B., Senturk, Y., Arifoğlu, E., Karaoğlu, K., Ceylan, Y. & Valente, A., 2022. Plastic occurrence in commercial fish species of the Black Sea. *Turkish Journal of Fisheries & Aquatic Sciences,* 22(SI), TRJFAS20504, http://doi.org/10.4194/TRJFAS20504

Bagaev, A., Mizyuk, A., Khatmullina, L., Isachenko, I., & Chubarenko, I. (2017). Anthropogenic fibres in the Baltic Sea water column: Field data, laboratory and numerical testing of their motion. *Science of The Total Environment*, 599, 560-571. https://doi.org/10.1016/j.scitotenv.2017.04.185

Baini, M., Fossi, M. C., Galli, M., Caliani, I., Campani, T., Finoia, M. G., & Panti, C. (2018). Abundance and characterization of microplastics in the coastal waters of Tuscany (Italy): the application of the MSFD monitoring protocol in the Mediterranean Sea. *Marine Pollution Bulletin*, 133, 543-552. https://doi.org/10.1016/j.marpolbul.2018.06.016

Balkıs, N., & Çağatay, M. N. (2001). Factors controlling metal distributions in the surface sediments of the Erdek Bay, Sea of Marmara, Turkey. *Environment international*, 27(1), 1-13. https://doi.org/10.1016/S0160-4120(01)00044-7

Barnes, D. K., Galgani, F., Thompson, R. C., & Barlaz, M. (2009). Accumulation and fragmentation of plastic debris in global environments. *Philosophical transactions of the royal society B: biological sciences*, 364(1526), 1985-1998. https://doi.org/10.1098/rstb.2008.0205

Beşiktepe, Ş. T., Sur, H. İ., Özsoy, E., Latif, M. A., Oğuz, T., & Ünlüata, Ü. (1994). The circulation and hydrography of the Marmara Sea. *Progress in Oceanography*, 34(4), 285-334. https://doi.org/10.1016/0079-6611(94)90018-3

Boerger, C. M., Lattin, G. L., Moore, S. L., & Moore, C. J. (2010). Plastic ingestion by planktivorous fishes in the North Pacific Central Gyre. *Marine pollution bulletin*, 60(12), 2275-2278. https://doi.org/10.1016/j.marpolbul.2010.08.007

Boucher, J., & Friot, D. (2017). Primary microplastics in the oceans: a global evaluation of sources (Vol. 43). Gland, Switzerland: Iucn. ISBN: 978-2-8317-1827-9 https://doi.org/10.2305/IUCN.CH.2017.01.en

Chubarenko, I., Bagaev, A., Zobkov, M., & Esiukova, E. (2016). On some physical and dynamical properties of microplastic particles in marine environment. *Marine Pollution Bulletin*,*108*(1-2), 105-112. https://doi.org/10.1016/j.marpolbul.2016.04.048

Cole, M., Lindeque, P., Halsband, C., & Galloway, T. S. (2011). Microplastics as contaminants in the marine environment: a review. *Marine pollution bulletin*, 62(12), 2588-2597. https://doi.org/10.1016/j.marpolbul.2011.09.025

Collignon, A., Hecq, J. H., Glagani, F., Voisin, P., Collard, F., & Goffart, A. (2012). Neustonic microplastic and zooplankton in the North Western Mediterranean Sea. *Marine pollution bulletin*, 64(4), 861-864. https://doi.org/10.1016/j.marpolbul.2012.01.011

Cózar, A., Echevarría, F., González-Gordillo, J. I., Irigoien, X., Úbeda, B., Hernández-León, S., Palma, Á. T., Navarro, S., García-de-Lomas, J., Ruiz, A., Fernández-de-Puelles, M. L., Duarte, C. M. (2014). Plastic debris in the open ocean. *Proceedings of The National Academy of Sciences*, 111(28), 10239-10244. https://doi.org/10.1073/pnas.1314705111

