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RESEARCH PAPER

Microplastic Pollution and Possible Sources in Datça-Bozburun Special Environmental Protection Area

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Abstract

Microplastic (MPs) pollution emerges as a significant environmental issue that poses a threat to aquatic ecosystems and human health on a global scale. Present study investigated MPs pollution in the Datça-Bozburun Special Environmental Protection Area (SEPA) located in the south-eastern Mediterranean coastline of Türkiye. Samples were collected from 17 stations revealed that the abundance of MP contaminations ranged from 10 MPs.m^{-3} in pristine areas to 56.7 MPs.m^{-3} in the most polluted zone and average size of 1.49±1.11 mm was detected. Fiber particles were the most common type, accounting for 92.9% of the pollution. The most common polymer types are ethylene/propylene copolymer and polyethylene terephthalate, accounting for 37.5% and 16.7% of the sample, respectively. The analyses conducted regarding the terrestrial land use information of the sampling area have identified potential pollution sources in six sampling areas due to anthropogenic activities. It was found that a high population density significantly influenced pollution levels in three of these areas. In the other three areas, pollution was shaped not only by the dense population but also by agricultural practices and the presence of a port. Besides that, two heavily polluted stations lacked significant land use activities, suggesting that regimes effective in the region might play a role in transporting MP particles to the area. Our result indicated that MPs pollution in the SEPA is a concern, and further research is needed to better understand the sources and pathways of MPs contamination in this critical base for biodiversity of Türkiye's Mediterranean coastline.

Introduction

Plastic pollution is a long-term environmental issue due to the durable component of plastic materials. Since 1950, only around 9% of 400.3 million metric tons of plastic waste generated globally is recycled (Geyer, 2020). It is estimated that more than %70 percent of plastic produced ends up in landfills or in the marine environment (Geyer, 2020; Singh & Walker, 2024). Plastics can be transported to the marine environment through a variety of ways, including rivers (Lebreton et al., 2017), offshore fishing and aquaculture-related operations (Lebreton et al., 2022), and littering along coastlines (Jambeck et al., 2015). Prolonged exposure to physical, chemical, and biological factors such as UV radiation, waves, microbial activities, and pH changes can cause macroplastics (>2.5 cm) to degrade into mesoplastics (0.5-2.5 cm), microplastics (MPs) (1 µm - 5 mm), and nanoplastics (<1 µm) in the marine environment (Lin et al., 2022). Depending on the time of exposure to environmental factors, various sizes of marine litter can be ingested by more than 500 marine species such as plankton, fish, seabirds, turtles, whales, and invertebrates, enter the food chain (Kühn et al., 2015). The trophic transfer of MPs poses a potential threat to human health through seafood consumption (Farrell & Nelson, 2013; Nelms et al., 2018). The main concern, however, is the accumulation of hazardous chemicals such as bisphenol A (BPA), alkylphenols, and nonylphenols, which adhere to MPs (Graca et al., 2024; Gu et al., 2016; Lu et al., 2021). Since MPs remain in the gastrointestinal tract, typically not consumed, these chemicals pose a greater risk to humans.

As part of the Global Plastic Cycle (Zhu, 2021), plastic products input from coastal regions into the ocean are predicted to be more than 20 million tons by 2030 (Borrelle et al., 2020). The Mediterranean Sea is a hotspot for MP pollution, with abundances exceeding the global average (Lebreton et al., 2012). MP pollution is increasingly expanding due to factors like atmospheric deposition, wind dispersion, surface runoff, and human activities such as industrial production, transportation, and agriculture (Xu et al., 2020; Yang et al., 2021; Su et al., 2022). It is estimated that plastic accumulation ranges from 1,000 to 3,000 tons in the Mediterranean Sea, due to a combination of high human activity and the basin's unique hydrodynamics (Cózar et al., 2015). The complexity of MP pollution increases in regions where agricultural and urban areas intersect. The absence of clear boundaries between these functions further complicates the pathways and impacts of MPs. Coastal areas of the Mediterranean Sea are heavily polluted, with an average plastic density of 2.60×10^5 items km^{-2} (Hu et al., 2024; Pedrotti et al., 2022). Human activities related to land use play a significant role in the transport of MPs from land to the sea (Y. Zhang et al., 2022; Bi et al., 2023). There is a limited understanding of the sources, land use, and fate of MP in The Mediterranean coast of Türkiye. The aims of this study were: *i*) to quantify the prevalence and characterizing the morphology of MP pollution in the region; *ii*) to examine the relationship between land cover and MP pollution; *iii*) to identify potential anthropogenic sources.

