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REVIEW

Microplastic pollution in bottled water: a systematic review

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Abstract

Microplastic contamination of drinking water is a growing issue that is spreading across the globe. A systematic review focused on bottled drinking water has not yet been done. Thus, the review's objective is to examine the most recent developments in microplastics research around the world, as well as the physical properties of microplastics and the different kinds of polymers in bottled water. Two reputed databases were used to achieve the objectives. The results showed that the number of published articles has generally been increasing over the years, with a few fluctuations. China and Iran have equal and the greatest number of published articles, with around 14% each share, and Asia has the largest publication count, 38% of the total. According to the review, the abundance of microplastics was recorded in a range of 56–100% of the analyzed bottle samples. Fragments constituted the majority of microplastics, accounting for around 50%, with fibers comprising around 36%. Polyethylene Terephthalate is the dominant polymer. Overall, the study's outcomes contribute valuable information to understanding global research trends, geographic concentrations, physical characteristics, polymer types, and estimated daily intake related to microplastic contamination in bottled water. The study highlights a critical research gap regarding the health risks associated with microplastic exposure, emphasizing the need for further investigation in this area. Moreover, research on microplastic pollution relies on snapshot techniques instead of seasonal approaches. A crucial need exists for longer-term studies, mainly focusing on consistent monitoring of specific bottled water brands.

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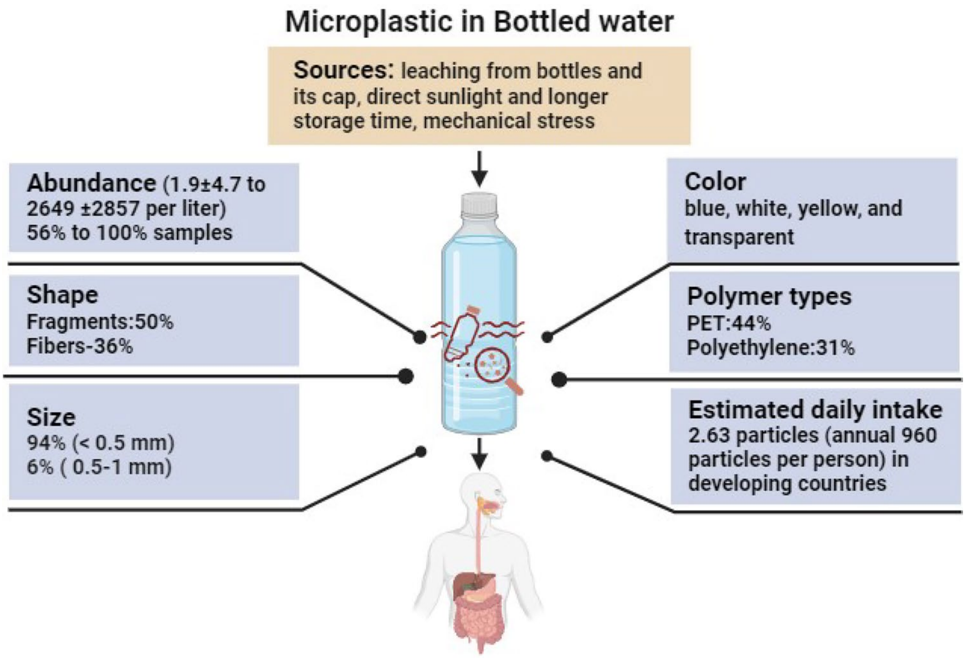
Graphical Abstract



Keywords Freshwater · Microplastic pollution · Mineral water · Plastics · Polymer

Introduction

The bottled water market has grown rapidly throughout the years, approaching a global production of more than 6000 million gallons annually in 2015 (Luo et al. 2018). The recent worldwide sales of bottled water are approximately valued at over 270 billion US dollars and 350 billion liters. Approximately 50% of the worldwide bottled water industry is comprised of the Asia–Pacific region, while global south countries collectively account for around 60%. The combined market share of the USA, China, and Indonesia accounts for 50% of the global market (Bouhlel et al. 2023).

