

Review

Microplastics in Our Waters: Insights from a Configurative Systematic Review of Water Bodies and Drinking Water Sources

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Abstract: Microplastics (MPs), defined as plastic particles smaller than 5 mm, are an emerging global environmental and health concern due to their pervasive presence in aquatic ecosystems. This systematic review synthesizes data on the distribution, shapes, materials, and sizes of MPs in various water sources, including lakes, rivers, seas, tap water, and bottled water, between 2014 and 2024. Results reveal that river water constitutes the largest share of studies on MP pollution (30%), followed by lake water (24%), sea water (19%), bottled water (17%), and tap water (11%), reflecting their critical roles in MP transport and accumulation. Seasonal analysis indicates that MP concentrations peak in the wet season (38%), followed by the dry (32%) and transitional (30%) seasons. Spatially, China leads MP research globally (19%), followed by the USA (7.8%) and India (5.9%). MPs are predominantly composed of polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET), with fibers and fragments being the most common shapes. Sub-millimeter MPs (<1 mm) dominate globally, with significant variations driven by anthropogenic activities, industrial discharge, and environmental factors such as rainfall and temperature. The study highlights critical gaps in understanding the long-term ecological and health impacts of MPs, emphasizing the need for standardized methodologies, improved waste management, and innovative mitigation strategies. This review underscores the urgency of addressing microplastic pollution through global collaboration and stricter regulatory measures.

Keywords: microplastics; pollution; environment; freshwater; public health; mitigation strategies; tap and bottled water



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1. Introduction

Microplastics (MPs), defined as plastic particles smaller than 5 mm, have become a critical environmental issue due to their widespread distribution and persistence in aquatic systems [1,2]. These particles originate from various sources, including personal care products, synthetic textiles, and the breakdown of larger plastic debris, eventually accumulating in ecosystems across the globe [3–5]. Microplastics are now found in lakes, rivers, seas, and even freshwater sources like drinking water, raising concerns about their ecological, economic, and potential health impacts [6,7]. Their ubiquity underscores a global crisis requiring immediate attention.

The unique characteristics of microplastics, such as their small size, durability, and ability to carry pollutants, exacerbate their risks. These particles not only persist in the environment but also adsorb harmful chemicals, making them dangerous carriers of toxins that threaten aquatic organisms and, ultimately, human health [8–10]. Recent studies reveal that global warming is compounding this problem by releasing previously trapped microplastics from Arctic ice [11]. This highlights the far-reaching consequences of microplastic pollution, extending beyond traditional water bodies.

In lakes, microplastic pollution has been documented in varying concentrations, often influenced by local activities such as urbanization and agriculture [12,13]. For instance, research on Poyang Lake, China, and Lake Ontario, Canada, reveals alarming levels of contamination, affecting fish and other aquatic organisms that ingest these particles [12,14]. Such findings reflect a broader trend, as lakes worldwide are similarly affected by regional human activities.

Rivers play a pivotal role in transporting microplastics from land to the oceans. These waterways carry pollutants from urban runoff, industrial discharge, and agricultural sources [15,16]. In Asia, studies on the Yellow River indicate significant seasonal variations in microplastic concentrations, influenced by monsoon patterns and agricultural runoff [17,18]. Storm events further exacerbate these issues, with regions like South Korea observing sharp increases in microplastic levels after heavy rainfall [19,20]. As critical conduits, rivers highlight the interconnected nature of terrestrial and marine pollution.

Seas and coastal waters face the brunt of microplastic pollution, with concentrations especially high near urban centers due to industrial activities and coastal runoff [21,22]. Studies in the Northwestern Pacific and the Bohai Sea reveal extensive contamination, with particles carried by ocean currents to remote regions [23]. These microplastics are ingested by marine organisms, leading to bioaccumulation and trophic transfer within food webs, which can ultimately impact human consumers [8–10].

Freshwater sources, including drinking water, pose direct risks to human health. Microplastics have been detected in tap water, bottled water, soft drinks and even table salt, raising concerns about human ingestion [6,24,25]. For example, studies in Bangkok, Thailand, found microplastics in both tap and bottled water, suggesting current treatment processes are insufficient [26]. Despite growing evidence, the long-term health implications of chronic exposure remain uncertain, warranting further research and improved filtration technologies [27].

Despite extensive research on microplastic pollution in aquatic environments, significant gaps remain in our understanding. Existing studies often focus on specific water systems—lakes, rivers, seas, tap water, or bottled water—without providing a comprehensive comparison across these sources [1,4]. This limits our ability to identify extensive patterns and interconnections, such as the role of rivers in transporting microplastics from terrestrial to marine ecosystems [15]. Regional and seasonal variability is frequently highlighted, but these findings are seldom synthesized to reveal global drivers like industrial activities, land use changes, and climate impacts [17,18]. Additionally, inconsistent methodologies in sampling, analysis, and reporting hinder comparability across studies, leading to fragmented knowledge [6,20].

Research also falls short in addressing the long-term health effects of microplastics in drinking water and food supplies, despite their widespread detection [25,26]. Studies identifying specific pollution sources and pathways remain sparse, particularly in under-represented regions like Africa and South America [28,29]. Furthermore, the predominance of smaller microplastic particles (<1 mm) raises concerns about their bioavailability and potential trophic transfer, yet this aspect is inadequately explored [8,9]. This review seeks to bridge these gaps by synthesizing data across multiple water sources, analyzing regional

and seasonal variations, and identifying priorities for future research on health impacts and mitigation strategies.

The aim of this study is to systematically review the presence, distribution, and impacts of microplastics in various water sources, including lakes, rivers, seas, tap water, and bottled water, providing a comprehensive synthesis of existing literature. This research seeks to address key questions:

- What are the dominant sources and types of microplastics found in each water source?
- How do regional and seasonal factors influence their distribution and abundance?
- What are the potential ecological and health impacts associated with microplastic contamination in these systems?

By answering these questions, the study aims to inform strategies for mitigation and future research priorities. Moreover, the methodology of this review details the careful development of our literature, while the results section is structured into two parts. First, we offer a concise summary of the key understandings from the reviewed articles. Next, we conduct an in-depth systematic review analysis, presenting the findings in a comprehensive fashion. Later, we outline the direction for future studies, highlighting the importance of understanding the impacts of MPs.

2. Methodology

2.1. Reporting

To comprehensively investigate the subject of microplastics in water, as illustrated in Figure 1, we conducted a systematic review according to the guidelines set forth by Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).

2.2. Search Strategy

This review aimed to identify and analyze articles published between January 2014 and December 2024, utilizing the institutional library. We extensively investigated the articles relevant to our topic by following a search strategy that applies a general-to-specific approach. We incorporated a handful of keywords commencing with the topic ‘Microplastics and Water’, followed by the same keywords searched within the topic. We then refine our search using the following keywords: ‘Microplastics and Lakes’, ‘Microplastics and Rivers’, ‘Microplastics and Sea Water’, ‘Microplastics and Tap Water’, and ‘Microplastics and Bottled Water’.

2.3. Inclusion and Exclusion Criteria

While extracting data, we took measures to ensure that our research was trustworthy and of superior quality. Initially, we limited our focus to English-language articles and cross-referenced each article’s sources to identify relevant literature. We organized the chosen articles in the “Author’s Sur Name and Year” format, discarding review articles, duplicate articles, books, book chapters, irrelevant articles, and others. We presumed the chosen database upheld all criteria during the peer-review procedure, ensuring high quality. We considered that all articles should be published in Scopus-indexed journals because these journals are widely recognized for their high quality, credibility, and impact in academic research. Researchers, institutions, and funding agencies prefer Scopus-indexed studies because of their rigorous peer-review process, comprehensive and reliable indexing, global recognition and accessibility, quality control, and ethical standards.

2.4. Quality and Risk of Bias Assessments

Two investigators, GS and AB, conducted the data extraction process separately to minimize potential biases. To determine the eligibility of the articles, the researchers

scrutinized the article title, year, and abstract and made independent judgments. In instances of dissension, GS, who led this research, supervised the procedure and settled any divergences.

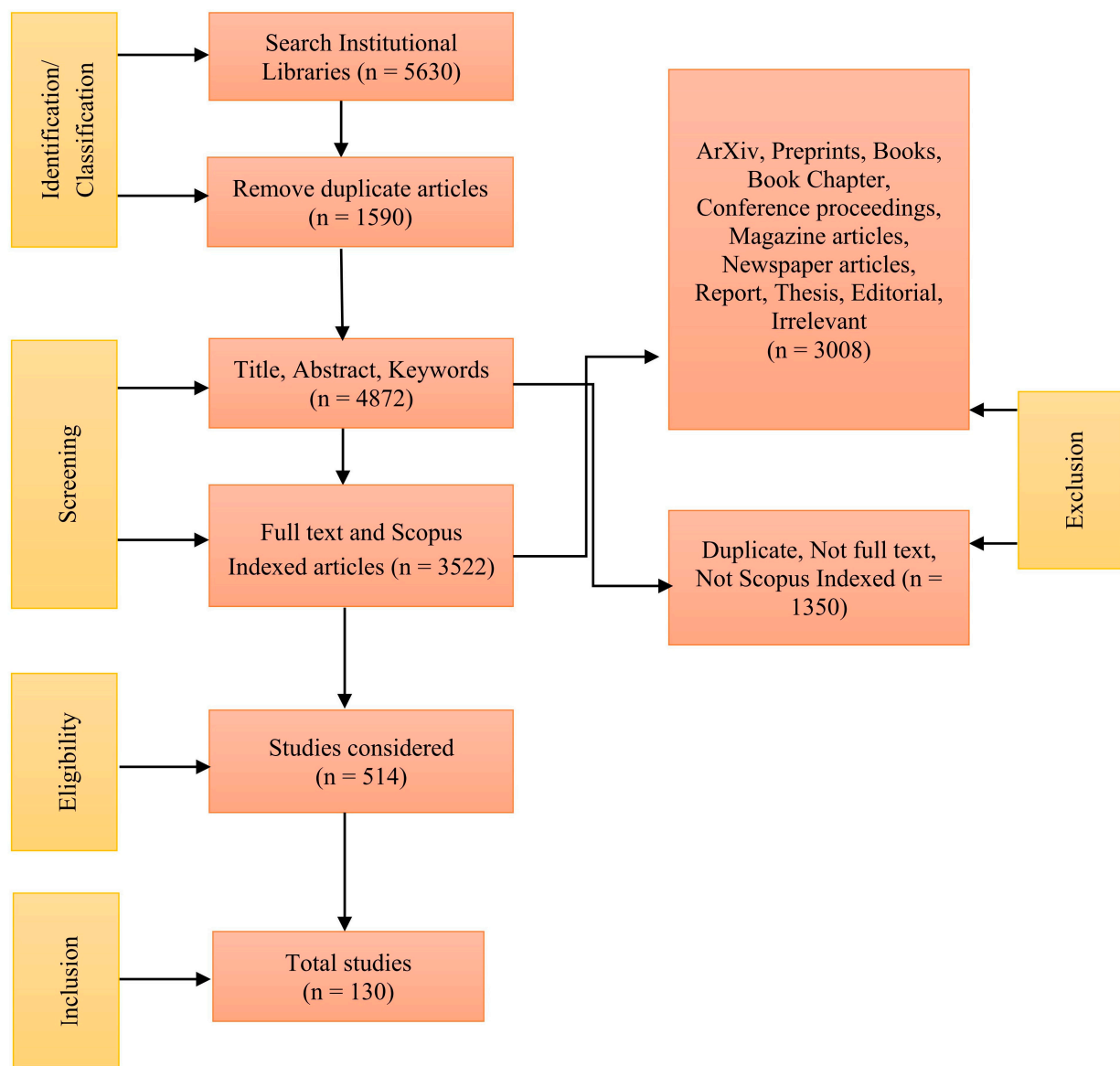


Figure 1. PRISMA diagram for our research.

2.5. Search Findings and Study Characteristics

During our search, we initially identified 5630 articles related to microplastics in water, focusing on peer-reviewed articles published between January 2014 and December 2024, indexed in Scopus, and written in English. We further narrowed the search by focusing on specific water sources, which resulted in the following categories: 461 articles on microplastics in lakes, 1152 in rivers, 1576 in sea water, 425 in tap water, and 426 in bottled water. To ensure relevance, we considered only journal articles, excluding preprints, book chapters, books, magazines, report, thesis, short communication, etc. Following a thorough review of titles and abstracts, 514 articles were chosen for detailed full-text screening. Ultimately, 130 articles were included in the current review study. To avoid duplication, each study was assigned to a single category based on its primary research focus. If a study investigated multiple water bodies (e.g., rivers feeding into lakes), it was

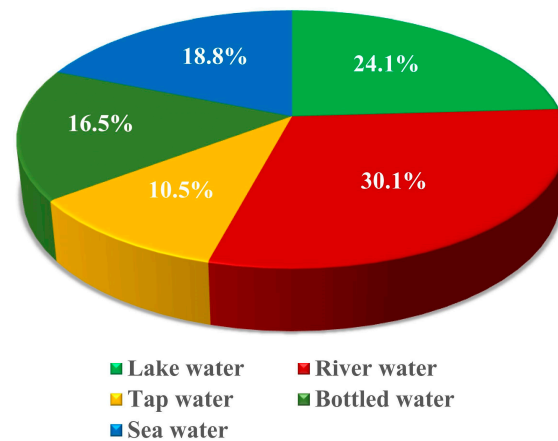


Figure 3. Percentage of research conducted on different water samples.