Çullu, A. F., Sönmez, V. Z., & Sivri, N. (2021). Microplastic contamination in surface waters of the Küçükçekmece Lagoon, Marmara Sea (Turkey): Sources and areal distribution. *Environmental Pollution*, 268, 115801. https://doi.org/10.1016/j.envpol.2020.115801

de Lucia, G. A., Caliani, I., Marra, S., Camedda, A., Coppa, S., Alcaro, L., Campani, T., Gianetti, M., Coppola, D., Cicero, A.M., Panti, C., Baini, M., Guerranti, C., Marsili, L., Massaro, G., Fossi, M.C., & Matiddi, M. (2014). Amount and distribution of neustonic micro-plastic off the western Sardinian coast (Central-Western Mediterranean Sea). *Marine Environmental Research*, 100, 10-16. https://doi.org/10.1016/j.marenvres.2014.03.017

Derraik, J. G. (2002). The pollution of the marine environment by plastic debris: a review. *Marine pollution bulletin*, 44(9), 842-852. https://doi.org/10.1016/S0025-326X(02)00220-5

Erkan, H. S., Turan, N. B., Albay, M., & Engin, G. O. (2021). A preliminary study on the distribution and morphology of microplastics in the coastal areas of Istanbul, the metropolitan city of Turkey: The effect of location differences. *Journal of Cleaner Production*, 307, 127320. https://doi.org/10.1016/j.jclepro.2021.127320

Galgani, F., Brien, A. S. O., Weis, J., Ioakeimidis, C., Schuyler, Q., Makarenko, I., Griffiths, H., Bondareff, J., Vethaak, D., Deidun, A., Sobral, P., Topouzelis, K., Vlahos, P., Lana, F., Hassellov, M., Gerigny, O., Arsonina, B., Ambulkar, A., Azzaro, M., & Bebianno, M. J. (2021). Are litter, plastic and microplastic quantities increasing in the ocean? *Microplastics and Nanoplastics*, 1(1), 1-4. https://doi.org/10.1186/s43591-020-00002-8.

Galloway, T. S., Cole, M., & Lewis, C. (2017). Interactions of microplastic debris throughout the marine ecosystem. *Nature ecology & evolution*, *1*(5), 1-8. https://doi.org/10.1038/s41559-017-0116

Gaylarde, C. C., Neto, J. A. B., & da Fonseca, E. M. (2021). Paint fragments as polluting microplastics: A brief review. *Marine Pollution Bulletin*, 162, 111847. https://doi.org/10.1016/j.marpolbul.2020.111847

Gerin, R., Poulain, P. M., Beşiktepe, Ş. T., & Zanasca, P. (2013). On the surface circulation of the Marmara Sea as deduced from drifters. *Turkish Journal of Earth Sciences*, 22(6), 919-930.

GESAMP. (2019). Guidelines for the monitoring and assessment of plastic litter in the ocean (Kershaw, P.J., Turra, A. & Galgani, F. Eds.), (IMO/FAO/UNESCOIOC/UNIDO/WMO/IAEA/UN/UNEP/ UNDP/ISA Joint Group of Experts on the Scientific Aspects of Marine Environmental Prote. Rep. Stud. GESAMP, no 99, 130p.

http://www.gesamp.org/publications/guidelines-forthe-monitoring-and-assessment-of-plastic-litter-in-theocean

Güven, O., Gökdağ, K., Jovanović, B., & Kıdeyş, A. E. (2017). Microplastic litter composition of the Turkish territorial waters of the Mediterranean Sea, and its occurrence in the gastrointestinal tract of fish. *Environmental Pollution*, 223, 286-294. https://doi.org/10.1016/j.envpol.2017.01.025

Güven, O., 2022. Spatio-temporal distribution and characterization of microplastic pollution in the three main freshwater systems (Aksu and Köprü Streams, Manavgat River) and fishing grounds located in their vicinities in the Antalya bay. *Turkish Journal of Fisheries & Aquatic Sciences*, 22(SI), TRJFAS20507,), http://doi.org/10.4194/TRJFAS20507

Hardesty, B. D., Harari, J., Isobe, A., Lebreton, L., Maximenko, N., Potemra, J., van Sebille, E., Vethaak, A.D., & Wilcox, C. (2017). Using numerical model simulations to improve the understanding of micro-plastic distribution and pathways in the marine environment. *Frontiers in marine science*, 4, 30. https://doi.org/10.3389/fmars.2017.00030

Hidalgo-Ruz, V., Gutow, L., Thompson, R. C., & Thiel, M. (2012). Microplastics in the marine environment: a review of the methods used for identification and quantification. *Environmental science & technology*, 46(6), 3060-3075. https://doi.org/10.1021/es2031505