Materials & Methods

Samplings and Laboratory Processes

The Datça-Bozburun region, encompassing the Datça Peninsula and Bozburun Peninsulas, was designated a SEPA in 1990. This region, the largest SEPA in the Mediterranean basin, spans a vast area of 1,443.89 km² on land and 763 km² in the surrounding sea. Its exceptional biodiversity and significant archaeological treasures make the Datça-Bozburun SEPA a crucial protected area in Türkiye (Okus et al., 2007; Optimar, 2010; Bann & Başak, 2013).

Surface water samples were collected from 17 stations during the winter period in 2024. 16 sampling spots were chosen within the Datça-Bozburun SEPA region, while Bördübet Bay, just outside the region, was included to complete the coastline of the Datça peninsula. (Figure 1). For each sampling, three submersible pumps (6000 $L.h^{-1}$) were used simultaneously to collect triplicate samples (in total 51 samples). At each station, 100 L of surface water (0-30 cm depth) was collected using a flow meter and pumped into sealed metal filtration units. These units employed

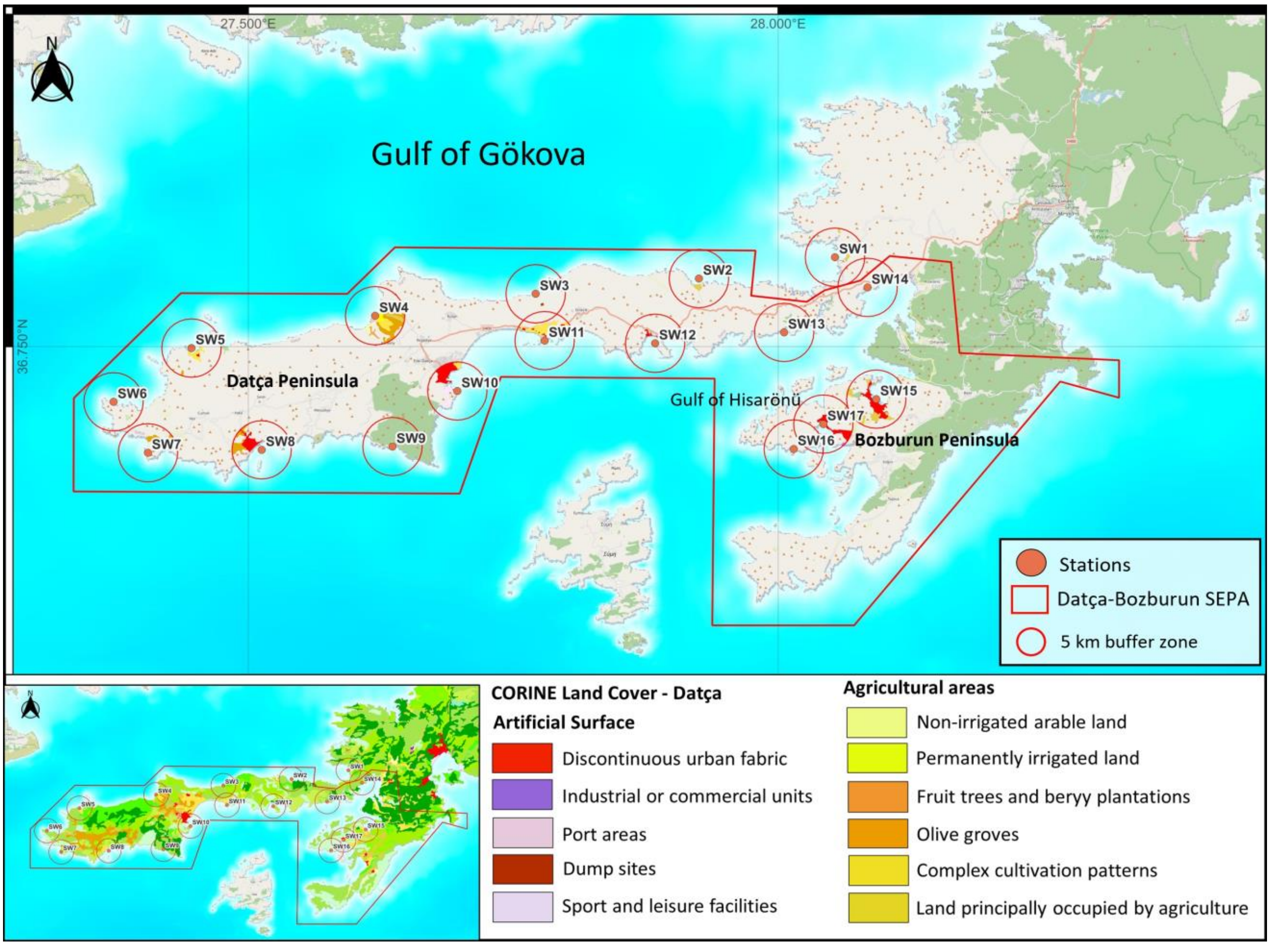

Figure 1. Maps of sampling stations and CORINE LULC classification.

filters with an 8.5 cm diameter and a 200 µm mesh size to capture and assess MP pollution. After on-site filtration, the filters were carefully stored in falcon tubes and transported to the laboratory for subsequent analysis.

Filters were subjected to a chemical treatment involving a 1 molar solution of potassium hydroxide (KOH) to remove organic materials. This treatment was conducted at room temperature for a duration of one to two days (Lusher et al., 2013). Following the organic material removal solutions were filtered to a 26 µm mesh size filters with vacuum filtration unit. Afterwards MPs were examined using an Olympus SZX16 Stereo microscope with a magnification of up to 11.5X. An Olympus 5.0 MP DP25 Digital Camera attached to the microscope captured images of identified MPs. Particle length measurements were obtained from these images using ImageJ (Abramoff et al., 2004). MPs were visually identified and categorized based on their physical characteristics, including size, colour, and type (European Commission, 2013; GESAMP, 2019). Based on the categorized of detected microscopic particles examined under the light microscope, a representative subsample of MPs was selected to reflect the characteristics of the entire sample. FTIR spectra of the samples were acquired using a Shimadzu IRTracer-100 spectrometer equipped with a QATR™ 10 Single-Reflection ATR with a Diamond Crystal, operating at a resolution of 0.25 cm^{-1} and covering the mid-IR region (4000-400 cm^{-1}). The obtained MP spectra were identified by comparison with the Shimadzu IR Spectral Database Collection.