Figure 4 depicts the distribution of microplastics sample collections across three distinct seasonal periods: the dry season, the wet season, and a period that spans both seasons. The data highlights the effort to capture microplastic presence under varying environmental conditions, enabling a more comprehensive understanding of seasonal influences on MP distribution and transport. Approximately 32% of MP samples were collected during the dry season. This period, typically marked by minimal rainfall, likely influences the retention and deposition of MPs in the environment. With limited water flow, MPs might accumulate in specific locations, making dry season sampling crucial for understanding their static distribution patterns. The wet season accounted for 38% of MP samples, representing the largest share. The wet season is characterized by increased rainfall and surface runoff, which can facilitate the transport of MPs into water bodies, soils, and other areas. Sampling during this time provides insights into how dynamic hydrological processes, such as flooding or storm water flow, contribute to the movement and dispersal of MPs. Additionally, 30% of the samples were collected during transitional periods encompassing both the dry and wet seasons. This category likely captures the influence of seasonal transitions on MP distribution, offering insights into the combined effects of varying environmental conditions. Sampling during these periods is essential for understanding how shifts between dry and wet conditions impact MP deposition, movement, and accumulation.

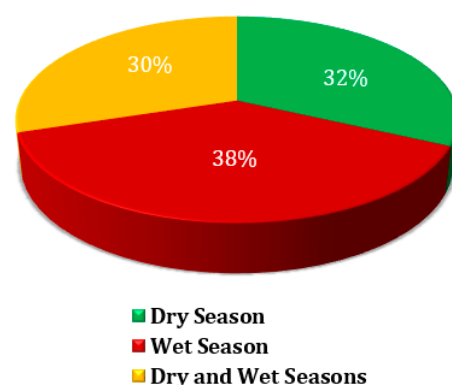


Figure 4. Percentage of sample collections by period.

The temporal distribution of articles is shown in Figure 5. Among all the articles on MPs in freshwater environment, the oldest one was from 2014, while the latest is from 2024. The trend shows that the number of articles published started showing an upward trend

from 2018 onwards. This proves that it is one of the emerging environmental pollutants. In 2023 alone, 21.1% of the articles considered in this study were published.

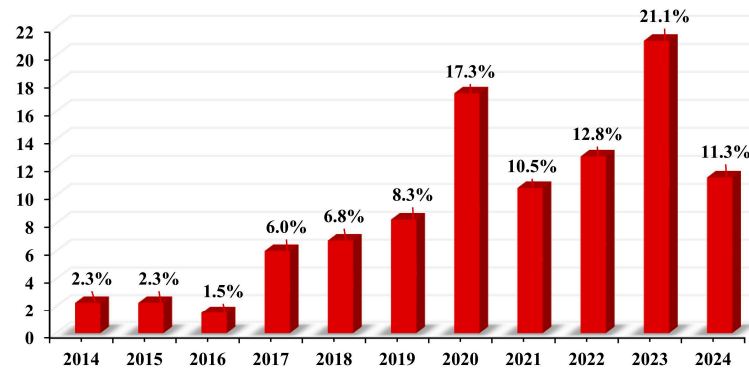


Figure 5. Percentage of articles published between 2014 to 2024.

Figure 6 shows the percentage of articles published in different journals. Environmental Science journals make up the highest number of articles, followed by Environmental Pollution journals. This highlights the growing interdisciplinary interest in microplastics research, spanning fields such as chemistry, biology, environmental science, sustainable resource management, disaster risk reduction, and climate change. Consequently, there is a strong need for current and localized information on the presence and impact of microplastics in the environment. Addressing this need further underscores the importance of this review at the present stage.

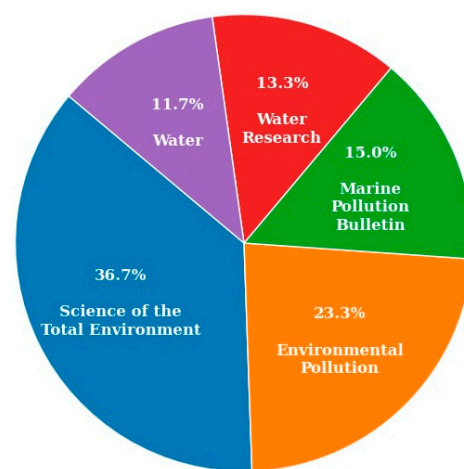


Figure 6. Percentage of articles published in the journals.

Figure 7 shows the spatial distribution of MPs sample collection. The chart illustrates the percentage distribution of MPs samples collected across various countries, highlighting their contributions to studies on MP pollution. China accounts for the largest share, with 19% of the samples, reflecting its significant role in microplastic research. The USA follows with 7.8%, and India ranks third with 5.9%, indicating these countries' substantial efforts in monitoring and studying microplastic pollution. The chart also highlights a notable contribution from European countries, such as Spain (4.6%), Germany (3.3%), Italy (2.6%), and Finland (2.6%). These nations, often regarded as having cleaner environments compared to many parts of the world, including the USA, show a significant percentage of MPs collection samples. This suggests that even countries with robust environmental regulations are not immune to the pervasive issue of microplastic pollution and underscores their active engagement in addressing it through research. On the other hand, African

nations, such as South Africa (2.6%) and Nigeria (1.3%), also feature in the chart, albeit with smaller contributions. This reflects a growing awareness of microplastic pollution in the African continent, which faces unique challenges such as waste management infrastructure and monitoring systems. The representation of African countries in this research highlights the global reach of microplastic pollution and the importance of studying its effects across diverse ecosystems, including developing regions.

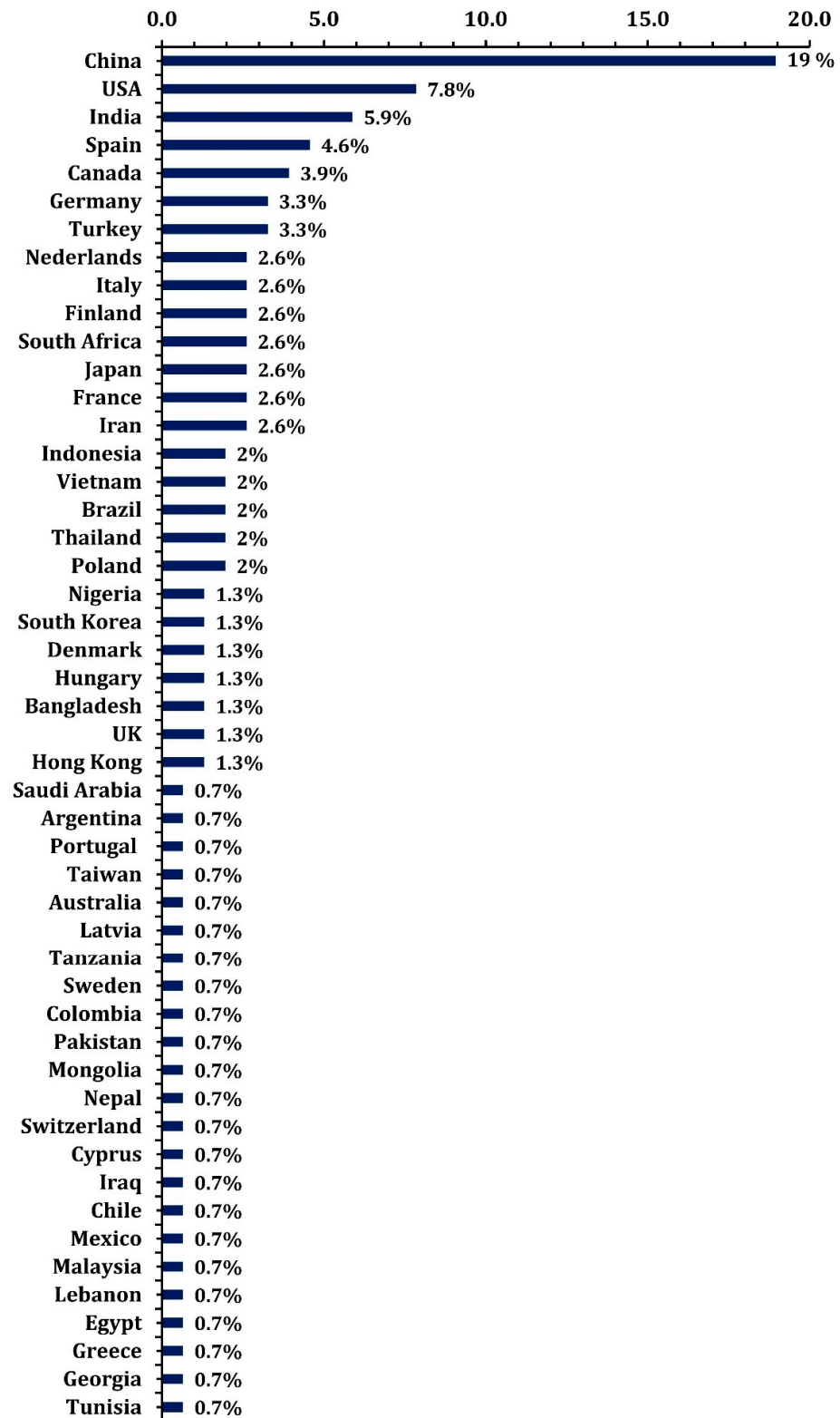


Figure 7. The proportion of countries where microplastic samples have been collected.

4. Discussion

Microplastics, plastic particles smaller than 5 mm, have been part of the ecosystem for a long time. In 2004, Richard Thompson, a professor of Marine Biology at the University of Plymouth, and his team were the first to demonstrate that microplastic particles have existed and accumulated in the oceans since the 1960s and are now globally prevalent in our seas [30]. Since the term “microplastic” was introduced, approximately 7000 research studies have been published to date, highlighting that the rate of global plastic production has doubled over the past two decades and, according to Thompson, could triple by 2060 [31].

In the following subsections, we will discuss in detail the presence, forms, structures, and other characteristics of these microplastic particles in various aquatic environments.

4.1. Microplastics in Lakes

Table 1 summarizes the MPs pollution in lakes from different areas of the world with important characteristics of MPs like abundance, shapes, materials, colors, and sizes.

Lakes show a large global variation in microplastic pollution level. This is affected by environmental and anthropogenic factors. For instance, particulate abundance reaches up to 2×10^7 particles/km² in Lake Ontario (Canada/USA) [32] and only 0.03 particles/m³ in remote Great Slave Lake (Canada) [33]. In China, lakes along the Yangtze River have been found to have high concentrations—between 1660 and 8925 particles/m³ [34]. Seasonal studies show even more variability, with dry season concentrations of up to 8329 particles/m³ [28].

The dominant shapes of MPs vary across regions, with fibers being the most common. For example, they account for 95% of MPs in Lake Mead, USA [35], and 93–97% in Lake Phewa, Nepal, depending on the season [36]. Similarly, fibers dominate in Taihu Lake, China, comprising 48–84% of MPs [37]. Fragments are prominent in Sierra Nevada Lakes (60%) [38] and Lake Ontario (up to 42%) [32]. Lesser shapes like foam, films, and pellets are also observed, such as in the Mercy et al. [29] study of Bangladeshi lakes, where films comprise 28%.

The materials of MPs highlight diverse sources of pollution. Common polymers such as polyethylene (PE), polypropylene (PP), and polyester (PES) dominate globally, including in Lake Ontario [32] and Songshan Lake, China [39]. Specific materials like cellophane (CE) are detected in Vesijärvi Lake, Finland [40], linking pollution to packaging waste. Seasonal variations also influence material profiles, as seen in Ox-Bow Lake (Nigeria), where PET dominates in the dry season (72.63%), while PVC is prevalent during the rainy season (81.5%) [28].

The analysis of MPs colors offers insights into pollution origins and degradation. Transparent, blue, and black are globally prevalent. For instance, blue dominates in Taihu Lake, China (50–63%) [37], and Sierra Nevada Lakes, Spain (53%) [38]. In Vesijärvi Lake, Finland, 87% of MPs are white or transparent [41]. Unique regional patterns include gold fragments in Luruaco Lake, Colombia [42], hinting at localized sources.

Microplastics size distribution predominantly skews toward smaller particles. Sub-millimeter MPs (<1 mm) dominate globally, such as in Mahodand Lake, Pakistan, where 57% of MPs are 300–500 µm [43], and Ox-Bow Lake, Nigeria, where sizes below 1 mm comprise 75–80% of MPs [28]. Larger MPs (<5 mm) are observed less frequently, as in Poyang Lake, China [12]. Vesijärvi Lake (Finland) reports fragment sizes of 1100 ± 230 µm and fibers at 430 ± 49 µm [41].