Horton, A. A., Walton, A., Spurgeon, D. J., Lahive, E., & Svendsen, C. (2017). Microplastics in freshwater and terrestrial environments: evaluating the current understanding to identify the knowledge gaps and future research priorities. *Science of The Total Environment*, 586, 127-141. https://doi.org/10.1016/j.scitotenv.2017.01.190

Imhof, H. K., Laforsch, C., Wiesheu, A. C., Schmid, J., Anger, P. M., Niessner, R., & Ivleva, N. P. (2016). Pigments and plastic in limnetic ecosystems: A qualitative and quantitative study on microparticles of different size classes. *Water Research*, 98, 64-74. https://doi.org/10.1016/j.watres.2016.03.015

Isobe, A., Uchida, K., Tokai, T., & Iwasaki, S. (2015). East Asian seas: a hot spot of pelagic microplastics. *Marine Pollution Bulletin*, 101(2), 618-623. https://doi.org/10.1016/j.marpolbul.2015.10.042

Isobe, A. (2016). Percentage of microbeads in pelagic microplastics within Japanese coastal waters. *Marine Pollution Bulletin*, 110(1), 432-437. https://doi.org/10.1016/j.marpolbul.2016.06.030

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., Narayan, R., & Law, K. L. (2015). Plastic waste inputs from land into the ocean. *Science*, 347(6223), 768-771. DOI: 10.1126/science.1260352

Jang, Y. C., Lee, J., Hong, S., Lee, J. S., Shim, W. J., & Song, Y. K. (2014). Sources of plastic marine debris on beaches of Korea: more from the ocean than the land. *Ocean Science Journal*, 49(2), 151-162. http://dx.doi.org/10.1007/s12601-014-0015-8

Julienne, F., Delorme, N., & Lagarde, F. (2019). From macroplastics to microplastics: Role of water in the fragmentation of polyethylene. *Chemosphere*, 236, 124409. https://doi.org/10.1016/j.chemosphere.2019.124409

Kaiser, D., Kowalski, N., & Waniek, J. J. (2017). Effects of biofouling on the sinking behavior of microplastics. *Environmental Research Letters*, 12(12), 124003. https://doi.org/10.1088/1748-9326/aa8e8b

Kataoka, T., Nihei, Y., Kudou, K., & Hinata, H. (2019). Assessment of the sources and inflow processes of microplastics in the river environments of Japan. *Environmental Pollution*, 244, 958-965. https://doi.org/10.1016/j.envpol.2018.10.111

Küçükali, U. F. (2013). Basin-Scale Ecological Risk Assessment Methodology, Example of Nilufer Creek and Its Subbasins. *Journal of International Scientific Publications*: *Ecology & Safety*, 7(3), 1313-2563.

La Daana, K. K., Officer, R., Lyashevska, O., Thompson, R. C., & O'Connor, I. (2017). Microplastic abundance, distribution and composition along a latitudinal gradient in the Atlantic Ocean. *Marine Pollution Bulletin*, 115(1-2), 307-314. https://doi.org/10.1016/j.marpolbul.2016.12.025

Law, K. L., Morét-Ferguson, S., Maximenko, N. A., Proskurowski, G., Peacock, E. E., Hafner, J., & Reddy, C. M. (2010). Plastic accumulation in the North Atlantic subtropical gyre. *Science,* 329(5996), 1185-1188. DOI: 10.1126/science.1192321

Lebreton, L. C., Van Der Zwet, J., Damsteeg, J. W., Slat, B., Andrady, A., & Reisser, J. (2017). River plastic emissions to the world's oceans. *Nature communications*, 8(1), 1-10. https://doi.org/10.1038/ncomms15611

Lönnstedt, O.M. & Eklöv, P. (2016). Environmentally relevant concentrations of microplastic particles influence larval fish ecology. *Science*, 352 (6290), 1213-1216. DOI: 10.1126/science. aad8828

Mansui, J., Molcard, A., & Ourmières, Y. (2015). Modelling the transport and accumulation of floating marine debris in the Mediterranean basin. *Marine Pollution Bulletin*, 91(1), 249-257. https://doi.org/10.1016/j.marpolbul.2014.11.037

MAR-AAT (2021). Marmara Denizi Havzası Noktasal Kirlilik Yükü Tespiti Projesi. T.C Ministry of Environment, Urbanization, and Climate Change. July 2021. Ankara.