In many places, bottled water, also known as natural mineral water, spring water, and processed water, has become a popular drinking option (Guart et al. 2014; Rowell et al. 2016). Bottled water is generally preferable to tap water in many regions of the world because of its safety, flavor, purity, quality, and availability (Salazar-Beltrán et al. 2018; Santana et al. 2014). Regarding packaging, glass and plastic bottles are two major forms (Salazar-Beltrán et al. 2018). Plastic bottles are mostly composed of polyethylene terephthalate (PET), polycarbonate (PC), and high-density polyethylene (HDPE). The caps of these bottles are manufactured from HDPE, low-density polyethylene (LDPE), and polystyrene (PS). Various polymer materials, bottle formats, shapes, and colors are employed in many bottling industries (Guart et al. 2011). Synthetic polymers, characterized by their lightweight, durability, elasticity, moldability, affordability, and hydrophobicity, were initially developed to enhance human convenience. Nevertheless, the fact that they are not capable of being broken down by natural processes and instead accumulate rapidly, transforming into micro/nano plastic structures through mechanical and physio-chemical deterioration, presents substantial risks to living creatures and the environment (Menon et al. 2023).

Microplastics are diverse in nature and display unique characteristics, which vary based on their physical attributes, including shape, size, and particle density (Zbyszewski et al. 2014; Wang et al. 2021). Microplastics are categorized into primary and secondary types based on their origin. Primary types, such as pellets, granules, and microspheres, are produced by the industry specifically for use as raw materials in the manufacturing of other products (Boucher and Friot 2017). Secondary microplastics, which include the form of fragments, filaments, foams, and films, are produced when larger plastic components break down due to environmental variables such as solar radiation, waves, oxidation, and biodegradation (Auta et al. 2017). Films and fibers typically have irregular shapes that result from the breakdown of waste materials, construction activities, laundry, and greenhouse poly bags. These shapes undergo further deterioration due to photo-degradation and mechanical abrasion (Zhang 2017; Filella 2015).

Microplastics access freshwater ecosystems through many pathways, predominantly by surface run-off and the discharge of wastewater, including both treated and untreated sources. Additionally, they can enter through combined sewer overflows, industrial waste, deteriorated plastic debris, and atmospheric deposition (WHO 2019). The available information suggests that certain microplastics detected in drinking water could originate from the processes involved in treating and distributing tap water and bottling packaged water (WHO 2019). Bottle capping is another reason for microplastics in bottled water, which was reported by Weisser et al. (2021). Microplastics were detected throughout the entire process of bottling mineral water, with a significant rise from less than one microplastic to an average of 317 ± 257 per liter, primarily caused by bottle capping. According to Weisser et al. (2021), the primary way microplastics enter bottled mineral water is by abrasion caused by the sealings, which are made of a cap-sealing substance that is 81% similar to polyethylene (PE). The presence of microplastics in bottled water can be attributed to two main sources: background contamination of the water before it is bottled and subsequent contamination caused by the release of microplastics from the plastic bottles into the water (Taheri et al. 2023). Menon et al. (2023) found that elevated temperature and ambient humidity enhance the photo-catalytic breakdown capacity of plastic polymers when exposed to sunlight or UV-B radiation.

Microscopic plastic particles have been found in water (Singh et al. 2022; Jang et al. 2021; Karapanagioti and Kalavrouziotis 2022; Glöckler et al. 2023; Muthulakshmi et al. 2023; Dybas 2020), soil (Da Costa et al. 2019; Sajjad et al. 2022; Guo et al. 2020), and air (Dybas 2020; Xie et al. 2022; Perera et al. 2023; Zhang et al. 2020), and are entering living cells. The invasion of these microplastics into the food chain cycle is resulting in significant detrimental effects on all living species. Microplastics that penetrate the food chain are typically inert, exhibiting various sizes and forms. Upon penetration into a cell or tissue, it causes mechanical harm, triggers inflammation, disrupts metabolism, and may even result in necrosis (Menon et al. 2023). Microplastics pose potential risks in three distinct ways: firstly, the particles themselves pose a physical threat; secondly, there are substances such as unbound monomers, additives, and sorbed chemicals from the environment; and finally, microbes can adhere to and colonize microplastics, forming biofilms (WHO 2019). Microplastics in natural aquatic habitats tend to combine with other substances like clay sediments, metallic oxides, and organisms etc. This results in the formation of diverse agglomerates, making the aggregation of microplastics heterogeneous (Wang et al. 2021). Microplastics promote the growth of microorganisms and the formation of biofilms, which are influenced by the qualities of the microplastics, the species of microorganisms, and the natural conditions of the water (Miao et al. 2021; Lagarde et al. 2016).