Seasonal and environmental factors significantly influence MPs distribution. For example, dry season concentrations in Ox-Bow Lake, Nigeria, are much higher than rainy season levels, indicating reduced dilution during dry periods [28]. Snow and ice in Vesijärvi

Lake, Finland, contain MPs, with concentrations in snow reaching 117.1 ± 18.4 MPs/L, compared to 7.8 ± 1.2 MPs/L in ice [40]. Seasonal studies in Lake Phewa, Nepal, show higher MPs concentrations during the dry season [36].

Table 1. Abundance of microplastics in lakes, and their shapes, materials, colors, and sizes.

Ref.	Region, Sampling Collection Year, and Abundance	Shape of MPs	Materials of MPs	Color of MPs	Sizes of MPs
[12]	Poyang lake, China, November 2017, 5–34 items/L	Fiber (41.2%), Film, Fragment, Pellet	PP (38.5%), PE (32.3%), Nylon, PVC (6.2%)	White, Black, Colored (48.9%), Transparent (35.9%)	Less than 0.5 mm (73.1%)
[13]	Flathead lake, USA, Summer, 2018, 8×10^4 – 4.22×10^5 particles/km ² , MPs: 100 µm–5 mm	Fiber (55.2–98.5%), Sheet, Fragment, Line	PE, PET, PP, PVC, PS	-	-
[14]	Lake Ontario, Canada, 0.8 particles/L	Fiber (28%), Film (27%), Foam (8%), Fragment (34%), others	PET, PE, PVC, PP, PA, CA	White	-
[28]	Ox-Bow lake, Nigeria, December 2018 to June 2019, Dry season: 1004–8329 particles/m ³ , Rainy season: 201–8369 particles/m ³	Fiber, Pellet, Fragment, Bead, Film, Flake	Dry season: PET (72.63%), PP (6.3%), PVC (10.9%), HDPE (7.7%), Rainy season: PVC (81.5%), PA (1.7%), PET (2.6%)	Rainy season: Green (61.2%), Dry season: Red (42.4%), Black, Yellow, Blue, White, Purple	Dry season: 0.02–0.5 mm (4.3%), 0.51–1 mm (6.7%), 1–3 mm (74.9%), 3–5 mm (14.1%), Rainy season: 0.02–0.5 mm (4.9%), 0.51–1 mm (89.1%), 1–3 mm (4.7%), 3–5 mm (2.3%)
[29]	Dhanmondi, Gulshan, Hatir Jheel lakes, Bangladesh, September 2021, 8 to 36 items/L	Film (28%), Pellet (25%), Fiber (23%), Fragment (21%), Foam (1%)	HDPE (40%), LDPE (30%), PP (10%), PVC (10%), PC (10%)	Transparent (50%), Black (20%), Red (7%), White (9%), Blue (14%)	<100 µm (30%), 101–200 µm (20%), 201–400 µm (23%), 401–600 µm (7%), 601–800 µm (5%), 801–1000 µm (9%), >1000 µm (7%)
[32]	Lake Ontario, Lake Erie, Lake Superior, Canada and USA, 2018–2019, max. 2×10^7 particles/km ²	Lake Ontario: Fragment (37%), Foam (11%), Commercial fragments (19%), Irregular Microbeads (17%), Lake Erie: Fragment (41%), Foam (12%), Irregular Microbeads (25%), Spherical microbeads (11%), Lake Superior: Fragment (42%), Foam (41%)	PE (61%), PS (12%), PP (16%), PVC	Transparent (50%), White (17%), Grey (15%)	1.00–4.75 mm, 0.335–1.00 mm (80%)
[33]	Great Slave lake, Canada, July to August 2021, 0.03–2.04 particles/m ³	Mostly Fiber, Fragment, Film, Foam	PP, PE, PA, PET, PS, etc.	Colored	-

Table 1. Cont.

Ref.	Region, Sampling Collection Year, and Abundance	Shape of MPs	Materials of MPs	Color of MPs	Sizes of MPs
[34]	20 lakes of Hanjiang, & Yangtze rivers of Wuhan, China, April 2016, 1660 ± 639.1 to 8925 ± 1591 n/m ³	Fiber (52.9 to 95.6%), Pallet, Film, Granule	PET, PE, PP, Nylon, PS	Colored (50.4% to 86.9%), Transparent, Blue, Purple, Red	<2 mm (>80%)
[35]	Lake mead, USA, July to October 2018, $0.44\text{--}9.7$ particles/m ³	Fiber (95%), Fragment, Film, Pallet	PES (65.7%), PP (6.5%), Rayon (6.7%)	Blue, Red and Black (75%), Yellow, White, Transparent, Green, Gray	-
[36]	Lake Phewa, Nepal, February & July 2021, Dry: 2.96 ± 1.83 particles/L, Wet: 1.51 ± 0.62 particles/L	Fiber: Dry season (93.04%), Wet season (96.69%), Film, Foam, Fragment	-	Transparent (Dry: 40.51%, Wet: 31.41%), White, Red, Blue, Black, Yellow, Green, Purple	Dry season: 1.0–5.0 mm (0%), 0.2–1.0 mm (100%) Wet season: 1.0–5.0 mm (1%), 0.2–1.0 mm (99%)
[37]	Taihu lake, China, Year: August 2015, $3.4\text{--}25.8$ items/L	Fiber (48–84%), Pellet, Film, Fragment	Cellophane	Blue (50–63%), Green, Yellow, Red, White, Black, Transparent	5–100 μ m, 100–1000 μ m, 1000–5000 μ m
[38]	35 Lakes, Sierra Nevada, Spain, Avg: 21.3 particles/L	Fragment (60%), Fiber (39%) Sphere (1%)	-	Blue (53%), Transparent (28%), Red (8%), White (2.5%), Black (2%)	<50 μ m (26%), 50–100 μ m (16%), 100–200 μ m (19%), 200–300 μ m (11%), 300–500 μ m (11%), >500 μ m (17%)
[39]	Songshan lake, Dongguan, China, March 2018, 2.29 ± 0.98 items/m ³	Film (60.7%), Fragment (24.2%), Foam (3.9%), Fiber (11.2%)	PE, PP, PE-PP, PS, PVC	Transparent (41%), Black (17%), Blue (16%), White (14%), Red (8%), Green (4%)	0.18–0.6 mm (43.3%), 0.112–0.18 mm (38.1%), 0.6–2 mm (12.4%), 2–5 mm (6.2%)
[40]	Vesijärvi lake, Finland, March 2018, Snow: 117.1 ± 18.4 MPs/L, Ice: 7.8 ± 1.2 MPs/L	Fiber, Fragment	Snow: PP/PE (19.6%), PA (14.6%), PE-PET (2.4%), CE (39%), Ice: CE (45.8%), PE/PP (16.6%), PA (8.3%), PU (2.1%)	-	100–700 μ m
[42]	Lake Saimaa, Finland, Avg: 0.7 ± 0.1 n/L	Fiber (40%), Fragment	PP, PE, PS, PES (41%), PMMA, PA, PVC	Transparent/White (87%), Brown, Blue, Grey, Red	Fragment (1100 \pm 230 μ m), Fiber (430 \pm 49 μ m), 100–500 μ m (59%)
[43]	Mahodand Lake, Pakistan, June & July, 2019, 0–5 MPs/L	Fiber (50%), Sheet (28%), Fragment (22%)	LDPE (44.4%), PVC (30.5%), HDPE (5.5%)	-	300–500 μ m (57%), 150–300 μ m (28%), 50–150 μ m (15%)
[44]	Lake Hovsgol, Mongolia, July, 2013, Avg: 20,264 particles/km ²	Fragment (40%), Film (38%), Line/Fiber (20%), Pellet (1%), Foam (1%)	-	-	0.36–1 mm, 10–4.75 mm, >4.75 mm

Table 1. Cont.

Ref.	Region, Sampling Collection Year, and Abundance	Shape of MPs	Materials of MPs	Color of MPs	Sizes of MPs
[45]	West and South Dongting lakes, China, April 2018, West: 616.67 to 2216.67 items/m ³ , South: 716.67 to 2316.67 items/m ³	Fiber (12.17 to 77.42%), Fragment, Pallet, Film	PS (38%), PET (28%), PP (16%), PE (12%)	Transparent, White, Blue, Black, Red, Blue, Green	<0.5 mm, 0.5–5.0 mm
[46]	Xianjia, Meixi, Yang, Yue, Yuejin, Nianjia, Dong, Donggua lakes, China, 2425 ± 247.5 items/m ³ to 7050 ± 1060.66 items/m ³	Line, Film, Foam, Fragment	PP (33.75%), PE (27.5%), PS (13.75%), PVC (3.75%), PET (11.25%), PA (7.5%)	Transparent	<2 mm (89.5%)
[47]	Al-Asfar lake, Saudi Arabia: 0.7 to 7.8 items/L; Al-Hubail lake, Saudi Arabia: 1.1 to 9.0 items/L, Year: Winter, 2017–2018	Fiber (83%), Fragment (17%)	-	-	<250 µm (30%), Between 250 and 500 µm (70%)
[48]	Florentino Ameghino dam, Pico 1 lake, Pico 4 lake, Los Niños lake, Vintter lake, La Plata lake, Fontana lake, Toro lake, Musters lake, Argentina, December 2018, 0.3–1.9 particles/m ³	Fiber (66.7–96.4%), Foam, Fragment, Film, Rubber	PET (38.3%), PU (11.8%), PS (2.9%), PP (2.9%)	Blue (42%), Black (37%), Yellow, Red, White, Green, brown	<1 mm (70.7%), 1–2 mm, 2–3 mm, 3–4 mm, 4–5 mm, >5 mm
[49]	Lake Superior, USA, May & July 2018, 9000 to 40,000 particles/km ²	Fiber (70%), Fragment, Film, Foam, Bead	PE (93%), PP (77%), PS (78%), PET (81%), PVC (12%)	Translucent, Transparent, Blue, White, Black, Yellow, Green, Grey, Purple, Pink, Silver	<4 mm, >0.45 µm
[50]	Lake Sassolo, Switzerland, June 2019, 6.8 particles/L	Fiber (36%), Fragment, Film, Pellet, Bead	PE (76.92%), PP (23.08%)	Green, Transparent	125 to 5000 µm
[51]	Lake Michigan (LM), Lake Erie (LE), USA, September 2013, September 2014, LM: 65.2 p/kg, LE: 431 p/kg	Fiber/Line (>0.355 mm): 91% in LM, 75% in LE, Fragment (>0.355 mm): 1.5% in LM, 10.2% in LE, Pellet/Bead (>0.355 mm): 1.2% in LM, 3.4% in LE, Film (>0.355 mm): 0.9% in LM, 6.4% in LE, Foam (>0.355 mm): 5% in LM, and 5.4% in LE	LM: PET, HDPE, LE: PP, PVC	-	0.36–1 mm, >1 mm

Table 1. Cont.

Ref.	Region, Sampling Collection Year, and Abundance	Shape of MPs	Materials of MPs	Color of MPs	Sizes of MPs
[52]	Bay Mau, Ho Tay, Yen So, Cong Vien, Hoa Phu lakes, Vietnam, 70 to 611 items/m ³	Mostly Fiber, Fragment	-	-	Up to 5000 µm
[53]	Vellayani lake, Kerala, India, March 2022, 4.1 particles/L	Film (5%), Fiber (95%)	PES (95%), PP (5%)	White (30%), Colored (70%)	<1000 µm (71%), >1000 µm (29%)
[54]	Masurian Lakes (30) Poland, July 2019, 0.27 to 1.57 MPs/L	Fragment (36.7%), Film (25.6%), Foam (3.4%), Fiber (30.4%)	-	Blue (30.6%), Black (4.3%), Red (12.7%), Green (10.4%), Transparent (21.3%)	0.5–1 mm (10.3%), 1–2 mm (19%), 2–3 mm (15.9%), 3–4 mm (14.9%), 4–5 mm (35.0%)
[55]	Lake Balaton, Hungary, July 2022, Avg: 5.5 particles/m ³	-	PP, PE, PA, PES	-	50–100 µm
[56]	Lake Balaton, Hungary, July 2022, 1.50 to 106.84 MPs/m ³ , Avg: 21.0 ± 12.5 MPs/m ³	Fiber (13%), Fragment (87%)	PE (33.29%), PP (31.22%), PS, PVC, PU, PA	-	50 and 100 µm (26.27%), <500 µm (90%)
[57]	7 lakes in Da Nang City, Vietnam, Year: Apr & Dec 2021, Dry: 293.3 ± 23.1–6510 ± 380.4 items/m ³ , Wet: 366.7 ± 23.1–1143.3 ± 110.2 items/m ³	Fiber: 44.25% to 75.98% (Dry), 64.54% to 80.17% (Wet). Fragment: 20.78% to 45.86% (Dry), 13.36% to 28.18% (Wet)	PP (47.8%), PE (43.5%)	Blue: 18.47% to 49.35% (Dry), 12.10% to 50% (Wet). White: 22.85% to 50% (Dry), 16.06% to 41.13% (Wet), Black: 14.68% to 33.82%	1000–2000 µm: Dry (35.4–59.6%), Wet: 34.4–56.4%)
[58]	Tembisa (TL), Braamfontein (BL), Silver (SL) Lakes, South Africa, March to June 2023, TL: 4 to 20 particles/L, BL: 9.0 to 31 particles/L, SL: 4.7 to 16 particles/L	BL: Fiber (77%), Fragment (9.68%), Pellet (2.47%), Film (1.9%), TL: Fiber (83.6%), Fragment (13.8%), Film (1.5%), Pellet (1.0%), SL: Fiber (77.7%), Fragment (15.1%), Pellet (0.63%), Film (6.6%)	HDPE, PU, PET	BL: Fiber (Black, 37.5%, Green, 33.1%, Blue, 15%), TL: Fiber (Black, 33.6%, Green, 28.1%, Blue, 24.5%), SL: Fiber (Blue, 30.4%, Black, 26.7%, Transparent, 17.4%)	BL: <1 mm (80%) TL: <1 mm (75%) SL: <1 mm (72%)

4.2. Microplastics in Rivers

Microplastics (MPs) pollution in rivers varies widely across the globe, reflecting differences in environmental and anthropogenic factors. Some rivers, such as the Seine River in France, show a high prevalence of common polymers like polypropylene (PP) and polyethylene (PE), which are linked to industrial and urban waste [59]. In contrast, smaller river systems like the Gallatin River in the United States report much lower concentrations, ranging from 0 to 0.675 particles per cubic meter [60]. Seasonal variations significantly influence the abundance of MPs in rivers. For example, the Yellow River in China demonstrates that concentrations during the dry season can be more than double those recorded in the wet season due to reduced water flow and dilution effects [17].

