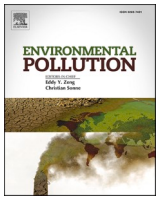
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Microplastics in the Euphrates: Assessing contamination in water, sediment, and commercial fish species☆

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ABSTRACT

Microplastics (MPs) are increasingly recognized as emerging pollutants in freshwater ecosystems, with implications for ecological integrity and food safety. This study presents the first integrated assessment of MP contamination in the Euphrates River (Türkiye), focusing on water, sediment, and six commercially important fish species. We hypothesized that MP abundance in fish would vary according to species-specific feeding behavior and habitat use. To test this, sampling was conducted at 23 sites encompassing urban, agricultural, and industrial zones. MPs were identified and quantified using stereomicroscopy and Fourier-transform infrared spectroscopy. MPs were detected in 52.2 % of water samples (0–6.6 MP/m^3) and 43.5 % of sediment samples (0–15 MP/kg), with fibers and polyethylene terephthalate were the dominant forms. Among fish species (*Capoeta trutta*, *Carasobarbus luteus*, *Cyprinus carpio*, *Cyprinion macrostomus*, *Chondrostoma regium*, and *Carassius gibelio*), MP abundance ranged from 0.2 to 1.76 MPs/individual. Contrary to our initial hypothesis, MP loads did not significantly differ among species or locations. Moreover, statistical analyses revealed no significant associations between MP ingestion and fish traits such as age, length, or weight. However, relatively high MP levels were observed in *C. trutta*, possibly reflecting its benthopelagic habitat and omnivorous diet. These findings point to a diffuse and widespread pattern of MP contamination, likely driven by multiple anthropogenic sources and hydrodynamic factors. The study underscores the need for targeted pollution control strategies and highlights the ecological vulnerability of the Euphrates River.

1. Introduction

Globally, the use of plastics has become an indispensable part of modern life due to their low cost, lightweight, durability, and processability, among many other features. Plastics do not biodegrade for decades under natural conditions (Deoniziak et al., 2022). Instead, they break down into tiny plastic fragments, termed microplastics (MP), which range in size from 1 μm to 5 mm (Whitacre, 2014; Ostle et al., 2019; Rochman et al., 2019; Wright et al., 2013). MPs enter aquatic ecosystems via solid waste, wastewater, and fishing activities, spreading globally via wind and currents (Antão-Barboza et al., 2018; Wang et al., 2021a; b). This widespread distribution facilitates bioaccumulation and poses threats to food security (Carbery et al., 2018; Huang et al., 2021; Kühn and van Franeker, 2020; Simul Bhuyan et al., 2021; Vázquez-Rowe et al., 2021; Xiang et al., 2022).

Aquatic organisms mistake MPs for food, leading to ingestion (de Sa et al., 2015; Anderson et al., 2016; Altunışık, 2025; Altunışık et al., 2024). The ingestion of MPs can lead to effects such as morphological deformities, immobility, oxidative stress, intestinal damage, and even death in organisms (Jaikumar et al., 2018; Kokalj et al., 2016; Lei et al., 2018; Miloloža et al., 2021; Zhang et al., 2021b). Through predation, MPs transfer to higher trophic levels (Chagnon et al., 2018; Tatlı et al., 2025a; b). The sensitivity of fish to MP ingestion may vary between fish species depending on their habitat and feeding habits (Cera et al., 2022; Güven et al., 2017; Jabeen et al., 2017; Murphy et al., 2017; Phillips and Bonner, 2015; Rummel et al., 2016). Therefore, MP pollution in aquatic ecosystems has a detrimental effect on fishery resources, which are of significant economic importance to many coastal communities (Huang et al., 2021; FAO, 2020).

Rivers are crucial in both transporting and trapping MPs in major

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water bodies (Eo et al., 2019; Terzi et al., 2025), as they receive inflows from terrestrial environments and wastewater treatment facilities (Lebreton et al., 2017; Schmidt et al., 2017a; Yan et al., 2021, Gallitelli and Scalici, 2022). About 80 % of oceanic microplastics originate from rivers (Horton et al., 2017; Barboza et al., 2018). Recent studies have documented widespread MP contamination in freshwater ecosystems globally, with concentrations ranging from 3.67 to 10.70 MP/m^3 in the Wei River (Ding et al., 2019) to 800–3088.9 MP/m^3 in the Yangtze River (He et al., 2021). In Türkiye, research in the Tigris and Ergene Rivers has likewise documented fiber-rich MP pollution linked to urban and industrial effluents (Aytan et al., 2023; Akdoğan et al., 2023). Despite its ecological and socioeconomic importance (Kalender & Aytimur, 2016), the Euphrates River—the longest river in Western Asia—lacks a comprehensive multi-matrix assessment of MP contamination. Dams, agricultural runoff, and textile industries along its course may influence MP distribution in complex ways.

Plastic pollution, including MPs, exacerbates existing pressures on the Euphrates, such as habitat degradation and non-native species introductions (Parmaksiz et al., 2024), potentially compounding ecological stress on native fish populations vulnerable to MP ingestion. Moreover, like most freshwater ecosystems, the Euphrates River system is exposed to a certain level of plastic pollution due to its proximity to many settlements. This study addresses the critical question: What is the extent and distribution of MP contamination across water, sediment, and commercial fish species in the Euphrates River within Türkiye, and how do these patterns reflect ecological and anthropogenic influences? Despite the Euphrates River's ecological and economic significance in Western Asia, no prior studies have systematically evaluated MP pollution across its multiple environmental matrices in this region.

This study aims to investigate the distribution and characteristics of MPs in the Euphrates River across three matrices: water, sediment, and commercial fish species (*Carasobarbus luteus*, *Capoeta trutta*, *Cyprinus carpio*, *Chondrostoma regium, Carassius gibelio*, and *Cyprinion macrostomus*). Additionally, the research seeks to understand the potential ecological risks and implications of MP contamination for aquatic biota and food safety. We hypothesized that MP abundance would be higher at stations with intensive urban, industrial, or agricultural activity, and that the levels of MP ingestion by fish species would be influenced by their feeding behavior and habitat preferences.

2. Materials and methods

2.1. Study area

The Euphrates River is the longest river in Western Asia, originating from the eastern Anatolia region of Türkiye, passing through Syria and Iraq, and draining into the Persian Gulf This river system holds significant importance for agriculture and the economy, and it is formed by the confluence of the Western Euphrates (Kara Su) and Eastern Euphrates (Murat Su) rivers (Yürekli et al., 2021). The construction of dams, hydroelectric power plants, and irrigation facilities along the Euphrates River has led to a substantial augmentation in agricultural production capacity. Reservoir lakes have further boosted local aquatic productivity (Oymak, 2000; Oymak et al., 2011).