Mateos-Cárdenas, A., O'Halloran, J., van Pelt, F. N., & Jansen, M. A. (2020). Rapid fragmentation of microplastics by the freshwater amphipod Gammarus duebeni (Lillj.). *Scientific Reports*, 10(1), 1-12. https://doi.org/10.1038/s41598-020-69635-2

Moore, C. J., Moore, S. L., Leecaster, M. K., & Weisberg, S. B. (2001). A comparison of plastic and plankton in the North Pacific central gyre. *Marine pollution bulletin*, 42(12), 1297-1300. https://doi.org/10.1016/S0025-326X(01)00114-X

Morkoç, E., Okay, O. S., Tolun, L., Tüfekçi, V., Tüfekçi, H., & Legoviç, T. (2001). Towards a clean Izmit Bay. *Environment international*, 26(3), 157-161. https://doi.org/10.1016/S0160-4120(00)00103-3

Murphy, F., Ewins, C., Carbonnier, F., & Quinn, B. (2016). Wastewater treatment works (WwTW) as a source of microplastics in the aquatic environment. *Environmental Science & Technology*, 50(11), 5800-5808. https://doi.org/10.1021/acs.est.5b05416

Müftüoğlu, E. (2008). Hydrodynamic structure of the bays and the estuary of the Sea of Marmara (in Turkish). Ph.D. Dissertation. Institute of Marine Sciences and Management, Istanbul University

Mülayim, A., Balkıs, N., Balkıs, H., & Aksu, A. (2012). Distributions of total metals in the surface sediments of the Bandirma and Erdek Gulfs, Marmara Sea, Turkey. *Toxicological & Environmental Chemistry*, 94(1), 56-69.

https://doi.org/10.1080/02772248.2011.633914

Pedrotti, M. L., Petit, S., Elineau, A., Bruzaud, S., Crebassa, J. C., Dumontet, B., Marti. E., Gorsky. G., Cózar, A. (2016). Changes in the floating plastic pollution of the Mediterranean Sea in relation to the distance to land. *PloS one*, 11(8), e0161581. https://doi.org/10.1371/journal.pone.0161581

Pekey, H. (2006). The distribution and sources of heavy metals in Izmit Bay surface sediments affected by a polluted stream. *Marine Pollution Bulletin*, 52 (10), 1197-1208. https://doi.org/10.1016/j.marpolbul.2006.02.012

Sari, E.. (2008). Sources and distribution of heavy metals in river sediments from the southern drainage basin of the Sea of Marmara, Turkey. *Fresenius Environmental Bulletin*, 17 (12), 2007-2019.

Schlitzer, R. (2014). Ocean Data View. http://odv.awi.de

Schmidt, N., Thibault, D., Galgani, F., Paluselli, A., & Sempéré, R. (2018). Occurrence of microplastics in surface waters of the Gulf of Lion (NW Mediterranean Sea). *Progress in Oceanography*, 163, 214-220. https://doi.org/10.1016/j.pocean.2017.11.010

Simon-Sánchez, L., Grelaud, M., Garcia-Orellana, J., & Ziveri, P. (2019). River Deltas as hotspots of microplastic accumulation: The case study of the Ebro River (NW Mediterranean). *Science of the total environment*, 687, 1186-1196. https://doi.org/10.1016/j.scitotenv.2019.06.168

Solmaz, S. K. A., Yonar, T., & Üstün, G. E. (2000). Terrestrial pollution inventory of Gemlik Gulf. In Book of Symposium on Sea of Marmara (pp. 513-519).

Song, Y. K., Hong, S. H., Jang, M., Han, G. M., & Shim, W. J. (2015). Occurrence and distribution of microplastics in the sea surface microlayer in Jinhae Bay, South Korea. *Archives of environmental contamination and toxicology,* 69(3), 279-287. https://doi.org/10.1007/s00244-015-0209-9

Song, Y. K., Hong, S. H., Jang, M., Han, G. M., Jung, S. W., & Shim, W. J. (2017). Combined effects of UV exposure duration and mechanical abrasion on microplastic fragmentation by polymer type. *Environmental Science & Technology*, 51(8), 4368-4376. https://doi.org/10.1021/acs.est.6b06155

Sundt, P., Schulze, P. E., & Syversen, F. (2014). Sources of microplastic-pollution to the marine environment. *Mepex for the Norwegian Environment Agency,* 86.