The shapes of microplastics in rivers are diverse, but fibers are often the dominant form. Fibers, typically originating from textiles and synthetic fabrics, make up a significant proportion of MPs in many rivers worldwide. For example, they account for 79.1% of MPs in the Yangtze River, China [61], 93.12% in the Lower Yellow River, China [17], and an astonishing 99.4% in the Orange-Vaal River, South Africa [62]. Fragments, which result from the breakdown of larger plastic items, are also common, particularly in industrial and urban environments like the Rhine River, Netherlands, where they constitute 37.5% of detected particles [63]. Films, granules, and other shapes such as spherules are observed in specific contexts, often tied to localized sources of pollution, such as packaging waste and cosmetic products.

The composition of microplastics in rivers often reflects the specific sources of pollution in the surrounding area. Common polymers like polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET) are frequently identified in rivers worldwide. These materials dominate in regions with significant industrial activities or high population densities. For instance, the Saigon River in Vietnam shows a prevalence of PE and PET, which are likely linked to urban and industrial discharge [16]. In other cases, less common materials, such as rayon and polyester (PES), are detected in rivers like the Qiantang in China, where textile industries are a major source of pollution [64].

The color distribution of microplastics in rivers provides valuable clues about their sources and the processes they have undergone. Transparent, blue, and black particles are the most commonly reported globally. The prominence of blue fibers in rivers such as the Ganges in India, where they account for 74% of detected MPs, suggests a significant contribution from textile and fabric waste [65]. Similarly, black particles are prevalent in the Ergene River, Turkey, making up nearly half of the MPs detected, possibly indicating industrial soot or tire wear particles [66].

The size distribution of microplastics in rivers is typically skewed toward smaller particles. Sub-millimeter MPs (<1 mm) often dominate, as they are formed through the degradation of larger plastic items and are difficult to filter out in water treatment processes. For example, particles smaller than 500 µm constitute 80% of the MPs detected in the Pearl River, China [67]. In the Nakdong River, South Korea, 74% of MPs are under 300 µm, further demonstrating the predominance of small particles [20]. Larger MPs, such as those over 5 mm, are much rarer and are usually associated with localized sources of industrial discharge, as observed in the Seine River, France [59].

Seasonal and environmental factors play a crucial role in shaping the distribution and concentration of microplastics in rivers. Seasonal fluctuations, particularly differences between wet and dry seasons, often lead to significant variations in MPs abundance. During the dry season, reduced water flow and dilution lead to higher concentrations of MPs, as seen in the Yellow River, China [17]. In colder regions, snow and ice accumulation can influence MPs transport and deposition, as observed in the Hillsborough River, USA, where particles are trapped in seasonal ice formations [68]. All these details are presented in Table 2.

Table 2. Abundance of microplastics in rivers, and their shapes, materials, colors, and sizes.

Ref.	Region, Sampling Collection Year and Abundance	Shape of MPs	Materials of MPs	Color of MPs	Sizes of MPs
[1]	Rhine and Meuse rivers, Netherlands, 2012–2013, 48–187 particles/L	Fiber, Foil, Sphere	-	-	10–300 µm (17–63%), 300–5000 µm (37–83%)

Table 2. Cont.

Ref.	Region, Sampling Collection Year and Abundance	Shape of MPs	Materials of MPs	Color of MPs	Sizes of MPs
[4]	Suzhou and Huangpu rivers, China, April to September 2017, 0.08–7.8 items/L	Fiber: Suzhou River (85%), Huangpu River (81%), Fragment, Film, Pallet	Fibrous PES (27.7%), Rayon (14.4%), PP (8.7%)	Blue and Red (46–76%), Yellow, Green, Purple, Brown, Gray, Black, Transparent, White	20 to 5000 μm , 100 to 1000 μm (57–80%)
[15]	Antua river, Portugal, March and October 2016, 58–1265 items/ m^{-3}	Fragment, Pellet, Film, Foam, Fiber	PP (29.4%), PE (29.4%), PS (8.8%), PVA (8.8%), PET (8.8%), PTFE, PMMA, PEA	-	-
[16]	Saigon river, Vietnam, April 2016, 172,000–519,000 items/ m^3	Fiber, Fragment, Film, Foam	PP (15%), PE (79%), PET (4%)	-	up to 5000 μm
[17]	Lower Yellow river, China, July 2018, March 2019, 380–1392 particles/L, dry season: 930 items/L, wet season: 497 items/L	Fiber (93.12%), Fragment (2.14%), Pellet	PE, PP, PS	-	50–100 μm , 100–200 μm , 200–500 μm , 500–5000 μm where <200 μm (87.94%)
[19]	Cooks river, Australia, 400–17,383 particles/ m^3	-	-	-	333 μm –1000 μm (7%), 1001 μm –5000 μm (4%)
[20]	Nakdong river, South Korea, February, May, August, October 2017, 293 \pm 83 particles/ m^3 (upstream), 4760 \pm 5242 particles/ m^3 (downstream)	Fragment (69%), Fiber (30%), Sphere and Film (<1%)	PP (41.8%), PES (23.1%), PE (9.4%), PA (5.8%), PS (2.1%), PU (1.4%), PVC (1.1%), Alkyd (4.2%), Acrylic (3.2%), etc.	-	<300 μm (74%)
[59]	Seine river, France	-	PP (35.2%), PE (26.0%), PET (20.7%), PS (10.8%)	-	-
[60]	Gallatin river, USA, 0–0.675 particles/ m^3	Microfiber (80%), Fragment (19.7%), Microbead 0.3%	PES (20%), PET (13%), PP (4%), PA (4%), Urethane (4%)	Transparent (30%), Red (13%), Black (11%), Others (13%), Blue (33%)	0.1–1.5 mm (71%), 1.6–3.1 mm (20%), 3.2–5 mm (6%), 5.1–9.6 mm (2%)
[61]	Yangtze river, China, July and August 2013, 0.5–10.2 n/L	Fiber (79.1%), Film (9.1%), Granule (11.6%), Spherule (0.2%)	-	White (8.7%), Black (6.2%), Colored (26.1%), Transparent (58.9%)	>0.5–1 mm (67%), >1–2.5 mm (28.4%), >2.5–5 mm (4.4%), >5 mm (0.2%)

Table 2. Cont.

Ref.	Region, Sampling Collection Year and Abundance	Shape of MPs	Materials of MPs	Color of MPs	Sizes of MPs
[62]	Orange-Vaal river, South Africa, Wet (April, May) and Dry (October, November) seasons, 2018, August, February, 2020, Microfiber: Wet, 2.3 ± 7.2 items/L, Dry, 1.4 ± 2.6 items/L.	Microfiber (99.4%), Fragment (0.6%)	-	Microfiber: Blue, 97.2%, Fragment: Green, 43%, White, 25%, Blue, 17%, Yellow, 9%, Orange, 3%, Red, 3%.	>50 mm
[63]	Rhine river, Netherlands, June–July 2014, 892,777 particles/km ²	Opaque spherule (45.2%), Fragment (37.5%), Transparent spherule (13.2%), Fiber (2.5%)	PS (29.7%), PP (16.9%), PES (5.1%), PVC (1.7%), Acrylate (9.3%)	Transparent	-
[64]	Qiantang river, China, wet (June), dry (November) seasons, 2018, Avg: 1183 ± 269 particles/m ³	Fiber (53.2%), Fragment (29.5%), Granule (8.4%), Film (8.5%), Foam (0.4%)	PET, PA, PES	White (45%), Black (23.4%), Transparent (14.6%), Red, Blue, Yellow, Green	-
[65]	Ganges river, India, Bangladesh, May–June, October–December, 2019, Dry: 0.051 ± 0.007 MPs/L, Wet: 0.026 ± 0.004 MPs/L	Fiber (91%), Fragment (9%)	Rayon (54%), Acrylic (24%), PET (8%), PVC (6%), PET (5%), Nylon (3%)	Blue (74%), Black (11%), Red (6%), Purple (4%), Brown (2%), Green, Yellow, Transparent (each 1%)	Avg: 2459 ± 209 mm
[66]	Ergene river, Turkey, May 2019, September 2020, Avg: May: 4.65 ± 2.06 items/L, September: 6.90 ± 5.16 items/L	Fiber (88%), Fragment (8%), Pellet (2%), Foam (1%), Rubber (<1%)	PET (28%), PA (27%), PE (19%), PS (19%), PP (5%), PI (2%)	Black (49%), Blue (25%), Red (14%), White (5%), Brown (2%), Transparent, Green, Orange, Purple (each 1%), Pink, Grey, Yellow (each <1%)	1000–2000 μ m (38%), 45–1000 μ m (31%), 2000–3000 μ m (18%), 3000–5000 μ m (13%)
[67]	Pearl river, China, December 2017, 19,860 items/m ³	Film, Fiber, Granule	PA (26.2%), Cellophane (23.1%), PP (13.1%), PE (10%), PVC	Blue, Transparent, Green, Red	<0.5 mm (80%)
[68]	Hillsborough river, Florida, USA, May to October 2019, max 14.06 particles/m ³	Fragment, Fiber	PE (50–60%), PET, HDPE, LDPE, PP (24.7%), PS (5.9%)	-	<1 mm, 1 mm to 5 mm, > 5 mm

Table 2. Cont.

Ref.	Region, Sampling Collection Year and Abundance	Shape of MPs	Materials of MPs	Color of MPs	Sizes of MPs
[69]	Ottawa river, Canada, summer, 2016, Avg: 1.35 items/m ³	Microfiber (73%), Microbead (7%), Fragment (20%)	-	-	-
[70]	Snake and Columbia rivers, USA, June, July, August 2016, Grab: 0 to 5.405 MPs/L, Net: 0 to 0.014 MPs/L	Fragment, Film, Bead, Fiber	-	-	100 to 333 mm
[71]	Ciwalengke river, Majalaya district, Indonesia, October, November, 2017, 5.85 ± 3.28 MPs/L	Fiber (65%), Fragment	PES	-	50–100 mm, 1000–2000 mm
[72]	Wei river, China, Winter 2017, 3.67–10.7 items/L	Fiber (38.25 to 61.95%), Pellet (0.4 to 7.8%), Foam (0.25 to 3.5%), Fragment (10.6 to 21.7%), Film (17.4 to 38.2%)	-	-	<0.5 mm (40.8% to 68.8%), 0.5–1.0 mm, 1–2 mm, 2–3 mm, 3–4 mm, 4–5 mm, >5 mm
[73]	Beijiang river, China, August 2016, 0.56 ± 0.45 items/m ³	Foam (37.78%), Film (21.81%), Fragment (24.67%), Fiber (15.73%)	PP (52.31%), PE (27.39%), PS, EPS (13.20%), PVC (1.98%), PET (0.99%)	-	0.6 to 2 mm (41.36%)
[74]	Sinos River, Southern Brazil, December 2018, Raw water (Avg: 330.2 particles/L), Drinking water: (Avg: 105.8 particles/L)	Raw water: (Fiber 89.4%, Pellet, 10.5%, Film, 0.1%), Drinking water: (Fiber 80.2%, Pellet, 19.1%, Film, 0.7%)	-	-	-

Table 2. Cont.