The study was conducted along the Euphrates River in Türkiye, spanning 23 sampling stations selected to represent urban, agricultural, and industrial zones, sampled in July 2024. These stations were chosen based on their proximity to known anthropogenic discharge points, detailed in Table S1 and mapped in Fig. 1, to assess MP distribution across diverse landscapes. Water, sediment, and fish samples were collected at each station to enable a comprehensive multi-matrix analysis.

2.2. Sample collection

Three types of samples were collected: surface water (n = 23), sediment (n = 23), and fish specimens (n = 117). Surface water samples (n = 23) were collected using Manta plankton nets with a rectangular opening (0.5 × 0.3 m) and mesh sizes of 26 μm. The nets were deployed in fast-flowing sections of the river for 15–30 min, depending on water velocity, measured with a Marsh McBirney FlowMate. The volume of water filtered was calculated using the net opening and duration of deployment. For reservoirs, Manta nets were towed behind a boat at low speed for 100–200 m. Samples were rinsed into clean glass jars (1 L), sealed, and transported to the laboratory (Altunışık et al., 2024; Tatlı and Altunışık, 2025).

Sediment samples (n = 23) were collected from riverbanks and lakebeds at depths of 0–3 cm using steel spatulas. Approximately 1 L of homogenized sediment was placed in aluminum containers, sealed with foil, and stored at 4 °C. Additional sediment samples were collected using a 150 mL scoop along a 50 m transect, pooled, and sieved through

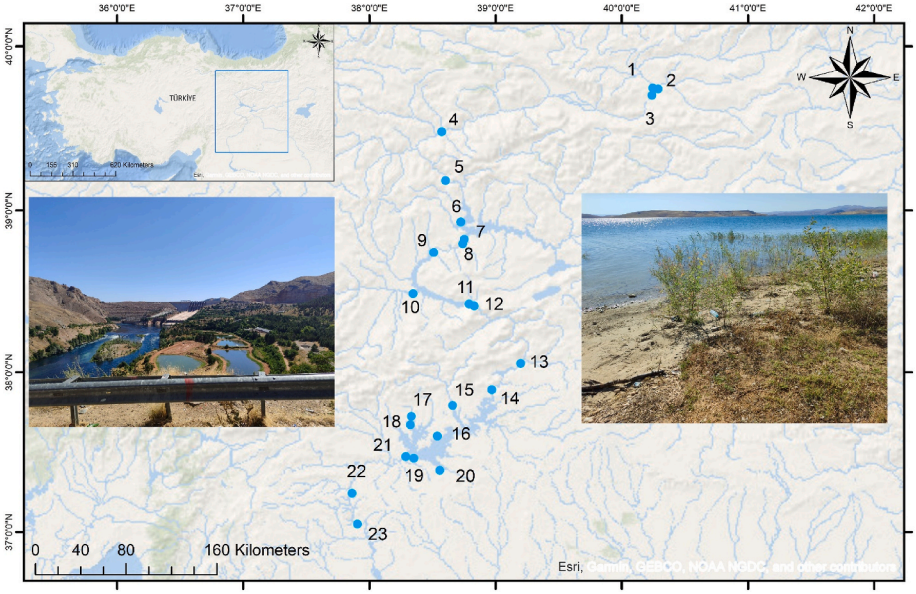


Fig. 1. Sampling locations of Euphrates river in this study.

a 5 mm mesh.

Six economically significant fish species were targeted: *Carasobarbus luteus*, *Capoeta trutta*, *Cyprinus carpio*, *Chondrostoma regium*, *Carassius gibelio*, and *Cyprinion macrostomus* (Olgunoğlu et al., 2009). A total of 117 fish were purchased from local fishermen at each station using gillnets and cast nets, ensuring representation of local catches. The sample size of 117 fish was determined to ensure statistical power across six species and 23 stations. These species were selected due to their economic importance and diverse feeding habits (e.g., benthic vs. pelagic), which may influence MP ingestion (Olgunoğlu et al., 2009). Specimens were stored in 5 L glass jars containing 70 % ethanol and kept at 4 °C until laboratory analysis.

2.3. Sample processing

Water samples were subjected to a digestion process involving 30 % hydrogen peroxide (H_2O_2). This digestion was carried out at a temperature of 60 °C and at a rotational speed of 80 rpm for a duration of 72 h. The purpose of this process was to remove any organic matter present in the samples. The solution was then filtered through Whatman GF/C filter paper with a pore size of 1.2 μm and a diameter of 47 mm. The filter paper was then dried and stored for microscopic analysis.

Sediment samples were subjected to an air drying process followed by sieving through a 5 mm mesh. Approximately 100 g of sediment was mixed with 200 mL of saturated $ZnCl_2$ solution (density: 1.65 g/cm^3) and stirred for 4 min. After settling, the supernatant was filtered. The process was reiterated on three occasions. Organic matter was digested using 30 % H_2O_2, and the final solution was filtered through GF/C filters for microscopic examination.

Fish gastrointestinal tracts (GITs) were dissected and weighed. Tissues were digested with 200 mL of 30 % H_2O_2 at 60 °C and 80 rpm for 72 h, a temperature chosen to balance organic matter breakdown with MP preservation, as validated by prior studies (Tatlı et al., 2022). The solution was filtered through GF/C filters and stored for further analysis.

2.4. Age determination of fish

Fish age was determined using scales collected between the operculum and dorsal fin, cleaned with 4 % KOH, and examined under a light microscope for annuli (Lagler, 1956). This was included to test the hypothesis that older fish might accumulate more MPs due to prolonged exposure, though no such correlation was expected based on mixed prior evidence (e.g., McNeish et al., 2018). The annual growth zones (annuli) on the scales were used for age determination, and the age of the fish samples was determined by counting the age rings under a light microscope.

2.5. Instrumental analysis

2.5.1. Visual analysis

The entire surface of the filters was examined under a stereomicroscope (Leica S6D). Any particles suspected of being MPs were transferred to a clean filter using a trolley and the image was recorded (Leica EC3, Leica Microsystems, Switzerland). Additionally, the National Institutes of Health (NIH)'s ImageJ application was used to analyze the recorded photos. After determining particle size, the particles were classified into fragments, films, and fibers, as these were the predominant shapes observed (Hidalgo-Ruz et al., 2012). Particle color was visually assessed under stereomicroscopy, and length was measured using ImageJ.