Quality Control

To minimize airborne fiber contamination, all laboratory procedures were conducted while wearing nitrile gloves and cotton laboratory coats. All glassware and dissection tools were thoroughly rinsed with distilled water before use. Laboratory procedures, including filtration and microscopic examination, were performed in a fume hood. "Procedural controls" were implemented as a further precaution against contamination. These controls consisted of 150 mm diameter glass containers filled with distilled water, placed within the work environment. Fibers detected in these controls were meticulously examined and categorized based on their colour, length, and thickness. Before statistical analysis, the final dataset was adjusted by excluding similar MPs identified in the procedural controls. This involved removing MPs that shared the same colour, size, and thickness as those found in the controls.

Statistical Analyses

Before conducting statistical analyses, we assessed the normality and homogeneity of our data using the Kolmogorov-Smirnov and Shapiro-Wilk tests. To assess the variability in MP particle size among replicate samples collected in the field, as well as to evaluate statistical differences in pollution levels across sampling stations, One-Way ANOVA post hoc test (Least Significant Difference (LSD) method ($p < 0.05$)) was employed. The study used CORINE Land Use Land Cover (LULC) data from the European Union's Copernicus Land Monitoring Service to assess the anthropogenic pressure in the study area (European Union, 2018). The data was processed using QGIS Version 3.34.8 (QGIS.org, 2024) and included land cover data (km^2) within a 5 km diameter buffer zone around each sampling point. The study focused on the "Artificial Surfaces" and "Agricultural Areas" levels of the CORINE data. To examine the relationship between LULC and MPs pollution, principal component analysis (PCA) was performed using the ORANGE program. The data was normalized between 0-1 and then heat map and cluster analysis were performed to determine the similarities between the stations. All results were presented as the arithmetic mean accompanied by the standard deviation (SD), unless otherwise specified.