Ref.	Region, Sampling Collection Year and Abundance	Shape of MPs	Materials of MPs	Color of MPs	Sizes of MPs
[75]	Surabaya river, Indonesia, February to May 2019, Surface: 1.47–43.11 particles/m ³ , Middle: 0.76–12.56 particles/m ³ , Bottom: 1.43–34.63 particles/m ³	Surface: Film (45.8–92.9%), Fragment (4.7–35.6%), Fiber (0.2–2.6%), Foam (0.8–20.7%), Pellet (0.5–2.6%); Middle: Film (57.1–88%), Fragment (2.8–30.5%), Fiber (0.8–12.4%), Foam (0.4–3.9%), Pellet (0.1–0.5%); Bottom: Film (63.4–88.7%), Fragment (3.4–25.1%), Fiber (0.3–11.5%), Foam (0.8–6.8%), Pellet (0.4–0.5%)	Surface: LDPE (44–68%), PP (18–41%), PS (1–17%), PE (10–12%), PET (1–2%); Middle: LDPE (39–73%), PP (13–58%), PE (1–17%), PS (1–6%), PET (1–2%); Bottom: LDPE (39–73%), PP (14–50%), PE (13–19%), PS (1–6%), PET (1%)	Surface: Transparent (26.2–73.9%), White (8.5–31.3%), Blue (4.7–27.2%), Red (1.7–10.6%), Black (2.6–7.6%), Yellow (0.5–7.3%); Middle: Transparent (33.1–79.9%), White (1.3–31%), Blue (4.1–23.6%), Black (6.9–13%), Red (3.1–9.6%), Yellow (0.3–8.2%); Bottom: Transparent (33.1–65%), White (7–56.5%), Blue (3.1–22.1%), Black (3.9–10.4%), Red (1.2–8.2%), Yellow (1.1–4.6%)	MPs: 0.3–5 mm
[76]	River Elbe, Germany, Avg: 5.57 particles/m ³	Fiber (46.5%), Fragment (22.9%), Sphere (20.1%), Foil (10.6%)	PE (47.5%), PP (45.0%), PS (2.5%)	Blue (19.7%), White (15.0%)	125/150–5000 µm
[77]	Fengshan river, Taiwan, September 2018, 334–1058 particles/m ³	Fiber (81–99%), Fragment	PE, PET, PA, PES	-	50–297 µm (43–69%), 297–5000 µm (31–57%)
[78]	Ofanto river, Italy, February, April, October, December, 2017, May 2018, 0.4–18 particles/m ³	Fragment (56%), Flake (26%), Pellet, Spherule, Line, Fiber, Film, Foam	PE (76%), PS (12%), PP (10%), PVC (0.7%), PU (0.35%)	White, Red, Yellow, Black (35%), Blue, Green, Transparent (56%), Brown	<500 µm (10–17%), 500–1000 µm (66%), 1000–2000 µm, 2000–5000 µm
[79]	Netravathi river, India, July 2019, 56–2328 particles/m ³	Fiber (51.59%), Film (34.92%), Fragment (8.13%), Foam (5.16%), Pallet (0.20%)	PE (58.33%), PP (3.57%), PET (28.57%), PVC (0.40%)	Transparent (32.5%), White (29.8%), Brown (13.3%), Black (10.7%)	1–5 mm (73.4%), 0.3–1 mm (26.6%)

Table 2. Cont.

Ref.	Region, Sampling Collection Year and Abundance	Shape of MPs	Materials of MPs	Color of MPs	Sizes of MPs
[80]	Alaknanda river, Uttarakhand, India, April 2019, 566 out of 955 MPs in water	Fragment, Film, Foam, Fiber/line, Pellet	PET, HDPE, PVC, LDPE, PP, PS	-	<1 mm (26%), 1–2 mm (22%), 2–3 mm (17%), 3–4 mm (24%), 4–5 mm (11%)
[81]	Pear river estuary, China, September and November 2020, Dry season: 545.4 n/m ³ , Wet season: 294.6 n/m ³	Fiber: Dry (40–82%), Rainy (63–81%), Granules: Dry (7–40%), Rainy (5–21%), Fragment: Dry (5–20%), Rainy (3–20%), Film	PE (Dry: 35.7, Rainy: 38.7%)	Transparent, Gray, White, Green, Dry: Gray (42.4%), White (31.4%),	<0.5 mm (53.5–73.9%)
[82]	6 rivers: Hei, Lao, Feng, Ba, Chan, Wei rivers, China, August 2020, 2.30–21.05 items/L	Film (41.19%), Fragment (41.24%)	PE (41.3%), PP (14.9%), PS (13.8%), PVC (9.6%), PA (12.5%), PET (4.8%)	White (43.2%), Blue (11.7%), Black (20.7%)	<500 µm (64.3%)
[83]	Themí river, Tanzania, 70–160 MP/kg ^{−1}	Fiber, Film, Fragment, Microbead	LDPE, HDPE, PP, PS, PET, PMMA, PVC	-	-
[84]	Arvand river, Iran, January 2018, 1 to 291 items/L	Fiber	PET (27%), PP, PS, Nylon (33%)	Black, Grey, Yellow, Orange	100–500 µm
[85]	River Yamuna, Delhi, Mar 2020, 500 MPs/m ³ –3900 MPs/m ³	Fragment (60.7%), Pellet (19.6%), Fiber (16.8%), Foam (1.9%), Film (0.9%)	LDPE, HDPE, PS, PET, PP	Transparent (13%), White (61%), Pink (5%), Blue (8%), Black, Grey, Red, Green, Yellow	-
[86]	Yellow river, China, March and September, 2021, Avg: Dry season: 433 ± 241 n/L, Wet season: 2510 ± 2971 n/L	-	Dry season: PBS (26–35%), PPC (16–25%), PET (19–33%), Wet season: PP (49–94%), PBS (5–17%)	-	<500 µm, 20–50 µm (66–89%)
[87]	Ganga river, India, October 2017, February 2018, May 2023, 92.85 ± 50.69 particles/m ³	Fragment, Pellet, Filament, Film, Foam	PET and PA (38%), PE (26%), PP (18%), PVC (10%), PS (5%)	Blue, Black, Red, Transparent/White, Pink, Green, Yellow	100 to 2000 µm
[88]	Nile River, Egypt, January, July, April, October, 2021, Avg: 2.24 ± 0.6 to 3.76 ± 1.1 particles/L	Fiber (79%), Fragment (15%) Foam (6%)	PES (0 to 7%), PE, PP, PS	Blue (43%), Red (16%), Black (15%), White, Green (each 10%)	<500 µm, 501–1000 µm, 1001–1500 µm, 1501–2000 µm, 2001–2500 µm, 2501–3000 µm, 3001–3500 µm, 3501–4000 µm

Table 2. Cont.

Ref.	Region, Sampling Collection Year and Abundance	Shape of MPs	Materials of MPs	Color of MPs	Sizes of MPs
[89]	Xiangjiang river, China, August 2020, 0.72 to 18.6 (Avg: 7.32 ± 5.35) items/L	Granular (51.0%), Film (18.3%), Fragment (16.4%), Fiber (14.2%)	Rayon (70.7%), PES (13%), PVA and acrylic (each 3.9%), PP (2.2%), PET (2%), PA (1.5%), PE and PS (each 1.3%)	Transparent (28.7%), Black (22.2%), Brown (20.1%), Yellow (15.3%), Red	50–100 μm (13.73–92.51%)
[90]	Banks of Ganga and Yamuna rivers, Haridwar, Agra, Prayagraj, Patna, India, wet (July), dry (December) seasons, 2021, Wet: Haridwar, highest: 0.165 ± 0.092 MPs/ m^3 , Patna, lowest: 0.0067 ± 0.003 MPs/ m^3 , Dry: highest: Agra, 0.022 ± 0.013 MPs/ m^3 , lowest: Patna, 0.007 ± 0.001 MPs/ m^3 and Haridwar, 0.007 ± 0.002 MPs/ m^3	Fiber, Fragment, Film	PAM (wet: 0–36.11%, dry: 8.75–32.50%), PVC (wet: 0–22%; dry: 8.75–36%), EVOH (wet: 11–22%; dry: 15–22%)	Blue (32.6%), Black (28.4%), Red (22.8%), Transparent (3.5%), Green (4.9%)	300 μm to 5 mm: 38–73% (wet season), 61–86% (dry season)
[91]	Xinyi river, Ashe river, Harbin, China, July (Wet season), November (Dry season) 2022, Avg: Xinyi (Dry: 37,328.4 n/ m^3 , Wet: 50,809.9 n/ m^3), Ashe (Dry: 22,638.8 n/ m^3 , Wet: 40,183.0 n/ m^3)	Xinyi (Dry and Wet: Fibrous, 40.27%, 39.94%, Debris, 25.48%, 25.01%, Filmy, 18.36%, 19.83%, Granular, 15.89%, 15.20%), Ashe (Dry: Fibrous, 40.27%, Debris, 25.48%, Filmy, 18.36%, Granular, 15.89%, Wet: Fiber, 36.49%, Film, 23.84%, Fragment, 22.55%, Particle, 17.12%)	Xinyi (Dry: PE, 35%, PP, 23.33%, PS, PA, PVC (each 11.67%), PET, 6.66%, Wet: PE, 23.19%, PP, PS (each 18.84%), PA, 14.49%, PVC, 13.04%, PET, 11.60%), Ashe (Dry: PE, 36.11%, PP, 25%, PS, 2.22%, PA, 11.67%, PVC, 13.89%, PET, 11.11%, Wet: PE, 26.02%, PP, 21.92%, PS, 16.44%, PA, 10.96%, PVC, 12.33%)	Xinyi (Dry: Colorless, 46.29%, White, 30.13%, Black, 12.29%, Blue, 4.42%, Red, 4.19%, Yellow, 2.68%, Wet: Colorless, 51.52%, White, 22.83%, Black, 11.86%, Blue, 5.17%, Red, 4.31%, Yellow, 4.31%), Ashe (Wet: Colorless, 45.56%, White, 21.68%, Black, 15.83%, Blue, 8.73%, Yellow, 4.16%, Red, 4.04%)	Xinyi (Dry: 20–100 μm , 28.98%, Wet: 20 to 5000 μm , 91.03%, 20–100 μm , 24.03%, 100–300 μm , 24.88%), Ashe (Dry: 20–100 μm , 34.68%)

4.3. Microplastics in Tap Water

Table 3 summarizes the abundance and characteristics of microplastics found in tap water. Microplastics have been detected in tap water worldwide, raising growing concerns about their presence and potential health impacts. Studies show significant regional variation in microplastic concentrations. For example, Tong et al. [7] reported

440 ± 220 particles/L in samples from various Chinese cities, with fragments (53.85–100%), fibers (1.18–30.77%), and spheres (2.27–36.36%) as the dominant shapes. These particles were primarily composed of polyethylene (PE), polypropylene (PP), and polystyrene (PS). Similarly, Mukotaka et al. [92] found concentrations ranging from 1.9 to 225 particles/L in samples from Japan, the USA, and European countries, with fragments and fibers being the predominant shapes and particle sizes ranging from 19.2 µm to 4.2 mm.

Regional differences in material composition and particle size are evident. Chanpiwat and Damrongsiri [26] detected 0.4–2.4 particles/L in tap water from Bangkok, Thailand, with fragments (85.6%) and PE (47.9%) being the most common. In Barcelona, Spain, Vega-Herrera et al. [93] reported smaller microplastics, ranging from 0.7 to 20 µm, primarily composed of PE and PP. Sultan et al. [94] identified fiber (52%) and fragment (43%) shapes in Mosul City, Iraq, with PVC (50–52%) and PET (12–14%) as the dominant materials. The diversity in sizes, from <50 µm (90%) in Iran [95] to particles larger than 1 mm in South Africa [58], underscores the complexity of microplastic contamination in tap water.

Table 3. Abundance of microplastics in tap water, and their shapes, materials, colors, and sizes.

Ref.	Region, Sampling Collection Year and Abundance	Shape of MPs	Materials of MPs	Color of MPs	Sizes of MPs
[7]	38 tap water samples collected from different cities of China, 440 ± 220 particles/L	Fragment (53.85 to 100%), Fiber (1.18 to 30.77%), Sphere (2.27 to 36.36%)	PE (26.7%), PP (24.4%), PE + PP (22%), PPS (7.3%), PS (6.5%), PET (3.3%), other (PMS, PTFE, PC, PMMA, PBT, PB, PVC) (9.8%)	-	<50 µm (31.25–100%), 50–100 µm (1.47–31.25 µm), 100–300 µm (1.72–31.25%), 300–500 µm (1.18–7.69%), 500–5000 µm (1.72–11.76%)
[25]	Brasilia, Brazil, January–February, 2018, 32 samples, 97–219 MPs/500 ml	-	-	-	5–6 µm
[26]	Bangkok, Thailand, Water sources: Chao Phraya and MaeKlong rivers, April and September 2019, 0.4–2.4 particles/L	Fiber, Fragment, Tap water: Fragment (85.6%)	PE, PP, PVC, PS, PET, PMA, PMMA, Tap water: PE (47.9%)	Tap water: Colorless (85.1%)	50–900 µm, >1000 µm, <300 µm (82.1%)
[58]	Gauteng province, Sources: Tembisa, Braamfontein, and Silver Lakes, South Africa, March to June 2023, 4.7 to 31 particles/L	Fiber (83.1%), Fragment (12.4%), Pellet/Bead (3.1%), Film (1.5%)	HDPE, PU, PET	Black, Blue, Green	Mostly <1 mm
[92]	42 tap water samples, Japan, USA, France, Finland, Germany, December to April 2020, 1.9 to 225 particles/L	Fragment, Fiber, Sphere	PS, PP, PES, PE, SEBS, PVC	-	19.2 µm to 4.2 mm

Table 3. Cont.