2.5.2. Polymer structure

To confirm the identity of all particles suspected of being MP, an attenuated total reflection Fourier transform infrared spectrometer (PerkinElmer, Spectrum 100) was utilized. The particles were then positioned on an ATR crystal, after which the spectra were measured within the 4000-650 cm^{-1} range with a resolution of 4 cm^{-1} (32 scans) (see Fig. 2). The obtained spectra were then compared with reference polymer spectra. Only particles with a >70 % match were verified as MPs (Altunışık et al., 2024a).

2.6. Quality assurance and control

To prevent the presence of microparticles throughout the entire experiment, strict preventive measures were enforced in the lab. These included limiting airflow through the ventilation system, managing access to and from the lab, and thoroughly cleaning all work surfaces (Hidalgo-Ruz et al., 2012). Experiments were conducted using cotton aprons and nitrile gloves. Negative blank tests were also performed. Empty beakers were utilized with GIT and sediment samples, replicating the same process as actual samples. Microscopic examination of a clean Petri dish involved adding filtered water to check for airborne MP contamination. Any MPs detected from negative blanks were deducted from the total count. To determine the recovery rate for GIT digestion and sediment density separation, three sets of positive control samples (N = 3) were employed. This involved placing pre-prepared Polyethylene (PE), Polypropylene (PP), and Polyethylene terephthalate (PET) particles (150–212 μm) into the beakers. Furthermore, 0.5 g of muscle tissue from a frog's hind leg was used, and MPs were extracted as described by Tatlı et al. (2022). H_2O_2 was subsequently added to the muscle tissue, and the procedure followed the same methodology used for the regular samples. For the sediment, density separation was first performed with 500 mL of $ZnCl_2$, using approximately 100 g of the sampled sediment. The particles that collected in the supernatant were then extracted. The $ZnCl_2$ solution was removed, and the sediment underwent digestion at 550 °C for 24 h to eliminate organic matter and any potential MPs. Next, the pre-prepared PET, PE, and PP particles were introduced to the sediment and thoroughly mixed. Density separation and $ZnCl_2$ filtration were then repeated in the same way as for the collected samples. For both tissue and sediment, particles captured on the filter were counted using a stereomicroscope, and recovery was calculated by dividing the number of particles added by the number extracted.

2.7. Data analysis

Data normality was assessed using the Shapiro-Wilk test, revealing non-normal distributions ($p < 0.05$) for MP abundance, prompting use of the Kruskal-Wallis test instead of one-way ANOVA for spatial variation analyses. Spearman's correlation tested relationships between fish total length (tip of snout to end of caudal fin) and body weight were measured, alongside MP abundance in GITs, water, and sediment samples.

A one-way ANOVA was conducted to examine differences in MP abundance across the sampling locations. The Kruskal-Wallis test (K-W) was used to assess the spatial variation in MP abundance and the differences in MP sizes based on MP shapes. Spearman's correlation was employed to investigate the correlation between the length and weight of the fishes and the abundance of MPs in their GITs. The data were analyzed using SPSS Statistical Software. All identified MPs were recorded according to length, polymer type, shape, and color. MP abundance was quantified both as the total number present in each sampling location and as the number of MPs per individual.

3. Results

3.1. MPs in river water and sediment

MPs were detected at 12 out of 23 stations in river water samples, with concentrations ranging from 0 to 6.6 MP/m^3 (mean: 2.02 ± 0.46), where zero values indicate no MPs detected (Fig. 3A, Table S2). Sites 11 and 18 were the stations where MPs were most abundant, while 11

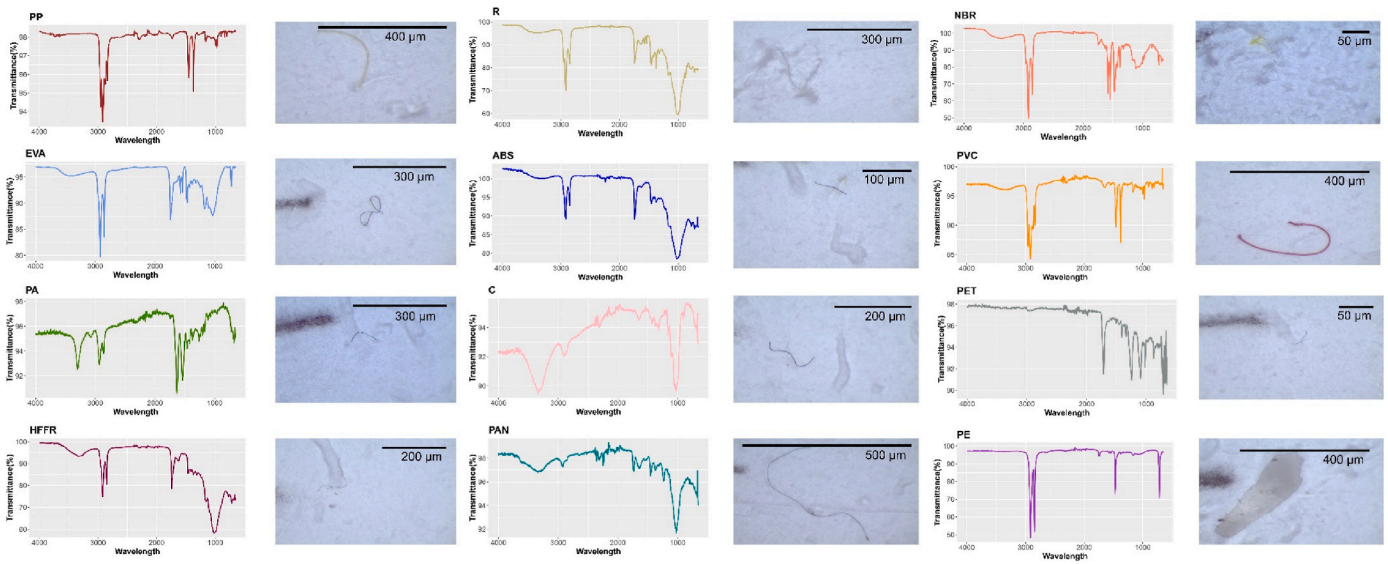


Fig. 2. FTIR spectra and stereomicroscope photographs of microplastics detected in the Euphrates River basin.

stations had zero MP presence. No significant spatial variation in MP abundance was found (Kruskal-Wallis test, df = 22, p = 0.46), reflecting high variability rather than uniform distribution. A total of 7 different types of polymers were found in the river water, and they were ranked as PET (40 %), PE (13.3 %), PP (13.3 %), Cellulose (C, 13.3 %), Acrylonitrile Butadiene Styrene (ABS, 6.7 %), Polyacrylonitrile (PAN, 6.7 %) and Polyvinyl chloride (PVC, 6.7 %) according to their percentages (Fig. 4A). Fibers constituted 73.3 % of MPs, with fragments making up 26.7 % (Fig. 4B). MPs were predominantly blue (47 %), followed by red (20 %), transparent (20 %), green (7 %) and yellow (7 %) (Fig. 4C). MP lengths ranged from 25 to 700 µm (mean: 298.66 ± 52.22 µm), with the dominant size range of 300–1000 µm (46.7 %) (Fig. 4D).