Results

MP pollution was evaluated at 17 stations with three replicate sampling in the study region. A total of 132 microplastics (1.49±1.11 mm) and 6 mesoplastics (6.63±1.62 mm) were detected in the water samples. While the MPs abundance ranged between 10 – 56.7 MPs.m^{-3}, the average abundance of MPs was detected 25.9±14.4 MPs.m^{-3}. There was no difference in MP size between replicates (ANOVA: 0.699, p=0.499). Statistically significant MP abundance difference was detected between sampling stations (ANOVA: 2.563, p=0.01). The station with the highest abundance of MPs was SW15 (56.7 MPs.m^{-3}), followed by SW8 (53.3 MPs.m^{-3}) and SW2 (43.3 MPs.m^{-3}). The station with the lowest abundance of MP was SW9-10-14 (10 MPs.m^{-3}) (Figure 2).

The most common type of MPs found was fiber (93.9%), followed by paint particles originated from exterior paints of ships (3.8%) and film (2.3%). In the regions with the highest MPs abundance (SW15, SW8, and SW2), only fiber particles were found. Film pollution was detected in SW5, SW3, and SW17, while paint was found in SW7, SW10, SW11, and SW12. The most common colour of MPs was black (71.2%), followed by blue (23.5%) and red (5.3%). Of the MPs analyzed using FTIR, 87.5% were fibers and 12.5% were film particles. The average spectral match score for the FTIR analysis was 713.67±81. Seven different polymers were identified in the sub-sample of MPs based on spectral analysis. Ethylene/propylene copolymers (EPCs) was the most common copolymer, accounting for 37.5% of the sample. Polyethylene terephthalate (PET) was the most common polymer, accounting for 16.7% of the sample. The rate of other detected polymers in the sample were: Polyester (PES) – 12.5%, Polyamide (PA) – 12.5%, Polyethylene (PE) – 8.3%, Polypropylene (PP) – 8.3%, and Low-density polyethylene (LDPE) – 4.2% (Figure 3).

The LULC patterns within a 5-kilometer radius of each sampling point, as revealed by CORINE LULC data, vary significantly across the region. SW10, situated in Datça's city center, is primarily characterized by discontinuous urban fabric, sport and leisure facilities. SW15 (Selimiye), SW17 (Bozburun), SW8 and SW11 exhibit a mix of discontinuous urban fabric and Land principally occupied by agricultural areas. SW1, SW2, SW4, SW5, SW7, and SW16 are dominated by agricultural areas (land principally occupied by agriculture, complex cultivation patterns, olive groves and permanently irrigated land). SW3 is primarily a dump site, while SW14 is characterized by sports and leisure facilities. Sampling stations SW6, SW9, and SW13 were characterized as pristine natural environments, lacking any significant human development or agricultural activities. Although a single dominant land cover is observed, SW12, SW14, and SW16 areas are characterized by small areas (Figure 4).

Discussion

Once MPs enter the aquatic environment, they spread across different environments such as the water column, surface water, and sediments. This widespread distribution of MPs has led to a global environmental pollution problem with widespread consequences, affecting various ecosystems such as terrestrial, aquatic, and atmospheric environments. The significant role of these plastic particles in disrupting marine ecosystems has been acknowledged, emphasizing the need to recognize them as a major environmental concern (Aydın et al., 2023; Su et al., 2022; Xu et al., 2020). This research, conducted in the Datça-Bozburun SEPA, aimed to assess the level of (MPs) pollution in the region and identify its possible origins. The predominance of smaller MPs (less than 2 mm) in this study aligns with previous research, which highlights the fragmentation of larger plastics as a significant source of MP pollution (Gürkan & Yüksek, 2022; Kermenidou et al., 2023; Öztekin et al., 2024). The average size observed in this