Ref.	Region, Sampling Collection Year and Abundance	Shape of MPs	Materials of MPs	Color of MPs	Sizes of MPs
[93]	42 samples, Barcelona, Spain, August to October, 2020, 0.7 to 20 μm	-	PE (69%), PP (57.1%), PI (42.9%), PBD (9.5%), PS, PA, PDMS	-	0.70–20 μm
[94]	48 samples, Mosul City, Iraq, October 2022 to February 2023, 25 to 71 items/L	Fiber (52%), Fragment (43%), Film (3%), Foam (2%)	PVC (50–52%), PA (15–17%), PET (12–14%), PE (9–12%), PP (2–5%), PS (2–3%)	Transparent (45–48%), Black (13–16%), Blue (11–17%), Red (8–10%), Orange (2–5%), White (4–6%), Green (4%), Yellow (1–2%)	-
[95]	10 tap water samples, Zahedan, Iran, Winter and Spring, Avg: 85–390 MP/ m^3 , 75–400 MP/ m^3	Fragment (>60%), Fiver (<40%)	PS (29.17%), Rubber (20.83%), PA (16.67%), PP and PVC (each 12.50%), PMMA (8.3%)	Red (16.7%), Blue (23.3%), Black (11.5%), Transparent (23.9%), White (24.6%)	<50 μm (>90%), >50 μm (<10%)
[96]	17 samples, Denmark, April to June, 2018	For >100 μm : Fiber (82%), Fragment (14%), Film (4%)	PET, PP, PS, ABS	-	>10 μm , >100 μm
[97]	3 samples, Hong Kong, 8–50 particles/L	-	-	-	1 to 10 μm
[98]	Eight different locations, Spain and Canary Islands, May, July 2022, 12.5 \pm 4.9 MP/ m^3	Fragment (46.4%), Film (7.1%), Fiber (46.4%)	Fragment and Film: PA, PES, PP, ACR, PTFE, PE, PS, PU, PLA, PVC Fiber: PA, PES, PP, ACR, PTFE, PE	-	41.0–379.5 μm
[99]	China, 49.67 \pm 17.49 items/L	Film (52.35%), Pellet (46.31%), Fiber (1.34%).	Cellulose (0.67%)	-	10–50 μm (75.50%), >301 μm (2.68%)
[100]	4 tap water samples, Chongqing, China, 1.4 particles/L	Fiber (42% Approx.)	Mostly PET, PE	-	<40 μm (Approx. 62%)

Table 3. *Cont.*

Ref.	Region, Sampling Collection Year and Abundance	Shape of MPs	Materials of MPs	Color of MPs	Sizes of MPs
[101]	England, Scotland, and Wales, UK, September 2021 to June 2022, Avg: 0.025 MP/L	-	PA (37%), PET (32%), PP (48%), PS (52%), PE (2%), PVC (12%), PU (18%), EVOH (40%), CA (27%), PMMA (17%), ABS (8%), PC (1%), POM (26%), EVAc (16%), PAN (10%), PBT (22%), PLA (17%), SI (8%)	-	>25 μm , 30 to 90 μm (32–91%)

4.4. Microplastics in Bottled Water

Microplastics are a widespread contaminant in bottled water, with significant variations in their concentration, shapes, materials, and sizes across regions and bottle types. Globally, microplastic contamination in bottled water ranges from as low as 8.5 ± 10.2 particles/L in Iran [102] to concentrations as high as 2649 ± 2857 particles/L in Germany [103]. Common shapes include fragments, fibers, and films, with fragments being the most dominant, often comprising up to 90% of the total microplastics [104]. Fibers, although less abundant, are a significant component in certain regions, such as Spain, where they account for 68.1% of microplastics in PET bottles [105].

The materials of microplastics in bottled water are diverse, reflecting the polymers used in manufacturing bottles, caps, and packaging. Polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET) are the most frequently identified materials. For instance, Mason et al. [106] reported that PP constitutes 54% of microplastics in bottled water from various countries, while PET was prominent in studies from Spain [107] and Thailand [108]. Interestingly, some studies also identified lesser-known materials like polystyrene (PS), nylon, and rubber [99].

Microplastic sizes in bottled water exhibit significant variation. Particles smaller than 50 μm are prevalent, particularly in studies from Hong Kong, where <50 μm particles were detected in concentrations as high as 17,817 particles/L [97]. In contrast, larger particles ranging from 500 to 5000 μm have been observed in regions such as India [109]. Color variations also provide insights into their origin, with transparent and blue particles being the most common, suggesting a link to bottle and cap materials [109,110]. All the details are presented in Table 4.

Table 4. Abundance of microplastics in bottled water, and their shapes, materials, colors, and sizes.

Ref.	Region, Sampling Collection Year and Abundance	Shape of MPs	Materials of MPs	Color of MPs	Sizes of MPs
[24]	Turkey, 30 soft drinks, PET bottles, 5 to 15 particles/L	Fiber (60%), Fragment (34%), Film (6%)	PA (42%), PET (34%), PE (24%)	Transparent (57%), Blue (28%), Grey (12%), Red (2%), Black (1%)	50–100 μm (31.0%), <100 μm (49%), >100 μm (51%)

Table 4. Cont.

Ref.	Region, Sampling Collection Year and Abundance	Shape of MPs	Materials of MPs	Color of MPs	Sizes of MPs
[97]	9 samples, Hong Kong, $\geq 50 \mu\text{m}$: 8–50 particles/L, $< 50 \mu\text{m}$: 1570–17,817 particles/L	-	-	-	$< 50 \mu\text{m}$, $\geq 50 \mu\text{m}$
[99]	China, Bottled water: (Plastic and Glass), 72.32 ± 44.64 items/L	Film (60.39%), Pellet (37%), Fiber (2.61%)	Cellulose (71.2%), PVC, PET, Rubber	-	$10\text{--}50 \mu\text{m}$ ($67.85 \pm 8.40\%$), $> 301 \mu\text{m}$ ($3.60 \pm 2.83\%$)
[102]	Kermanshah province, Iran, 11 samples, Avg: 8.5 ± 10.2 particles/L	Fragment (93%), Fiber (7%)	PET, PS, PP	Colorless ($> 95\%$), Black (5%)	-
[103]	Germany, 32 samples, PET and Glass bottles, Avg: 2649 ± 2857 to $6292 \pm 10,521$ particles/L	-	PP, PE, PET	-	$< 5 \mu\text{m}$ (90%), $< 1.5 \mu\text{m}$ (40%)
[104]	130 samples, Italy, Bottled materials: PET, recycled PET (rPET), Glass, PET: 5.09 ± 3.28 particles/L, rPET: 3.33 ± 1.34 particles/L, Glass: 8.65 ± 5.39 particles/L	Fragment (90.8%), Fiber	PE (74.5%), PET (21.7%), PS (2.9%), PET + PS (0.9%)	Transparent, White, Green, Blue	$< 10 \mu\text{m}$ (0.62%), $10\text{--}20 \mu\text{m}$ (3.92%), $20\text{--}50 \mu\text{m}$ (34.43%), $50\text{--}100 \mu\text{m}$ (35.05%), $> 100 \mu\text{m}$ (25.98%)
[105]	PET bottled, Spain, 0.64–1.58 MPs/L	Fibre (68.1%), Fragment (30.8%), Film (1.1%)	PES (79%), PE (14.8%), PA (2.5%), PS (1.2%), PP (1.2%), SIL (1.2%)	White, Transparent	$76\text{--}130 \mu\text{m}$
[106]	259 bottled samples, China, USA, Brazil, India, Indonesia, Mexico, Lebanon, Thailand, For each bottle: avg 10.4 MPs/L	Fragment (66%), Fiber (13%), Film (12%), Foam (5%), Pellet (3%)	PP (54%), Nylon (16%), PS (11%), PE (10%), PEST (6%)	-	$6.5\text{--}100 \mu\text{m}$
[107]	Barcelona, Spain, 14 samples, < 1000 ng/L	-	PET (33%), PE (55%), PP (10%)	-	700 nm to $20 \mu\text{m}$
[108]	Thailand, PET-bottled (65 samples), Glass bottled (30 samples), PET bottled: Avg: 140 ± 19 MPs/L, Glass bottled: Avg: 52 ± 4 MPs/L	Fiber, Fragment	PE, PET, PP, PA. For $\geq 50 \mu\text{m}$: PET (28.4%), PE (24.2%), PP (18.1%), PA (7.2%), etc.	-	$6.5\text{--}20 \mu\text{m}$, $20\text{--}50 \mu\text{m}$, $\geq 50 \mu\text{m}$

Table 4. Cont.

Ref.	Region, Sampling Collection Year and Abundance	Shape of MPs	Materials of MPs	Color of MPs	Sizes of MPs
[109]	9 samples, West Godavari region of Andhra Pradesh, India, September to October 2024, Avg: 2.89 ± 0.48 items/L	Fiber (21.42% to 100.0%), Fragment (0 to 25%)	PP (53.7%), PET (34.3%), Nylon (6.0%), PVC (3.0%), PA (1.5%), Cellulose (1.5%)	Transparent (34.3%), Blue (29.9%), Pink (16.4%), Yellow (6.0%), Black (6.0%), Green (4.5%), Violet (3.0%)	500 to 1000 μm (53.73%), 1000–2000 μm (23.8%), 2000–5000 μm (11.9%), <500 μm (8.9%)
[110]	Turkey, 150 bottle samples, natural (105) and mineral (45) waters, 1 to 40 particles/L	Fiber (52%), Fragment (32%), Film (9%)	PE (33%), PP (31%), PET (25%), PA (11%)	Blue (46%), Transparent (18%), Grey (19%), Black (14%), Purple (3%)	10 μm (5%), 30 μm (15%), 50 μm (26%), 70 and 90 μm (each 20%), >100 μm (14%)
[111]	Catania province, Italy, August to October, 2019, 656.8 ± 632.9 mg/L	-	-	-	2.44 ± 0.66 mm
[112]	Five samples, Germany, Glass bottles, 49 ± 3 MP/m ³	-	PE, PP, PVC, PS, PTFE, PA, PES, PLA	-	>11 μm , 11–50 μm (18–71%)
[113]	China, PET bottles, 23 samples, 2 particles/bottle to 23 particles/bottle	Fiber (33.3–100.0%), Fragment	PP (0.93%), PS (4.65%), PE (6.05%), PET (6.98%), PU (1.86%), PVC (1.4%), PA (4.19%), PAM, PAA, EVA, Cellulose (71.16%)	-	0.1–0.3 mm (29.20–49.20%), 0.05–0.1 mm (19.39–37.10%), 1 mm–5 mm (4.75–12.26%), 0.025 mm to 0.05 mm (0.35–14.16%), 0.3–0.5 mm (8.42–15.59%)
[114]	UK, August 2020	Sphere	PET, PP	Transparent	Type A: 66 (16.1%), 433 nm (83.9%), Type B: 140 nm (64.8%), 605 nm (31.4%), 5 μm (3.8%)
[115]	8 samples, Malaysia, PET bottles, June to November, 2021, 8 to 22 particles/L, Avg: 11.7 ± 4.6 particles/L	Fragment (90.1%), Fiber (9.1%)	PET, PP	Transparent (96.5%), Blue (2.7%), Green (0.8%)	<1 mm (83%), 300 to 500 μm (28%), 100 and 300 μm (31%)
[116]	100 samples, South Eastern, Nigeria, Fragment: 42.83 MP particles/0.75 L, Film: 1.16 MP particles/0.75 L, Pellet/Granule: 10.82 particles/0.75 L	Fragment, Film, Granule, Pellet	PET (45.08%), PE (24.79%), PDMS (17.90%), PVC (12.23%)	-	20 to 100 μm

Table 4. Cont.