The presence of micro-plastic in drinking water is a growing worldwide issue. WHO (2019) has highlighted the increasing necessity to assess the presence of microplastics in bottled water and evaluate their possible impact on human health (Praveena et al. 2022). Although numerous review articles are available on microplastic in drinking water, a systematic study specifically focused on bottled drinking water has not been conducted to date. The review aims to analyze the current global trends in microplastics research, the physical characteristics of microplastics, and the types of polymers found in bottled water.

Research methods

Systematic reviews are a critical component of evidence-based practice and research. They play a crucial role in summarizing and synthesizing existing research on a specific topic or question in a rigorous and methodical way. Through their rigorous process, systematic reviews often reveal gaps in the existing literature. Identifying these gaps can guide future research and help set research priorities (Snyder 2019; Munn et al. 2018). The current study employed the PRISMA flow diagram to organize and structure its methodology (Fig. 1). The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram visually depicts the systematic review or meta-analysis process, illustrating the flow of information through identification, screening, eligibility, and study inclusion phases. The diagram helps researchers transparently reveal the number of records identified, screened, assessed for eligibility, and included in the final synthesis, providing readers with a clear overview of the study selection process (Page et al. 2021).

Database and keywords used for systematic review

Two popular databases, Web of Science and Scopus, were employed for systematic review (Table 1). The keywords used in this study were,

Article selection criteria

Inclusive criteria

- Only research articles
- Paper written in 2014–2023 (10 years)
- Paper written in English
- Research conducted on microplastics and bottled water

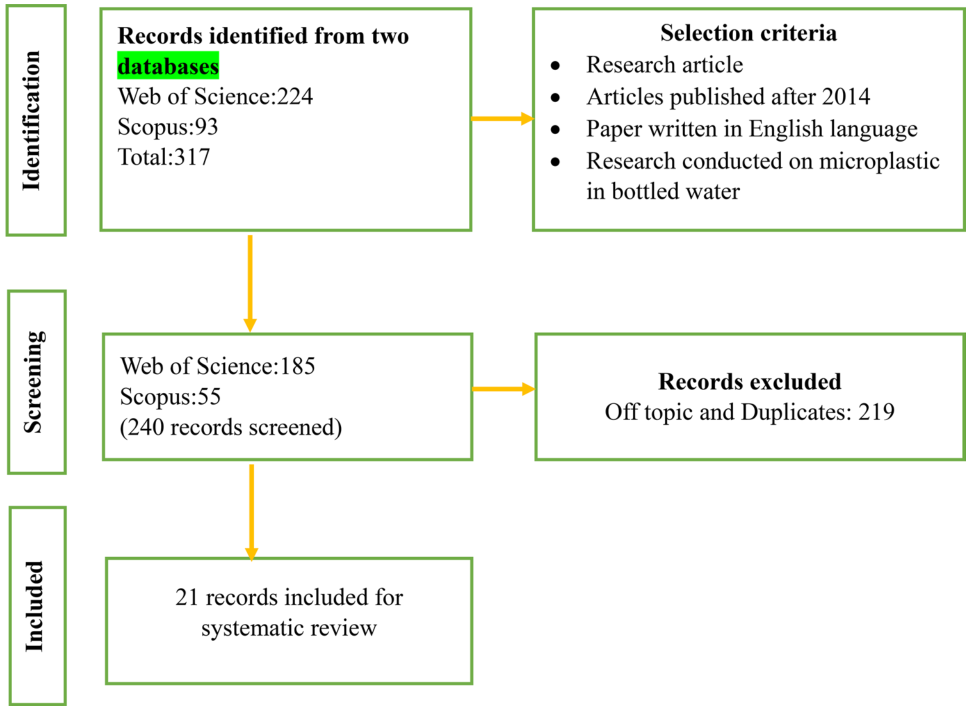


Fig. 1 PRISMA flow diagram

Table 1 Keywords used for review

Search term		Search term
Microplastics	AND	Bottled water
Microplastic contamination	OR	Bottled mineral water
Microplastic pollution		Bottled drinking water

Exclusive criteria

- Review articles
- Books, grey articles

Initially, 317 records were identified from two databases: Web of Science (224) and Scopus (93). The screening process, guided by specific criteria, including research article type, publication after 2014, English language, and relevance to the research topic, led to the examination of 240 records. Out of these, 219 were excluded due to being off-topic and duplicates. Ultimately, 21 records met the inclusion criteria and were included in the systematic review. (Fig. 1). To establish the identity of each study, data pertaining to the year and country of research were collected, and information on the research technique and significant findings were obtained based on the following research questions.