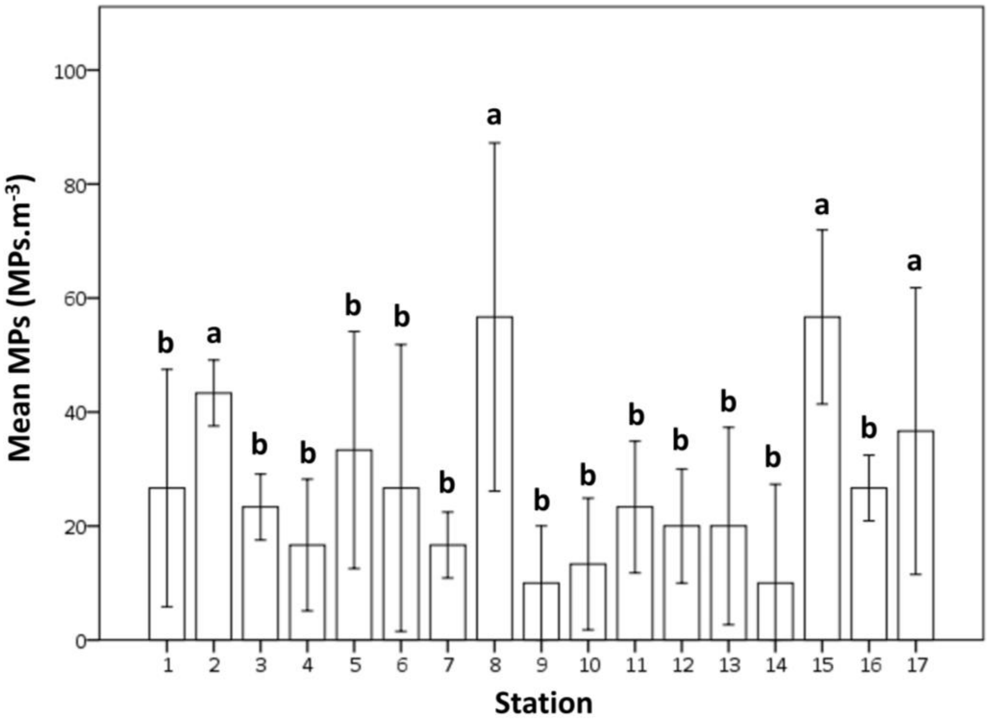

Figure 2. Abundance of MPs across sampling stations. Different lowercase letters indicate statistically significant differences between stations (ANOVA, LSD, p<0.05).

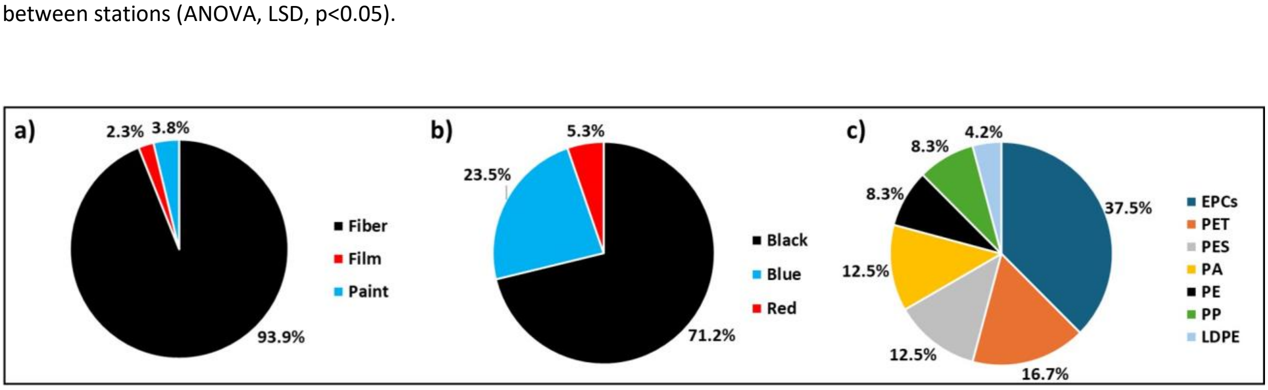

Figure 3. Distribution of type (a), colour (b) and polymer type (c) of the MPs in the study area.

study is similar to findings from other studies, such as (Guven, 2021) 1.8±1.2 mm, (Gürkan & Yüksek, 2022) 1.55mm, (Aytan et al., 2016) for fiber 1.253±0.954 mm and for fragments 1.035±0.429. (Öztekin et al., 2024) has a smaller average of 0.14±0.11 mm in the study, while (Tunçer et al., 2018) the average size is higher at 6.159±8.39 mm in the study.