Ref.	Region, Sampling Collection Year and Abundance	Shape of MPs	Materials of MPs	Color of MPs	Sizes of MPs
[117]	Chile, Dec 2021, Avg: 391 ± 125 particles/L	Fiber	HDPE, PET, PP	-	5–20 μm (57%),
[118]	Nine samples, Netherlands, March 2021, 7–364 particles/L (Avg: 96 particles/L)	-	PET and PU (81.9%), PA (8.9%), PVC (4.9%)	-	-
[119]	Four samples, Poland, 4167–14,556 particles/ m^3	Fragment (12%), Microbead (2 to 10%), Granule	-	Colored	-
[120]	20 samples, Netherlands, 28 and 85 items/500 mL	-	-	-	10–310 μm

4.5. Microplastics in Sea

Microplastics are pervasive contaminants in marine environments, with their abundance, shapes, materials, and sizes varying widely across different seas and oceans. In the Mediterranean Sea, Cózar et al. [121] reported concentrations ranging from 22 to 1934 g/km^2 , with fragments (87.7%) dominating the particle shapes, alongside pellets, films, and foams. Similarly, in the Sea of Japan, Isobe et al. [122] found an average of 3.7 items/ m^3 , primarily composed of fragments between 1 mm and 10 mm in size.

Regional studies reveal the prevalence of fibers as a dominant shape in certain seas. For example, in the Baltic Sea, fibers accounted for 82% of microplastics, with materials like polypropylene (PP) and polyethylene (PE) being the most common [123]. Likewise, in the Atlantic Ocean, Kanhai et al. [124] reported that fibers constituted 94% of microplastics, predominantly rayon and acrylic, with particles ranging between 0.25 and 5 mm in size. In the East China Sea and Arctic Ocean, fibers made up 83.8% of particles, with polyethylene terephthalate (PET) and rayon as the primary materials [125].

Microplastic materials reflect the polymers used in industrial and domestic applications, with PE and PP being ubiquitous across marine environments. For instance, PE and PP were the most frequently identified materials in the Baltic Sea [126] and the Tyrrhenian and Ionian Seas [127]. In the Arctic Ocean, particles were composed of polydimethylsiloxane (PDMS), PU, and PET, highlighting regional industrial influences [128].

Microplastic sizes in the sea range widely, from microplastics smaller than 0.3 mm in the Korean Southwest Sea [129] to larger particles exceeding 5 mm in the Bohai Sea [22]. White and transparent microplastics are frequently observed, suggesting contributions from degraded plastics and fishing gear, as seen in the Bohai Sea [130] and the Gulf of Gabes [131]. All the details are presented in Table 5.

Table 5. Abundance of microplastics in sea water, and their shapes, materials, colors, and sizes.

Ref.	Region, Sampling Collection Year and Abundance	Shape of MPs	Materials of MPs	Color of MPs	Sizes of MPs
[21]	Northwestern Pacific Ocean, August to September 2017, 10 ⁴ items/km ²	Sheet (26.7%), Line (8.9%), Granule (39.7%), Film (24.7%)	PE (57.8%), PP (36.0%), Nylon (3.4%), PVC (1.1%), PS (0.6%), PET (0.2%), Rubber (0.9%)	White (57.4%), Transparent (22.8%), Green (6.6%), Black (6.4%), Blue (2.8%), Yellow (2.5%), Purple (1.5%)	<0.5 mm (0.4%), 0.5 to 1.0 mm (52/2%), 1–2.5 mm (29.8%), 2.5–5.0 mm (17.6%)
[22]	Bohai Sea, China, August and October 2016, February and May 2017, Avg: 0.35 ± 0.13 particles/m ³	Line (38%), Fragment (35%), Foam (13%), Fiber (12%), Pellet, Film	PE (43%), PP (34%), PS (19%), PET (13%)	White (58%), Green (22%), Transparent (8%), Yellow (4%), Black (3%), Red, Blue	Macroplastics (5%), mesoplastics (26%), microplastics (69%)
[23]	Kattegat/Skagerrak Sea, Denmark, October to November 2020, 11–87 particles/m ³	Fragment (56%), Fiber (44%)	PES (46%), PP (16%), PE (6%)	-	<300 µm
[121]	Mediterranean Sea, Spain, Greece, France, Italy and Cyprus, May 2013, 22 to 1934 g/km ²	Pellet/Granule (1.8%), Film (5.9%), Foam (2.3%), Fragment (87.7%)	-	-	0.25–100 mm, >100 mm
[122]	Sea of Japan, Japan, July to September, 2014, Avg: 3.7 items/m ³	Fragment	-	-	1 mm to >10 mm
[123]	Baltic Sea, Sweden, June, July 2014, 4.2 × 10 ⁵ plastics/km ² to 4.7 × 10 ⁴ plastics/km ²	Fiber (82%), Fragment	PP (53%), PE (24%)	Blue, Red, Black, Green	Avg: 335 µm
[124]	Atlantic Sea, Germany, South Africa, November 2015, Avg: 1.15 ± 1.45 particles/m ³	Fiber (94%)	Rayon (67%), PA, PP, PVC, Acrylic, Polyester, PS, PU	Blue (72%), Transparent (9%), Pink (8%), Others (Purple, Brown, Red, Green, Grey, Black, Yellow, White: 11%)	0.25–5 mm, <5 mm (96%)
[125]	East China Sea to the Arctic Ocean, July to October 2017, 0.48 to 7.62 items/m ³	Fiber (83.8%), Fragment (10.6%), Line (5.6%)	PET (71.2%), Rayon (8.8%), PA, PS, PE, PP	Black (52.5%), Red (21.3%), White (18.4%), Transparent (7.5%)	0 to 1 mm (40.6%), 1 to 2 mm (41.3%), 2 to 3 mm (11.9%), 3 to 4 mm (5.6%), 4 to 5 mm (0.6%)

Table 5. Cont.

Ref.	Region, Sampling Collection Year and Abundance	Shape of MPs	Materials of MPs	Color of MPs	Sizes of MPs
[126]	Baltic Sea, Gulf of Riga, Latvia, May to September 2018, 0.09 to 4.43 particles/m ³	Fiber (66.1%), Fragment (30.2%), Film, Bead, Foam	PE (77.9%), PP (11.1%), PS (0.8%), PES (0.1%), Nylon (0.1%)	White (30.1%), Black (24.6%), Blue (20.5%), Pink (5.6%), Green (4.4%), Grey, Transparent, Purple, Yellow, Orange, Brown	0.3–1 mm (53.2%), 1–5 mm (43.4%), 5–10 mm (2.8%)
[127]	Central-southern Tyrrhenian Sea, Western Ionian Sea, Italy, July to August, 2017, Avg: 0.197 ± 0.130 items/m ²	Fragment (79%), Film (17%), Filament (2%), Pellet, Microbead, and Foam (each less than 2%)	PE (77.2%), PP (21.2%)	White, Opaque, and Transparent (83%)	1–2.5 mm (57%)
[128]	Southern Beaufort Sea, Arctic Ocean, Canada, USA, August to September 2022, 937 to 28,081 pieces/km ²	Fragment (96.6%), Line	PDMS (36.2%), PE (27.6%), PU (13.8%), PET (8.6%), PVC and PA (each 3.4%)	-	Avg: 2.31 mm, 0.5–1.0 mm (41.4%), 1.0–2.0 mm (36.2%), Mesoplastics (3.4%)
[129]	Korean Southwest Sea, China, Japan, Republic of Korea, 0.46 ± 0.27 particles/L	Fragment (69%), Fiber (31%)	PE (53%), PP (14%), Polyester (13%), Acryl (1%), Alkyd (19%)		0.02–0.3 mm (69%), 0.3–0.6 mm (16%)
[130]	Bohai Sea, China, August, 2016, Avg: 0.33 ± 0.34 particles/m ³	Fragment (46%), Line (24%), Film (22%), Foam (5%), Fiber (3%)	PE, PP, PS, PET, PU, PVC	White (68%), Yellow (6%), Transparent (11%), Green (10%), Blue, Red, Black	>2.5 mm (7%), 0.5–2.5 mm (38%), 0.3–5 mm (55%)
[131]	Gulf of Gabes, southern Mediterranean Sea, Tunisia, October–November, 2017, Avg: 63,739 items/km ²	Fragment, Film, Filament, Pellet, Foam	PE, PP	White, Blue, Black, Green, Red, Yellow, Orange, Grey, Purple	0.2 to 5 mm
[132]	Southeast Black sea, Turkey, Georgia, November 2014, February 2015, Avg: 1.2 ± 1.1 × 10 ³ particles/m ³ (November), 0.6 ± 0.55 × 10 ³ particles/m ³ (February)	Fiber (49.4%), Film (30.6%), Fragment (20%)	-	-	0.2–5 mm (92%)

Table 5. Cont.

Ref.	Region, Sampling Collection Year and Abundance	Shape of MPs	Materials of MPs	Color of MPs	Sizes of MPs
[133]	Ross Sea (Antarctica), Summer 2010, 0.0032 to 1.18 particles/m ³	Fragment (37%), Fiber (54%)	PE and PP (57.1%), Polyester (28.6%), PTFE (5.7%), PMMA (5.7%), PA (2.9%)	-	-
[134]	Gulf of Lion (NW Mediterranean Sea), France, February 2014 to April 2016, 6×10^3 items/km ² to 1×10^6 items/km ²	-	-	-	1.48 ± 0.88 mm
[135]	Sea of Marmara, Turkey, Summer 2017, Avg: 1.263 item/m ²	Fragment (61.2%), Film, Foam, Granule	PP, PS	White (30.6%), Black, Blue, Brown, Gray, Green, Red, Orange, Pink, Purple, Transparent	1 to 50 mm
[136]	Bering Sea, Chukchi Sea, China, July to October 2017, 0.018 to 0.31 items/m ³	Fiber (95.9%), Fragment (3.6%), Film (0.5%)	PET (67.5%), PP (10.5%), PA (7.4%) PE (5.9%), AC (3.9%), Rayon (2.9%)	White (70.5%), Black (13.5%), Red (7.2%)	<1 mm (52.5%)
[137]	South of Caspian Sea, Iran, May, 2019, 710 units/m ³	Fiber (97%), Fragment (3%)	PET, PS, Nylon	Black-Grey (49%), Blue-Green (17%), Yellow-Orange (16%), Red-Pink, White-Transparent	100–250 µm (23%), 250–500 µm (20%), 500–1000 µm (15%), >1000 µm (42%)
[138]	Baltic Sea, Finland, 0–1.6 and 0–766 ng/m ³	Fragment (97.6%), Fiber (2.4%)	PE (47%), PP (26%), PET (25%), PA, PS, ABS	-	0 to 700 µm
[139]	Western Arctic Sea, USA, Canada, July–August 2019 (ice), October–November 2020 (water), Avg: (ice: 23 ± 11 MPs/L, water: 1.9 MPs/L)	Fiber, Fragment, Bead	PVC	-	-
[140]	Port of Gdynia, Baltic Sea, Poland, 0.082 to 0.524 mg/m ³	Fragment, Film, Fiber, Sphere	PE, PP, PS, LDPE, HDPE, Nylon, PA, Acrylic, PVC, Polyester	Transparent, Black, White, Yellow, Blue, Green	0.3–5 mm

Table 5. *Cont.*

Ref.	Region, Sampling Collection Year and Abundance	Shape of MPs	Materials of MPs	Color of MPs	Sizes of MPs
[141]	Chukchi Sea, western Arctic Ocean, Japan, October 2020, September–October 2021, 0 to 18,815 pieces/km ²	Fragment (74.4%), Pellet (14%), Line (11.6%)	PE (34.9%), PP (18.6%), PU (16.3%), PET, PVC, PA (each 4.7%)	-	-
[142]	Southern Weddell Sea off Antarctica, 0.5 to 267.2 MPs/m ³	Fiber	PP, PA	-	11–500 µm, 11–300 µm (>98%)

4.6. Microplastics in Human, Domestic Animals, Birds, and Aquatic Organisms

Microplastics have become pervasive pollutants in aquatic environments, posing significant threats to ecosystems and human health [143]. Water serves as the primary medium for MPs dissemination, making aquatic organisms the most vulnerable to their effects. MPs are introduced into water bodies through various sources, including the breakdown of larger plastics and industrial discharges, leading to their ingestion by a wide range of aquatic species, from plankton to fish [8]. This ingestion can result in physical blockages, malnutrition, and exposure to toxic chemicals that MPs often adsorb, such as persistent organic pollutants (POPs) and heavy metals [144]. These pollutants bioaccumulate and biomagnify as MPs move up the food chain, ultimately affecting higher organisms, including humans and terrestrial animals [145].

The transfer of MPs from aquatic ecosystems to terrestrial organisms occurs via direct consumption of contaminated water and seafood. For instance, studies have reported that humans ingest MPs through seafood, such as shellfish and fish, which are often contaminated due to their filter-feeding behavior or consumption of smaller organisms with MPs in their systems [146]. In domestic animals, the use of contaminated water for drinking or irrigation also contributes to MPs exposure, potentially leading to health issues, including gastrointestinal blockages and toxicity [147]. Birds, especially those feeding near water bodies, are similarly affected; they ingest MPs directly or indirectly through their prey, leading to digestive tract damage and chemical exposure that disrupts reproduction and growth [148]. More research is required to better understand the health risks that microplastics may pose to domestic animals and the potential for human exposure through animal-derived products. Investigations have revealed the presence of notable amounts of microplastics in the food, feces, and tissues of domestic animals, highlighting extensive environmental pollution. Initial findings indicate that certain cooking and processing techniques may help lower microplastic contamination in animal-based products, but further studies are essential to validate these findings [149].