Tan, I., Polat Beken, Ç. S., & Öncel, S. (2017). Pressure-impact analysis of the coastal waters of Marmara Sea. *Fresenius Environmental Bulletin*, 26(4), 2689-2699.

Tan, I. (2022). Preliminary Assessment of Microplastic Pollution Index: A Case Study in Marmara Sea. *Turkish Journal of Fisheries and Aquatic Sciences*, 22, 5. http://doi.org/10.4194/TRJFAS20537

The Ministry of Environment, Urbanization, and Climate Change & TUBITAK-MAM (2017). "Denizlerde Bütünleşik Kirlilik İzleme Programı 2014-2016 Yılı Marmara Denizi Sonuç Raporu". Technical Report. TUBITAK-MAM Press. Kocaeli.

Tolun, L. G., Ergenekon, S., Hocaoglu, S. M., Donertas, A. S., Cokacar, T., Husrevoglu, S., Polat Beken, Ç., & Baban, A. (2012). Socioeconomic response to water quality: a first experience in science and policy integration for the Izmit Bay coastal system. *Ecology and Society*, 17(3). http://dx.doi.org/10.5751/ES-04984-170340

Tunçer, S., Artüz, O. B., Demirkol, M., & Artüz, M. L. (2018). First report of occurrence, distribution, and composition of microplastics in surface waters of the Sea of Marmara, *Turkey. Marine pollution bulletin*, 135, 283-289. https://doi.org/10.1016/j.marpolbul.2018.06.054

Turkish Statistical Institute (TUIK). https://data.tuik.gov.tr/Bulten/Index?p=Adrese-Dayali-Nufus-Kayit-Sistemi-Sonuclari-2021-45500

Turner, A. (2010). Marine pollution from antifouling paint particles. *Marine Pollution Bulletin*, 60(2), 159-171. https://doi.org/10.1016/j.marpolbul.2009.12.004

Ünlü, S., & Alpar, B. (2006). Distribution and sources of hydrocarbons in surface sediments of Gemlik Bay (Marmara Sea, Turkey). *Chemosphere*, 64(5), 764-777. https://doi.org/10.1016/j.chemosphere.2005.10.064

Ünlüata, Ü., Oğuz, T., Latif, M., Özsoy, E., 1990. On the physical oceanography of the Turkish Straits, L. J. Pratt (ed), The physical oceanography of sea straits, Kluwer Academic Publishers, 25-60

Vardar, S., Onay, T. T., Demirel, B., & Kideys, A. E. (2021). Evaluation of microplastics removal efficiency at a wastewater treatment plant discharging to the Sea of Marmara. *Environmental Pollution*, 289, 117862. https://doi.org/10.1016/j.envpol.2021.117862

Wang, T., Li, B., Zou, X., Wang, Y., Li, Y., Xu, Y., ... & Yu, W. (2019). Emission of primary microplastics in mainland China: invisible but not negligible. *Water Research*, 162, 214-224. https://doi.org/10.1016/j.watres.2019.06.042

Wang, T., Li, B., Zou, X., Wang, Y., Li, Y., Xu, Y., Mao, L., Zhang, C., & Yu, W. (2019). Emission of primary microplastics in mainland China: invisible but not negligible. *Water research*, 162, 214-224. https://doi.org/10.1016/j.watres.2019.06.042

Zeri, C., Adamopoulou, A., Varezić, D. B., Fortibuoni, T., Viršek, M. K., Kržan, A., Mandic, M., Mazziotti, C., Palatinus, A., Peterlin, M., Prvan, M., Ronchi, F., Siljic, J., Tutman, P., Vlachogianni, T. (2018). Floating plastics in Adriatic waters (Mediterranean Sea): From the macro-to the micro-scale. *Marine Pollution Bulletin*, 136, 341-350. https://doi.org/10.1016/j.marpolbul.2018.09.016

Zhang, H. (2017). Transport of microplastics in coastal seas. *Estuarine, Coastal and Shelf Science*, 199, 74-86. https://doi.org/10.1016/j.ecss.2017.09.032