The most common type of MPs found was fiber (92.9%), previous research, fiber was found to be dominant (Aytan et al., 2016; Guven, 2021; Gürkan & Yüksek, 2022; Öztekin et al., 2024). Textile products are the main source of fiber found in the marine environment. Synthetic textiles are responsible for polluting seawater with approximately half a million tonnes of MPs annually (Carr, 2017; Gavigan et al., 2020; Manshoven et al., 2022). Adding to this, investigations into agricultural and residential land demonstrate the dominance of fiber (Bi et al., 2023; Hu et al., 2024).

Our results show that the average abundance of MPs recorded on the surface water was 25.9±14.4 $MPs.m^{-3}$ (min-max: 10 – 56.7 $MPs.m^{-3}$). Considering previous studies from the Turkish coast and in the region, in the Marmara region, (Tunçer et al., 2018) study, designed to reflect the Sea of Marmara, assessed the status of MPs pollution and found an average MPs pollution of 12.63 $MPs.m^{-3}$. (Gürkan & Yüksek, 2022) study on the southern Marmara coast, which is exposed to different pressures, determined the levels of MPs pollution in bays. Surface water and water column MP abundances were compared. MPs abundance ranged from 0.17-2.52 $MPs.m^{-3}$. A 2021 study found that the Küçükçekmece lagoon in Istanbul has the highest levels of MP pollution, with an abundance of 33,000 $MPs.m^{-3}$ (Çullu et al., 2021). In the Black Sea coast, A 2016 study found an average MPs abundance of 1100 $MPs.m^{-3}$ while a later study by the same researcher in 2020 found a range of 1.80 to 47.97 $MPs.m^{-3}$ (Aytan et al., 2016, 2020). (Öztekin et al., 2024) the study examined MPs at seven different stations and five depths. The highest abundance averaging 21.07±3.84 $MPs.m^{-3}$, was found at a depth of 2 meters. Research on the Mediterranean coast, a 2021 study found the highest MPs pollution at 5 meters depth in the vertical distribution profile, with levels of 14.6 $MPs.m^{-3}$ in Aksu Stream, 16 $MPs.m^{-3}$ in Köprü Stream, and 13.7 $MPs.m^{-3}$ in Manavgat River (Guven, 2021). Another study identified potential MPs pollution hotspots along the western Mediterranean coast of Türkiye. The Gulf of Hisarönü had an average of 1.12 $MPs.m^{-3,}$ Marmaris/Fethiye had 0.93 MPs.m-3, Finike had 2.1 $MPs.m^{-3}$, Antalya had 1.12 $MPs.m^{-3}$ and Mersin had 0.91 $MPs.m^{-3}$ (Gedik et al., 2022). In the Aegean Sea, (Kermenidou et al., 2023)study reported an average MPs abundance of 1.9 $MPs.m^{-3}$, while (Adamopoulou et al., 2021) study found an average of 1.18 $MPs.m^{-3}$.

The most common polymer identified in FTIR analyses was EPCs, which were found exclusively in fiber particles. EPCs are often used as additives in plastics and textile production. This additive, incorporated during textile manufacturing, is utilized in Spunbond and Meltblown fabrics, waterproof coatings, and for imparting elastic properties (Allen et al., 2024). The second most abundant polymer among the samples was PET. This polymer is one of the most widely used polymers in the textile industry and plays an important role in a variety of applications. PET is a type of thermoplastic polymer that is a key component of polyester fibers, which are widely used in both clothing and industrial textiles (Aizenshtein, 2013; Kuczenski & Geyer, 2010).

Within the scope of the presented investigated the relationship between land cover patterns and MP pollution levels. Using data from the CORINE LULC database, PCA analysis (explained 61% of the variance), heatmap visualization, and cluster analysis were employed to explore this connection within a 5 km radius of the sampling sites (Figure 4-5). The analysis revealed three distinct groups based on land cover. SW4, characterized by intensive agricultural areas and port areas, exhibited low MPs pollution compared to other regions. The proximity of SW3 station to a dump site suggests it as a probable pollution source. SW2 and SW5, with complex cultivation patterns and land principally occupied by agriculture, were among the most polluted regions. SW17, SW15, and SW8, with high pollution levels, were identified as port areas, discontinuous urban fabric, land principally occupied by agriculture areas and complex cultivation patterns addition, the presence of Industrial structure in SW17. In the cluster analysis conducted, although it is in the same group in terms of land use, SW10 (Datça city centre) is the region where pollution is low.