The MP content in sediment samples ranged from 0 to 15 MP/kg (mean: 3.69 ± 1.05), with no MPs detected at 13 of the 23 stations (Fig. 3B–Table S2). Sites 1 and 18 were the stations where MPs were most abundant with 15 MP/kg. Regarding the MP abundance in sediment samples, no difference was found between the stations (K-W test, df = 22, p = 0.46). In addition, no correlation was found between water and sediments regarding MP abundance (Spearman Correlation Coefficient, r = 0.328, p = 0.13). Of the MPs found, 100 % were fibers, with polymer types comprising 29.4 % PET, 23.5 % Acrylonitrile Butadiene Styrene (ABS), 17.6 % Ethylene–vinyl acetate (EVA), 17.6 % Nitrile Butadiene Rubber (NBR), 5.9 % Polyamide (PA), and 5.9 % PVC (Fig. 4A–B). MPs were predominantly blue (94 %), followed by transparent (6 %) (Fig. 4C). MP lengths ranged from 53 to 502 µm (mean: 135.49 ± 32.86 µm), with the dominant size range of 20–100 µm (35.3 %) (Fig. 4D). In the diagram, nodes are also used to symbolize the relationships between the samples (water and sediment) and the categorical factors (Fig. 5). As shown in the Sankey diagram, fibers (n = 28) were the dominant MP shape, indicating textile-related sources. PET (n = 11) and ABS (n = 5) were the most common polymers, likely originating from packaging and synthetic fabrics. The high abundance of blue fibers (n = 23) suggests domestic wastewater as a major input pathway. MPs were found in both water and sediment, reflecting ongoing exchange between compartments. Most particles (n = 18) were between 20 and 200 µm (Fig. 5), indicating high potential for biological uptake. The variety of polymers points to mixed sources, including urban runoff and industrial effluents.

3.2. MPs in commercial fish species

A total of 117 fish specimens were sampled, with an average length of 255.25 ± 7.11 mm and an average weight of 344.08 ± 25.85 g (Table 1).

The species with the highest MP frequency of occurrence (FO) was *Capoetta trutta*, with 64 % of individuals containing MPs (Table 1). This species also showed the highest average MP count per individual among those containing MPs, with 2.72 MPs per fish. Conversely, *Carassius gibelio* exhibited the lowest frequency of occurrence of MPs, at only 15 %, and the lowest average MP count per individual in the total population, with 0.20 MPs per fish.

Overall, MP was identified in 45 out of the 117 sampled fishes. The distribution of MPs in the GITs of fishes ranged from 0.2 to 1.76 MP/ind. (Table 1), and this distribution was statistically significant (K-W test, p < 0.05). In terms of overall MP presence, *C. gibelio* displayed the lowest total MP count, with only 4 MPs detected across all samples, while *C. trutta* had the highest total count, with 30 MPs. Violin plot visualization of MP abundance among fish species revealed species-specific differences in both central tendency and distribution. *C. trutta* exhibited the highest levels and greatest variability in MP ingestion, with values reaching up to 6 MPs/individual (Fig. 6). This is consistent with its benthopelagic habitat and omnivorous feeding behavior, which likely increase its exposure to MPs suspended in both water column and sediment (Fig. 6). In contrast, *C. gibelio* and *C. regium* showed notably lower MP burdens (1 or 2 MPs), suggesting either reduced exposure due to habitat preference or species-specific feeding mechanisms that limit MP uptake. Furthermore, no significant correlation was observed between MP accumulation in the GITs and the length/weight or age parameters (Spearman correlation, p > 0.05).

A total of 9 different polymer types were detected in fish (Fig. 7A). Eight of these polymers (ABS, C, EVA, Halogen free and flame retardant (HFFR), NBR, PA, PET, PVC, Rubber (R)) were detected in *C.trutta* species. The predominant form of polymer in fish was fiber. However, MPs in the form of fragments were only detected in the *C. luteus*, *C. macrostomus* and *C. trutta* species (Fig. 7B). Only one polymer type (NBR) was detected in *C.regium* species. MPs were predominantly blue (80 %), followed by red (7 %), transparent (6 %), yellow (3 %), and other colors (4 %) in general (Fig. 7C). MPs detected in fish were commonly found to be 200 µm and below (Fig. 7D).

4. Discussion

Microplastics have emerged as a global pollutant threatening freshwater systems, but identifying the environmental drivers and biological interactions that govern their distribution remains challenging. This study study has evaluated the occurrence and characteristics of MPs in