Human health is significantly impacted by microplastics (MPs), as these particles have been detected in human blood, lungs, and even placental tissues [150]. MPs enter the human body through various pathways, including ingestion, inhalation, and dermal exposure. Once internalized, they can traverse biological barriers, such as the intestinal lining, blood-brain barrier, and placental barrier, leading to systemic distribution and accumulation in vital organs [151]. These accumulations are associated with inflammation, oxidative stress, and long-term health risks, particularly in vulnerable populations.

The gastrointestinal tract is a primary site for MP entry and transport, mainly through the consumption of contaminated food and water. MPs can penetrate intestinal epithelial cells via endocytosis, phagocytosis, and intercellular gaps, leading to disruptions in barrier integrity, alterations in gut microbiota, and systemic inflammation [152]. Research indicates that MPs in the gut impair nutrient absorption and enzymatic functions, contributing to oxidative stress, histopathological changes, and exacerbating gastrointestinal diseases such as inflammatory bowel disease [153]. MPs also carry toxic substances, such as persistent organic pollutants (POPs) and heavy metals, which further amplify their negative effects on health [144]. Additionally, MPs' ability to release toxic additives and contaminants exacerbates inflammatory responses and disrupts gut microbiota composition, further contributing to metabolic dysfunctions [154].

These disruptions in the gastrointestinal system are associated with broader metabolic dysfunctions, as MPs in the gut have been shown to increase systemic inflammation and oxidative stress [155]. Furthermore, MPs can induce histopathological changes that impair intestinal barrier integrity, which may worsen preexisting gastrointestinal conditions [151]. Addressing the impacts of MPs requires further research and improved measures to mitigate exposure through food and water sources.

Inhalation of MPs represents a significant exposure route, particularly in urban and industrialized environments where atmospheric MPs concentrations are higher [156]. MPs in the respiratory system can bypass mucociliary defenses, lodging in lung tissues and even entering the bloodstream. This translocation raises concerns about systemic inflammation and oxidative stress, which are linked to cardiovascular impacts such as atherosclerosis and thrombosis [157,158]. Long-term exposure to airborne MPs has also been associated with increased risks of chronic respiratory conditions, including asthma, chronic obstructive pulmonary disease (COPD), and pulmonary fibrosis [159].

Smaller MPs and nanoplastics (NPs) pose additional concerns due to their ability to penetrate deeper into the alveolar regions of the lungs, increasing the likelihood of translocation into systemic circulation. Once in the bloodstream, MPs can accumulate in detoxification organs such as the liver and spleen, compounding their potential for systemic harm [157]. Furthermore, MPs have been found in bronchoalveolar lavage fluid, emphasizing their possible role in exacerbating existing respiratory diseases [159].

Emerging research has also identified MPs in the human placenta, highlighting concerns about their impact on fetal development and maternal health. MPs have been shown to traverse the maternal-fetal barrier, with studies linking their presence to oxidative stress, hormonal imbalances, and adverse pregnancy outcomes such as preterm birth and low birth weight [160]. Additionally, MPs in the placenta have been associated with disruptions in the placental microbiome, which may lead to cascading effects on both maternal and neonatal health [161,162]. Exposure to MPs during pregnancy has further been implicated in developmental delays and neurotoxic effects in offspring, underscoring the need for stricter regulations on plastic production and pollution [163].

Dermal exposure to MPs, although less studied, remains another potential pathway for systemic distribution. MPs in personal care products such as exfoliants and creams can penetrate the skin through compromised barriers, hair follicles, or sweat glands [164]. Once absorbed, MPs can enter the lymphatic system and bloodstream, posing additional risks. This exposure is further complicated by chemical additives like bisphenols and phthalates, which are known endocrine disruptors and can interfere with hormonal balance [165].

The potential systemic effects of MPs extend beyond individual organ systems. Studies have detected MPs in the circulatory system, where they interact with cellular components, potentially inducing hemolysis, platelet aggregation, and vascular endothelial damage [166]. MPs in blood can also reach neural tissues, crossing the blood-brain barrier

and contributing to neuroinflammatory conditions, cognitive deficits, and other neurodegenerative diseases [158]. In reproductive health, MPs have been detected in semen and testes, with evidence linking their presence to reduced sperm quality, hormonal disruptions, and oxidative stress, ultimately affecting fertility [2].

The pervasive presence of MPs in the environment and their diverse pathways into the human body necessitate urgent action to mitigate exposure. Effective measures include improving waste management systems, advancing water filtration technologies, and conducting longitudinal studies to better understand the chronic ecological and health impacts of MPs. Additionally, public health campaigns and stricter regulatory frameworks are critical to addressing this growing concern. Policy interventions must focus on reducing human exposure to MPs across all pathways while protecting vulnerable populations, including children, pregnant women, and individuals with preexisting conditions. All these details are presented in Figure 8.

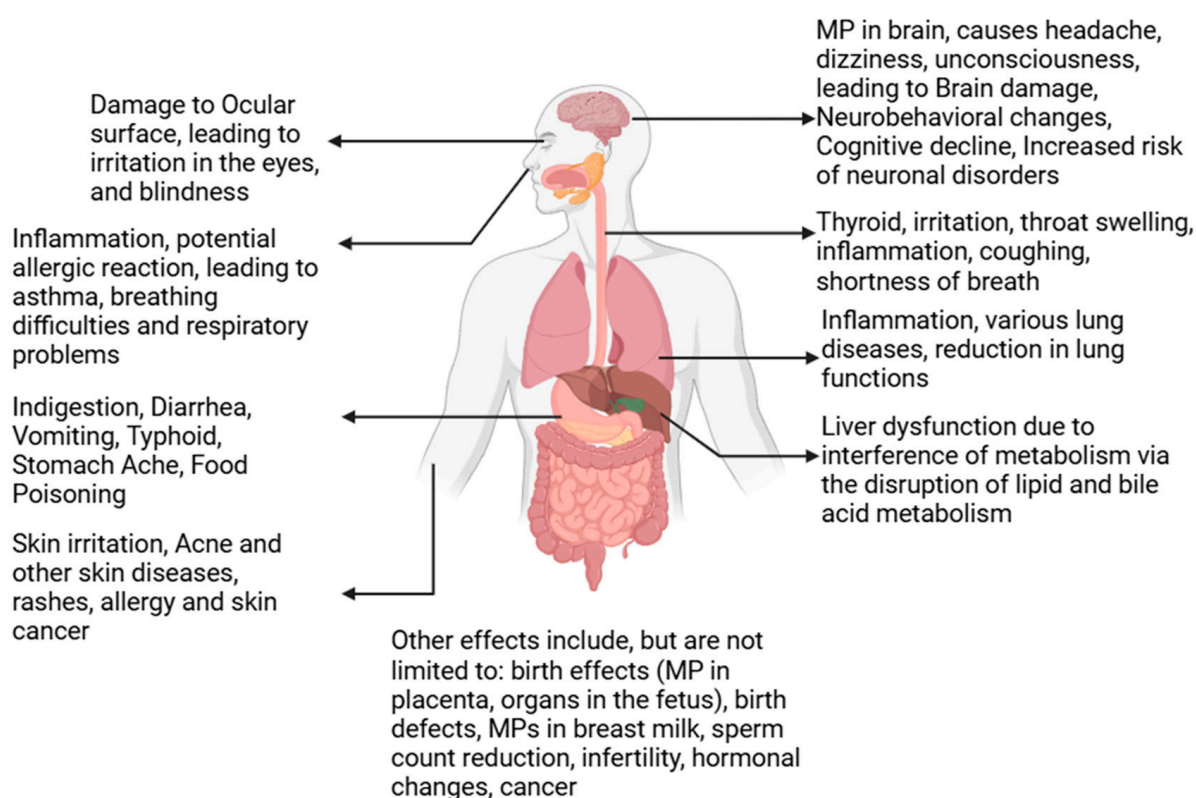


Figure 8. Effects of microplastics on humans.

5. Conclusions

This review demonstrates the widespread occurrence of microplastics across aquatic environments, from remote lakes to highly urbanized rivers and seas, as well as in drinking and bottled water. The variability in MP abundance, composition, and characteristics reflects the influence of local environmental factors, industrial activities, and water treatment efficiencies. Despite significant progress in identifying MP sources and impacts, knowledge gaps remain regarding their chronic health effects, bioaccumulation pathways, and ecological consequences. The prevalence of MPs in drinking water sources, in particular, calls for immediate action to enhance filtration technologies and establish global standards for monitoring and reporting MP pollution. Addressing these challenges requires interdisciplinary efforts to integrate scientific research with policymaking and community engagement.

6. Future Research Directions

One of the most pressing areas for future research is understanding the health impacts of MP ingestion, particularly through drinking water and food. While studies have detected MPs in human blood, tissues, and organs, the long-term effects of chronic exposure remain poorly understood. Research should focus on identifying potential toxicological pathways, including the role of MPs as vectors for harmful chemicals and pathogens, and their implications for human health, especially in vulnerable populations like children and pregnant women. Biomonitoring studies, particularly those on MP accumulation in human tissues, are crucial to strengthening the evidence regarding health risks, although this falls outside the scope of the current review.

Another critical need is the standardization of methodologies for sampling, analyzing, and reporting MP concentrations. The lack of uniform protocols across studies has led to inconsistencies, making it difficult to compare results and draw generalized conclusions. Future research should prioritize the development and adoption of standardized procedures that account for variations in particle sizes, shapes, and materials, enabling more reliable global assessments of MP pollution. Further efforts are also needed to address the duplication of studies in different categories, ensuring accurate synthesis and avoiding overrepresentation of specific research areas.

Understanding the ecological effects of MPs and their bioaccumulation across trophic levels is another key area requiring attention. Studies have highlighted the ingestion of MPs by aquatic organisms, but the extent of their accumulation and potential transfer through the food web is still unclear. Research should aim to quantify these processes and evaluate the ecological and economic consequences, such as impacts on fisheries and biodiversity. Additionally, investigating the interactions between MPs and natural organic matter, heavy metals, and persistent organic pollutants will deepen our understanding of the long-term fate of MPs in the environment.

Mitigation technologies also demand further exploration, particularly in the context of water treatment and filtration systems. Developing advanced and cost-effective methods to remove MPs from drinking water and wastewater will be crucial for reducing human exposure and environmental contamination. Innovations in membrane technology, adsorption techniques, and microplastic degradation methods should be a focal point for future studies. A comparative analysis of these technologies across regions would also be valuable to inform global strategies for MP pollution control.

Moreover, a significant research gap exists in understanding MP pollution in under-represented regions, such as Africa and South America. While developed nations have conducted extensive studies, data from low- and middle-income countries are limited, despite these regions often experiencing higher levels of plastic waste mismanagement. Expanding research efforts to these areas will provide a more comprehensive understanding of global MP distribution and inform targeted mitigation strategies.

Finally, translating research findings into actionable policies is essential to addressing the microplastic crisis. Future studies should focus on providing robust evidence to support the development of regulations for plastic production, recycling, and environmental release. By linking scientific discoveries with policymaking, researchers can help create sustainable solutions that minimize the generation and spread of MPs while promoting global collaboration to tackle this pervasive issue. Comparative analyses of regulatory frameworks across different regions could also provide valuable insights for global policymakers.

While this review focused on inland waters, there is a growing need to expand research to include studies from different regions, particularly Europe. Future research should consider the Danube River Basin and similar areas where microplastic pollution is a

significant concern. Expanding the geographical scope will provide a more comprehensive understanding of microplastic distribution globally.

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Abbreviations

PE	Polyethylene
PP	Polypropylene
PPS	Polyphenylene Sulfite
PS	Polystyrene
PET	Polyethylene Terephthalate
PMS	Poly alpha-Methylstyrene
PTFE	Polytetrafluoroethylene
PC	Polycarbonate
PMMA	Poly Methyl Methacrylate
PBT	Polybutylene Terephthalate
PB	Polybutene
PVC	Poly Vinyl Chloride
LDPE	Low-Density Polyethylene
PU	Polyurethane
PBS	Polybutylene Succinate
PPC	Polypropylene Carbonate
PA	Polyamide
UA	Urethane Acrylate
PVA	Polyvinyl Alcohol
PES	Polyethersulfone
HDPE	High-Density Polyethylene
CE	Cellulose
PI	Polyisoprene
PBD	Polybutadiene
PDMS	Polydimethylsiloxanes
ABS	Acrylonitrile Butadiene Styrene
CA	Cellulose Acetate
EVAc	Ethylene Vinyl Acetate
EVOH	Ethylene Vinyl-alcohol
PAN	Polyacrylonitrile
PEEK	Poly-Ether-Ether-Ketone
POM	Polyoxymethylene

PPSU	Polyphenylene Sulfone
PSU	Polysulfone
PLA	Polylactic Acid
SI	Silicone
SEBS	Styrene-Ethylene-Butylene
PDMS	Polydimethyl Siloxane
SIL	Polysiloxane

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