RQ1 What is the current trend of research on microplastics concerning bottled water?

RQ2 Which nations and regions exhibit the highest prevalence of studies on microplastic contamination in bottled water?

RQ3 What are the physical attributes (color, shape, size, and quantity/abundance) of microplastics found in bottled water?

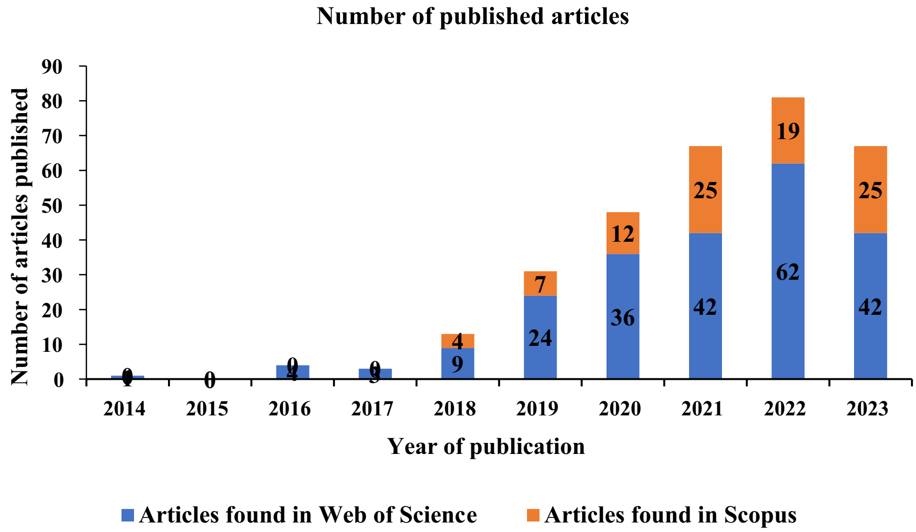
RQ4 What are the specific polymer types observed in bottled water?

Results and discussion

Year-wise published articles (searching keywords with microplastics and bottled water) found in two databases (2014–2023)

The number of articles found in Web of Science has been steadily increasing over the years. It started with just 1 article in 2014, and by 2022, it reached 62 articles, making it the primary source for articles in recent years. However, there was a slight decrease in 2023, with 42 articles. In recent years, Web of Science has consistently provided more articles compared to Scopus. This suggests that Web of Science is a more prominent source for research articles. The number of articles found in Scopus, while generally lower than Web of Science, has also seen growth. It started with 0 articles in 2015 and gradually increased over the years. In 2023, it remained constant at 25 articles. This might indicate that the data for the current year is incomplete (Fig. 2). These

Fig. 2 Year wise published articles found in two database (2014–2023)



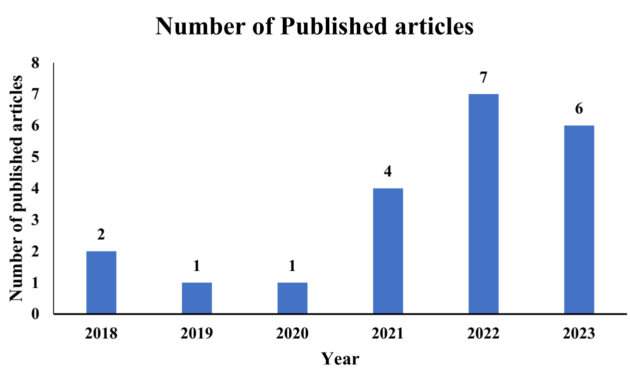


Fig. 3 Year-wise articles published from 2018–2023

trends and observations can be valuable for understanding the availability and growth of research articles in these two databases over the years.