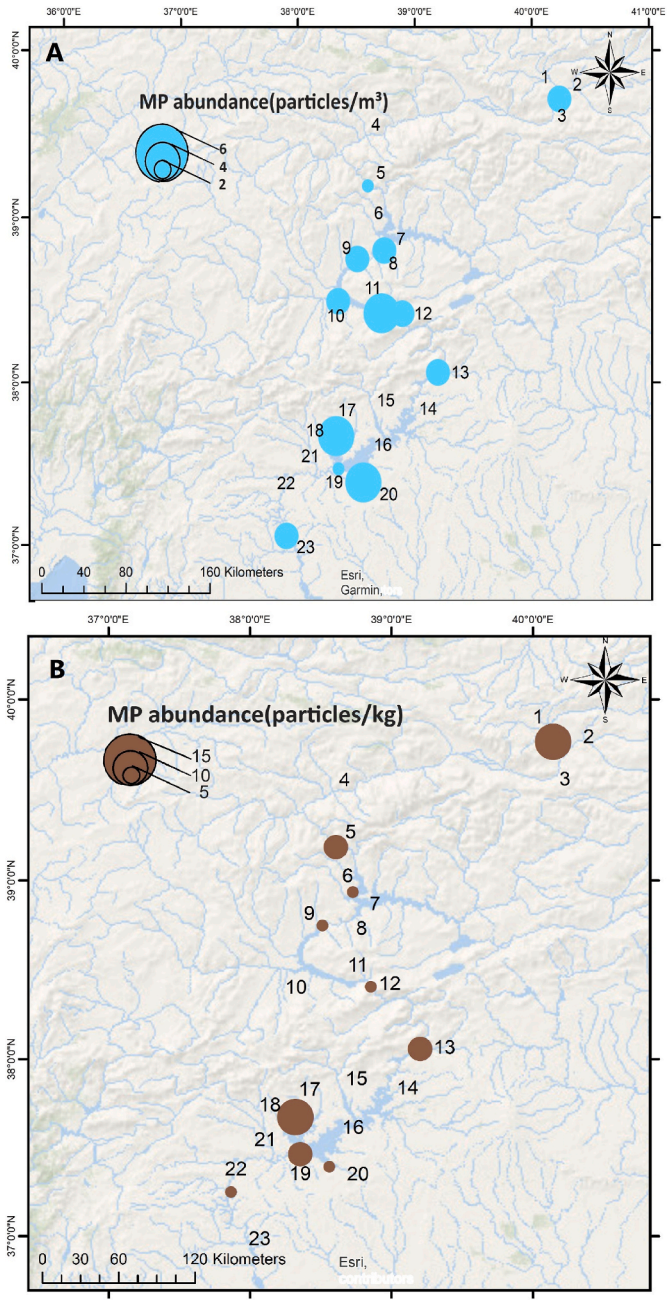


Fig. 3. Microplastic abundance in the river water (A) and sediment (B) samples collected from the Euphrates river basin, Türkiye.

the Euphrates River and test the hypothesis that MP concentrations would be higher in areas with intense anthropogenic activity. However, no statistically significant differences in MP abundance were observed between sampling stations in either water or sediment, and no correlation was found between MP levels and fish morphometric parameters. These findings highlight the complexity of MP dynamics and suggest that additional environmental variables must be considered to better understand spatial patterns of MP pollution.

4.1. Microplastics in river water and sediments

Microplastics are ubiquitous pollutants found in freshwater systems, and their abundance and distribution are influenced by both natural and anthropogenic factors. In river water samples, MPs were detected at 52.2 % of the stations, with concentrations ranging from 0 to 6.6 MP/m^3. In sediment samples, MPs were found at 43.5 % of the stations, with concentrations ranging from 0 to 15 MP/kg. Industrial activities, such as textile production in urban zones near Sites 11 and 18, likely contribute to the high PET fiber concentrations observed (15 MP/kg in sediment). Agricultural runoff from irrigation zones may introduce PE fragments. Dams, such as the Atatürk Dam, appear to influence MP distribution, with higher concentrations upstream (e.g., Site 1: 15 MP/kg) compared to downstream (e.g., Site 23: 0 MP/kg), suggesting sediment trapping effects. The MP concentrations detected in this study are consistent with findings from other rivers globally and within Türkiye. For instance, the fiber dominance observed in the sediment samples parallels findings from the Ergene River, where PET and PA fibers were prevalent in water and sediment (Akdoğan et al., 2023). Additionally, the presence of PE, PS, and PP as the dominant polymers in the Euphrates aligns with studies in the Munzur and Pülümür Rivers, which reported PE, PS, and PP as the most common polymer types, with concentrations ranging from 0.01 to 28.21 MP/m^3 (Gündoğdu et al., 2023). Similarly, studies in the Mersin region identified 293 MP/m^3 in various rivers, primarily comprising PE, PVC, cellulose, and PP polymers (Özgüler et al., 2022), while research in Antalya reported concentrations between 0.2 and 1.4 MP/m^3, with fiber, film, fragment, and foam shapes (Güven et al., 2017). On the other hand, the Tigris River showed a comparable mean MP abundance in water, predominantly in fiber form, corroborating this study's observation that fibers constituted 73.3 % of detected MPs (Aytan et al., 2023). The dominance of PET and PE polymers in river water samples, as observed in our study, is consistent with global trends, where these materials are frequently reported due to their extensive use in consumer products and packaging (Kılıç et al., 2022; Atamanalp et al., 2022). Similar results were found in global studies, such as those conducted on the Mississippi River (Wontor et al., 2024), Pearl (Lin et al., 2018) and the Seine River (Dris et al., 2015), indicating the pervasive nature of these polymers in freshwater systems.

Compared to global rivers, MP concentrations in the Euphrates are within the range observed in systems with significant human influence. For example, MP concentrations were reported to range from 1.6 to 2.55 MP/m^3 in the Vistula River, Poland (Sekudewicz et al., 2021), from 0.9 to 13 MP/m^3 in the Ofanto River, Italy (Campanale et al., 2020), and from 3.67 to 10.7 MP/m^3 in the Wei River, China (Ding et al., 2019). However, MP levels in the Euphrates are much lower than those in the Yangtze River, China, where concentrations ranged from 800.0 to 3088.9 MP/m^3 (He et al., 2021).The fiber-shaped MPs detected in our study mirror those reported in the Wei and Ergene Rivers, suggesting that textile-related activities and wastewater discharges might be significant contributors. Globally, studies such as those on the Ganges River (Hassan et al., 2024) support the findings of fiber dominance in sediment matrices, highlighting similar pollution patterns in rivers influenced by urban and industrial activities. The lower sediment MP concentrations in the Euphrates River (0–15 MP/kg), compared to highly polluted rivers like the Amazon or Yangtze, may be attributed to factors such as upstream damming, sediment trapping, and reduced urban or industrial discharge, rather than high flow velocity, as the Euphrates generally exhibits lower flow rates than those rivers (Schmidt et al., 2017a). Given that the Euphrates River flows through a semi-arid, heavily dammed, and agriculturally exploited region, our results may have broader relevance to other hydrologically similar systems in the Middle East, Central Asia, and parts of North Africa. These regions often share challenges related to low wastewater treatment capacity, textile industries, and high seasonal variability in flow, all of which contribute to diffuse MP contamination. Thus, the study provides a valuable reference point for MP monitoring and mitigation efforts in comparable geographic contexts.