80% of MPs resources originate from terrestrial sources and reach marine systems (Duis & Coors, 2016). Our results indicate that increasing urbanization, including the expansion of residential areas, port, and industrial developments, contributes to MPs pollution, supporting findings from previous studies (Li et al., 2023; Y. Zhang et al., 2022) and our research confirms previous findings that agricultural land use significantly impacts MP pollution (Gündoğdu et al., 2022; Bi et al., 2023; Hu et al., 2024).

The presence of MPs at sampling stations SW6, SW9, and SW13, despite the absence of nearby artificial areas or agricultural lands, highlights the need for comprehensive assessments of pollution sources. This is because MPs can travel long distances and originate from unexpected sources due to hydrodynamic processes like currents, tides, and waves (Auta et al., 2017; Cole et al., 2011; Mancuso et al., 2023). Surface current circulation plays a significant role in the dispersion of MPs and can help explain their presence in seemingly unexpected locations. Particle tracking models are valuable tools for understanding these transport dynamics and identifying potential sources of MPs (Lebreton et al., 2012; H. Zhang, 2017).

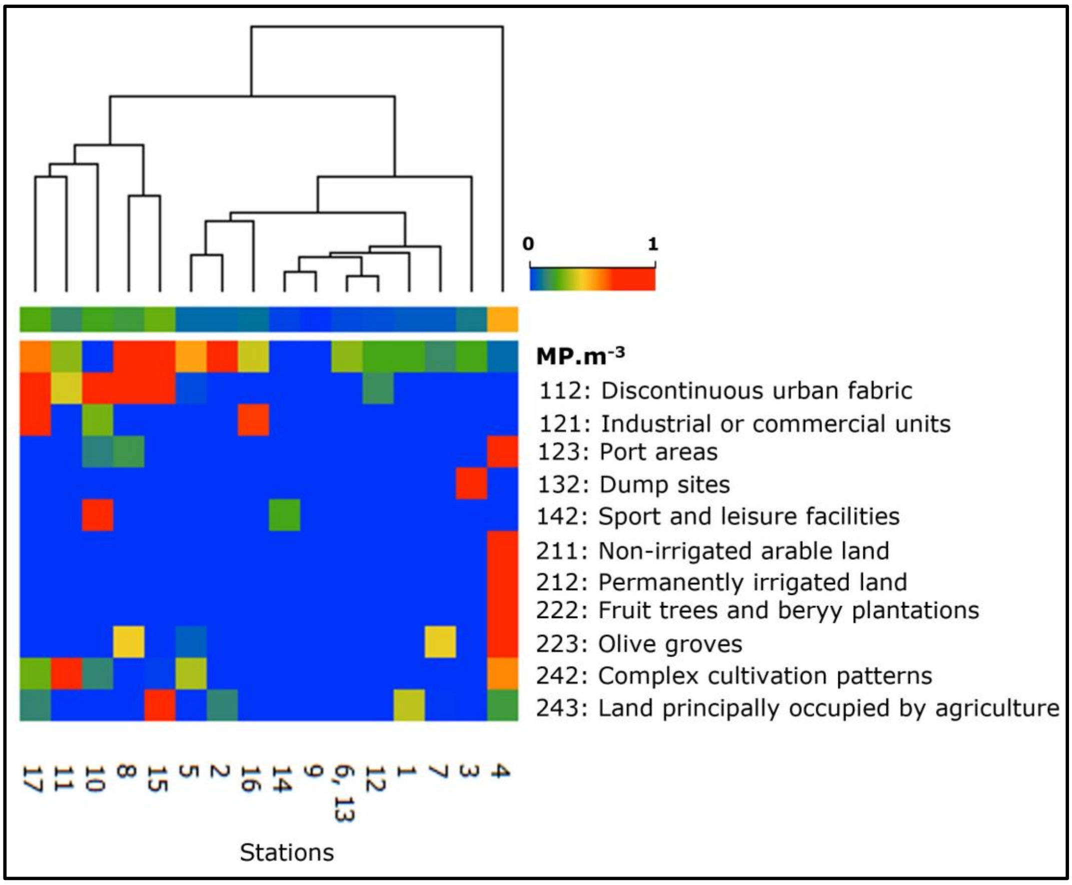

Figure 4. Relationship between CORINE LULC data and MPs pollution at stations with heat map and cluster analysis (data is normalized to 0-1).