The lower sediment MP concentrations in the Euphrates (0–15 MP/kg) compared to global rivers like the Amazon, Yangtze and may stem from the river's high flow rates, which facilitate MP transport to downstream or marine environments, reducing sediment deposition (Schmidt et al., 2017a). The lack of spatial variation in MP abundance,

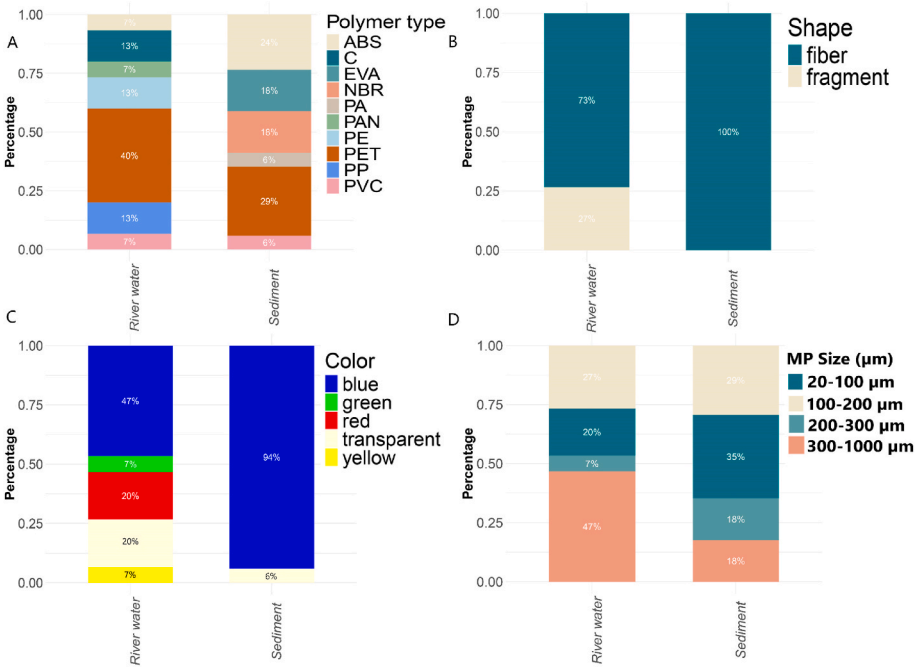


Fig. 4. A stacked bar chart depicting the proportional distribution of microplastic polymer types (A), shapes (B), colors (C), and sizes (D) in river water and sediments from the Euphrates River basin. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

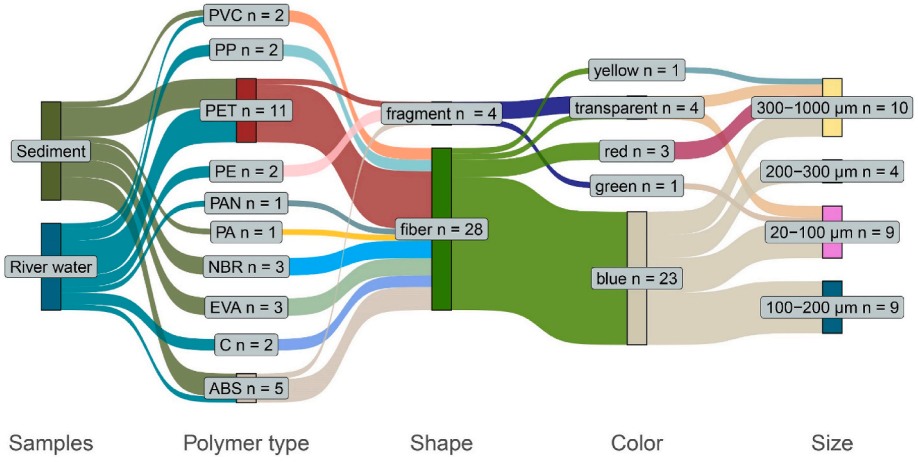


Fig. 5. The relationships between the samples, polymer type, shape, color, and size are depicted in a Sankey diagram. Nodes in the flow were formed by microplastic patterns. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 1
Data on microplastics detected in the gastrointestinal tracts of different fish species sampled from the Euphrates River in Türkiye.

Species' ID	Species' Name	Fish N	Age (years) mean	Length (cm) Mean	Weight (g) Mean	[v]Fish -MP	[w]FO %	[x]MP	[y]MP ind·	[z]MP ind·
1	*Carasobarbus luteus*	20	5.40	265.00	308.55	8	40	14	1.75	0.70
2	*Capoeta trutta*	17	2.58	278.23	362.82	11	**64**	30	2.72	**1.76**
3	*Cyprinus carpio*	20	6.15	331.25	757.90	8	40	14	1.75	0.70
4	*Cyprinion macrostomus*	20	2.60	127.50	30.55	9	45	15	1.66	0.75
5	*Chondrostoma regium*	20	5.05	310.75	345.70	6	30	7	1.16	0.35
6	*Carassius gibelio*	20	3.90	222.25	261.80	3	**15**	4	1.33	**0.20**
	Total	117	4.32	255.25	344.08	45	38	84	1.86	0.72

[v]The number of fish MP detected.
[w]Frequency of occurrence.
[x]Detected total microplastic.
[y]Per individual for fish containing microplastic.
[z]General average.

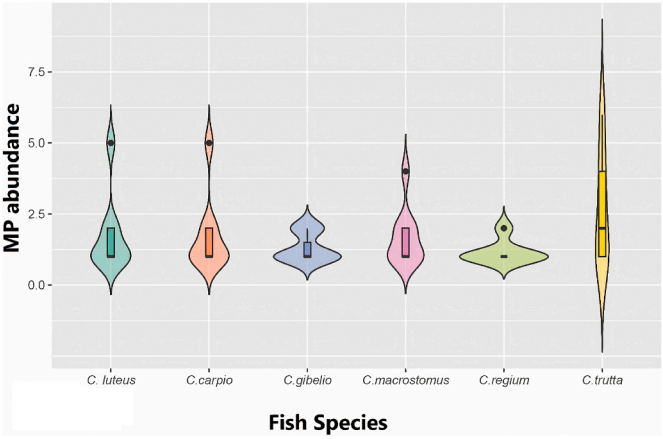


Fig. 6. Microplastic abundance distribution according to fish species from The Euphrates River basin, Türkiye.

despite expectations of higher concentrations in urban and industrial zones, suggests that diffuse pollution sources, such as agricultural runoff or atmospheric deposition of textile fibers, dominate over localized inputs (Yürekli et al., 2021). Methodological factors, such as the use of 1.2 μm filter papers, may also underestimate smaller MPs, contributing to lower reported concentrations compared to studies employing finer meshes (Cai et al., 2020). Additionally, the Euphrates basin's mixed land use and limited wastewater treatment infrastructure likely result in consistent MP inputs across zones, contrasting with global patterns where urban hotspots drive elevated concentrations (Rowley et al., 2020; Drabinski et al., 2023). The lack of significant correlation between MP abundance in water and sediment in this study reflects the complexity of MP deposition and resuspension processes, as also suggested by studies in the Rhine and Mignone rivers (Klein et al., 2015; Gallitelli et al., 2020). Regionally, studies on sediment contamination in Türkiye, such as in the Euphrates River's Iraqi segment (86.7 MP/kg, predominantly fiber-shaped; Kadhum et al., 2020), further emphasize the importance of understanding sediment as a reservoir for MP pollution. Our findings also align with observations from the North Saskatchewan River in Canada, where fibers were a dominant shape, and polymer types included PE, PP, and PET (Bujaczek et al., 2021).

The observed variability in MP concentrations and polymer types across different studies may result from methodological differences, sampling strategies, and local hydrodynamic conditions. The higher MP concentrations near urban stations (e.g., Sites 11 and 18) suggest wastewater and runoff as key sources, consistent with global patterns in rivers like the Thames (Rowley et al., 2020), warranting targeted pollution controls in Türkiye's urban zones. Studies such as those on the Antua River (Portugal) and Citarum River (Indonesia) have demonstrated that proximity to urban and industrial areas significantly influences MP distribution (Rodrigues et al., 2018; Sembiring et al., 2020). The spatial distribution of MPs in both water and sediment samples showed a clear pattern corresponding to surrounding land use. Higher MP concentrations were detected in stations located near urban settlements and agricultural zones, indicating that domestic wastewater discharge, surface runoff, and plastic-intensive agricultural practices may act as major input sources. These observations are consistent with previous studies emphasizing the role of anthropogenic activities in freshwater MP pollution (e.g., Zhang et al., 2021a,b; Altunışık et al., 2024).

This study underscores the importance of addressing MP pollution in the Euphrates River through targeted mitigation strategies. Long-term

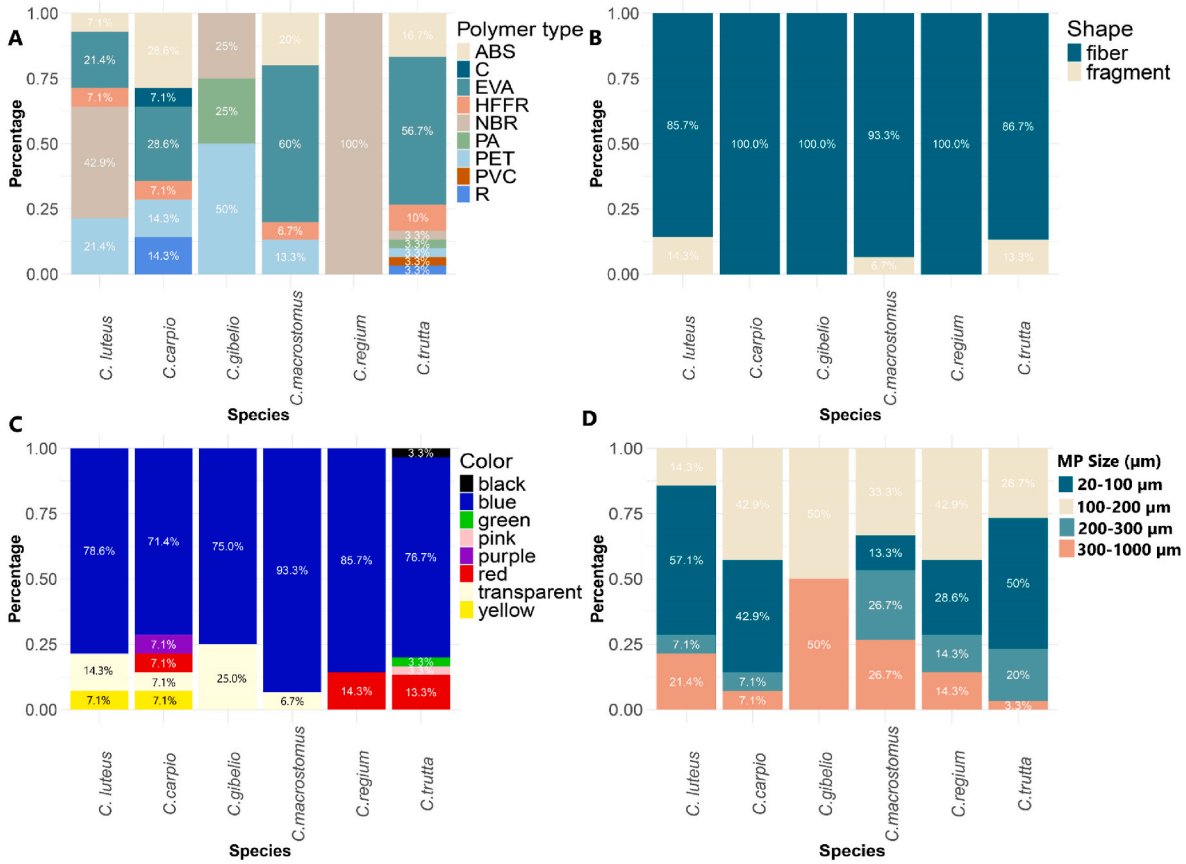


Fig. 7. A stacked bar chart depicting the proportional distribution of microplastic polymer types (A), shapes (B), colors (C), and sizes (D) in fish from the Euphrates River basin. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

monitoring programs, combined with source identification and transport pathway analyses, are essential for developing effective management policies. Furthermore, interdisciplinary approaches that incorporate ecological, socio-economic, and policy perspectives are critical to tackling this pervasive environmental challenge. By providing baseline data for the Turkish segment of the Euphrates River, this study paves the way for future research and policy initiatives aimed at mitigating MP pollution and protecting this vital water resource.