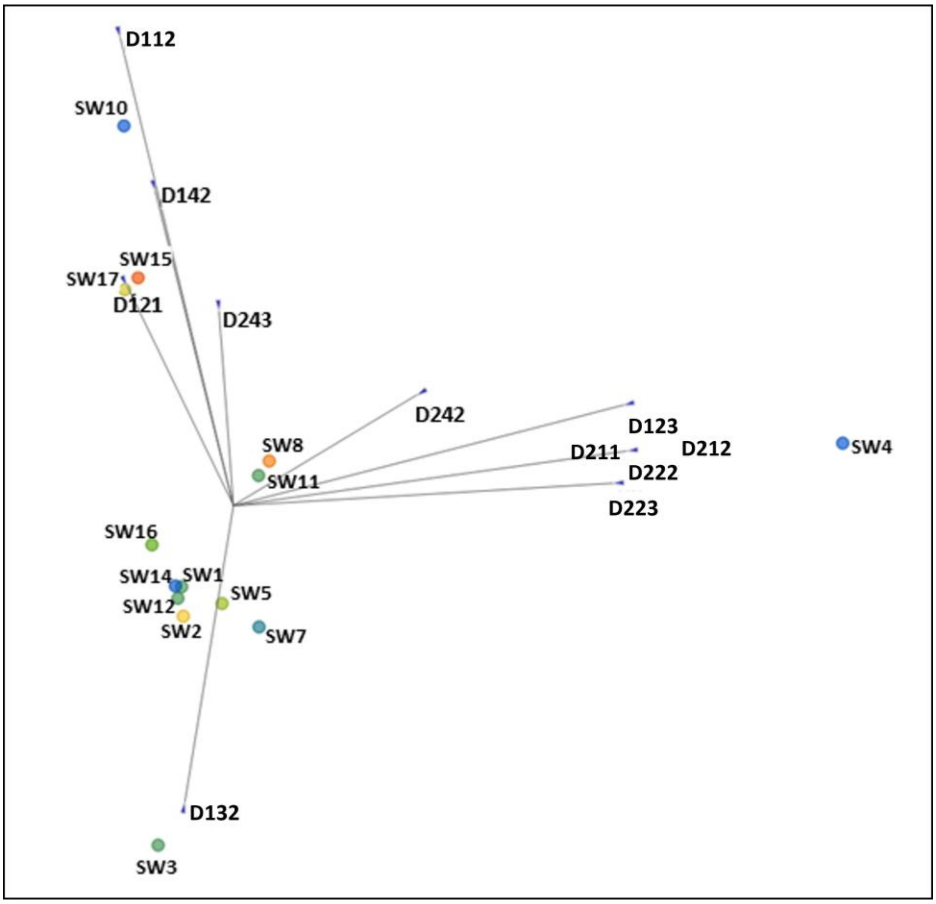

Figure 5. Principal Component Analysis (PCA) plot indicates the relationships between CORINE LULC data and sampling site.

Conclusion

This study examined the distribution and potential sources of MPs across different land use types in the Datça-Bozburun SEPA, an area with special environmental protection status. The findings revealed that various land use types and human activities significantly influence the accumulation of MPs in the environment. MP pollution was primarily observed in three regions with high human activity, such as residential areas, industrial sites, and holiday facilities. In three other regions, pollution was linked to both human activities and the presence of agricultural areas and port facilities. Although terrestrial land use data provided insights into pollution sources, it was noted that some stations with detected pollution showed no direct artificial or agricultural areas use. The source of MPs in coastal areas may not necessarily be local but could be influenced by factors like surface currents. To better understand the relationship between pollution and its sources, more comprehensive approaches are needed.

Ethical Statement

This study does not require an ethics committee report.

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Author Contribution

İdris Koraltan: Analysis, Conceptualization, Data Curation, Writing -review and editing

Kerem Gökdağ: Field work, Methodology, Writing -original draft

M.Tunca Olguner: Field work, Methodology, Funding acquisition, Writing -original draft

Olgaç Güven: Supervision, Analysis, Writing -review and editing

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 the work reported in this paper.

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