4.2. Microplastics in fish species

The occurrence of MPs in 45 out of 117 fish specimens (38.5 %) demonstrates the pervasive nature of plastic pollution in aquatic biota. The dominance of fibers and the presence of PET and ABS polymers in fish gastrointestinal tracts are consistent with findings from the Karasu River and other freshwater ecosystems (Atamanalp et al., 2022; Kılıç et al., 2022). Globally, the ingestion of MPs by fish has been reported in numerous studies, such as in the Amazon River Basin (da Costa et al., 2023; Rico et al., 2023) and the Great Lakes (McNeish et al., 2018), underscoring a widespread issue across diverse ecosystems. Differences in MP abundance among fish species highlight the role of ecological and behavioral factors in exposure risk. Notably, *Capoetta trutta* exhibited the highest frequency of MP occurrence (64 %), with an average of 2.72 MPs per individual. This may be attributed to its benthopelagic and omnivorous feeding behavior, which involves foraging on sediment surfaces and consuming detritus, algae, and benthic invertebrates. Since MPs tend to accumulate in sediments, such bottom-oriented feeding strategies can increase ingestion risk. *C. trutta* individuals were predominantly collected from stations with elevated sediment MP concentrations, further supporting the link between habitat use and exposure level (Atamanalp et al., 2022). Similar patterns were observed in studies on the Thoothukudi coast, where benthic species exhibited higher MP loads compared to pelagic species (Keerthika et al., 2023). Turkish studies report varied MP ingestion; for instance, 57 % occurrence in Tigris River fishes (Aytan et al., 2023), with fibers comprising 96.2 % of the plastics. Likewise, Böyükalan and Yerli (2023) found fiber-shaped MPs dominating the gastrointestinal tracts of multiple fish species from Turkish lakes and dams. The average MP length in our study (300–1000 μm) closely aligns with the 0.10–4.85 mm range observed in these studies. In the Orontes River, Kılıç et al. (2022) reported MPs in 95 % of analyzed fish, averaging 5.1 MPs per individual. The dominance of fibers (93.5 %) and black-colored MPs mirrors our findings, where fibers constituted 73.3 % and blue was the most prevalent color (47 %). However, our study's lower mean abundance of MPs (2.02 MPs per fish) compared to the Orontes River indicates potentially lower anthropogenic pressure or differences in riverine dynamics and local activities. On the other hand, da Costa et al. (2023) reported MP ingestion in fish from the Amazon River Basin, with fibers as the predominant type. Similarly, McNeish et al. (2018) highlighted significant MP contamination in the Great Lakes. The dominance of fiber-shaped MPs across studies suggests that textile-related activities and wastewater discharge are common pollution sources in both freshwater and marine environments. The presence of MPs in fish species raises significant ecological and socio-economic concerns, given their potential bioavailability and entry into the food chain. Similar concerns have been documented in studies on the Rhine (Germany) and Tropical Andean (Ecuador) Rivers, where MPs were detected in aquatic organisms (Mani et al., 2015; Donoso & Rios-Touma, 2020).

The prevalence of fibers (73.3 % in water, 100 % in sediment) suggests potential entanglement risks for filter-feeding organisms and bioaccumulation in higher trophic levels. PET and PE, detected in 38.5 % of fish, may adsorb pollutants (Wright et al., 2013), posing risks to local fisheries and human consumers reliant on the Euphrates for food security. Laboratory studies have demonstrated that MP ingestion can lead to oxidative stress, reduced growth, and altered immune responses in fish (Miloloža et al., 2021). The absence of correlation between MP accumulation and fish size, weight, or age indicates that these factors alone do not explain ingestion patterns. However, our hypothesis that feeding behavior and habitat use influence MP uptake is supported by the higher MP load in *Capoeta trutta*, a benthopelagic species with omnivorous feeding habits. Similar species-specific patterns have been documented in the Amazon and Orontes rivers (da Costa et al., 2023; Kılıç et al., 2022).

4.3. Mechanisms and implications

Our findings of uniform MP levels across stations, despite variable land use, point to several controlling processes. First, dam-induced sediment trapping upstream (e.g., Atatürk Dam) likely retains particles, leading to elevated MP loads in reservoir sediments but more homogeneous downstream transport. Second, textile and municipal effluents—rich in fibers—appear to be diffuse sources, resulting in fiber dominance even at ostensibly rural sites. Third, hydrodynamic sorting during high-flow events may redistribute MPs laterally and vertically, masking localized point sources.

The predominance of fibers (>70 % in water; 100 % in sediment) underscores the role of laundry effluents and wastewater treatment bypasses. Ecologically, fiber-rich MPs pose entanglement and ingestion risks for benthic and filter-feeding organisms. From a management perspective, targeted interventions—such as upgrading treatment plants to better retain fibers, and implementing catchment-scale stormwater controls—could mitigate MP inputs.

4.4. Limitations and future directions

This study provides essential baseline data for the Turkish segment of the Euphrates River. However, its interpretive power is limited by the lack of land-based pollution metrics, hydrological flow data, and seasonal sampling. We did not use quantitative models (e.g., multivariate regression or machine learning) to assess the contributions of urban runoff, agricultural inputs, and industrial effluents to MP loads. Although we focused on MP abundance, future studies should quantify ecological risks using indices such as the H index, bioaccumulation potential, and feeding-related exposure pathways. To address these gaps, longitudinal studies incorporating land use analysis, source tracking, and ecotoxicological effects are needed to establish causality and guide mitigation policies. Finally, assessing dietary exposure and human health risks from fish consumption is critical to inform public health strategies.

5. Conclusions

This pioneering study establishes baseline MP contamination levels in the Euphrates River, Türkiye, revealing pervasive fiber and PET pollution across water, sediment, and fish, with *Capoeta trutta* showing elevated ingestion risk (2.72 MPs/ind). These findings highlight the river's role as a conduit and sink for MPs, driven by regional anthropogenic inputs, and call for urgent waste management interventions to protect this vital ecosystem and its fishery resources. The lack of a significant relationship between MP abundance in water and sediment underscores the complexity of MP deposition and resuspension processes in dynamic freshwater systems. Additionally, no significant correlation was found between fish morphology (length, weight, or age) and MP abundance, suggesting that exposure is more influenced by environmental factors than by biological traits. These findings underscore the Euphrates River as a critical reservoir for MPs, with implications for ecological health and food safety. To address this pervasive issue, targeted mitigation strategies, such as improved waste management and stricter pollution control policies, are essential. Future research should focus on identifying MP sources, understanding long-term ecological impacts, and exploring potential trophic transfer of MPs in freshwater ecosystems. This foundational study not only enriches

the understanding of MP pollution in Türkiye but also contributes to the global discourse on managing plastic pollution in aquatic environments.

CRediT authorship contribution statement

Abdullah Altunışık: Writing – review & editing, Writing – original draft, Visualization, Supervision, Methodology, Investigation, Formal analysis. **Hale Tatlı:** Visualization, Methodology, Formal analysis, Conceptualization. **Necmettin Doğan:** Writing – original draft, Formal analysis, Conceptualization. **Göksal Sezen:** Writing – review & editing, Methodology, Investigation, Conceptualization. **Arif Parmaksız:** Writing – review & editing, Validation, Supervision, Investigation, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envpol.2025.126863.

Data availability

Data will be made available on request.

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