Year-wise articles published from 2018–2023

Number of published articles applying inclusion criteria

The number of published articles has generally been increasing over the years, with a few fluctuations. In 2018, there were 2 articles, and this number dropped in 2019 to 1. However, since 2020, there has been a consistent increase each year. In 2023, there has been no additional growth in the number of published articles. This might indicate that the data is not complete for the current year (Fig. 3).

Country-wise and region wise publication

The data includes a variety of countries from different regions, indicating a global distribution of published articles (Table 2). China and Iran have the highest and equal number of published articles, with 3 each. This suggests a significant contribution to the research or publication output. Many countries have only one published article, indicating a lower research output in comparison to China and Iran (Table 3).

Asia is the region with the highest number of published articles, with a total of 8 articles (38%) (Fig. 4). This suggests a significant research output in Asian countries. The Middle East region has the second-highest number of published articles, with 6 articles (28%). It is notable for its research contributions, although it's still fewer than Asia. Europe, despite being known for its strong research output, has 4 published articles in this study. It has fewer publications than both Asia and the Middle East. Africa, South America, and Oceania have a lower number of published articles, with 1 article each.

Number of published articles recorded in different journals

The data includes articles from a variety of journals, indicating that the research has been published across different platforms. The journals "Science of the Total Environment" and "Water Research" have equal and the highest number of published articles, with 3 each (14%) (Table 4). This suggests that it is a prominent journal for the type of research in microplastic pollution. Some articles are published in journals with broader scientific or analytical themes, such as "Analyst" or "International Journal of Environmental Analytical Chemistry", suggesting an interdisciplinary approach to the research. The diversity of journals may imply that the research in microplastics covers various aspects of environmental science, pollution, and related fields.

Table 2 Number of published papers in year and country wise

Sn	Publication year	Name of journal	Country	Region	References
1	2022	Analyst	China	Asia	Li et al. (2022)
2	2023	Environmental Science and Pollution Research	Turkey	Middle East	Altunışık (2023)
3	2021	International Journal of Environmental Analytical Chemistry	Nigeria	Africa	Ibeto et al. (2021)
4	2021	Journal of Water Process Engineering	Iran	Middle East	Makhdoumi et al. (2021)
5	2018	Water Research	Germany	Europe	Oßmann et al. (2018)
6	2021	Journal of Water Process Engineering	China	Asia	Zhou et al. (2021)
7	2022	International Journal of Environmental Research and Public health	Hong Kong	Asia	Tse et al. (2022)
8	2019	Water Research	Italy	Europe	Zuccarello et al. (2019)
9	2023	Environmental Monitoring and Assessment	Iran	Middle East	Taheri et al. (2023)
10	2022	Environmental Pollution	Malaysia	Asia	Praveena et al. (2022)
11	2023	Environmental Pollution	Chile	South America	Nacaratte et al. (2023)
12	2022	Science of the Total Environment	Australia	Oceania	Samandra et al. (2033)
13	2021	Environmental Monitoring and Assessment	Saudi Arabia	Middle East	Almaiman et al. (2021)
14	2023	Frontiers in Environmental Science	Bangladesh	Asia	Hossain et al. (2023)
15	2020	Science of the Total Environment	Thailand	Asia	Kankanige and Babel (2020)
16	2018	Water Research	Germany	Europe	Schymanski et al. (2018)
17	2022	Su Urunleri Dergisi	Turkey	Middle East	Yozukmaz (2022)
18	2022	Water and Environment Journal	Iran	Middle East	Ravanbakhsh et al. (2022)
19	2023	Science of the Total Environment	China	Asia	Li et al. (2023)
20	2023	Journal of Hazardous Materials	Netherlands	Europe	Nizamali et al. (2023)
21	2022	Environmental Engineering Science	India	Asia	Parveen et al. (2022)

Table 3 Country-wise contribution of published article (%)

Country	Number of published articles	% Share
China	3	14.30
Iran	3	14.30
Germany	2	9.52
Turkey	2	9.52
Nigeria	1	4.76
Hongkong	1	4.76
Italy	1	4.76
Malaysia	1	4.76
Chile	1	4.76
Australia	1	4.76
Saudi Arabia	1	4.76
Bangladesh	1	4.76
Thailand	1	4.76
Netherlands	1	4.76
India	1	4.76
Total (15)	21	100

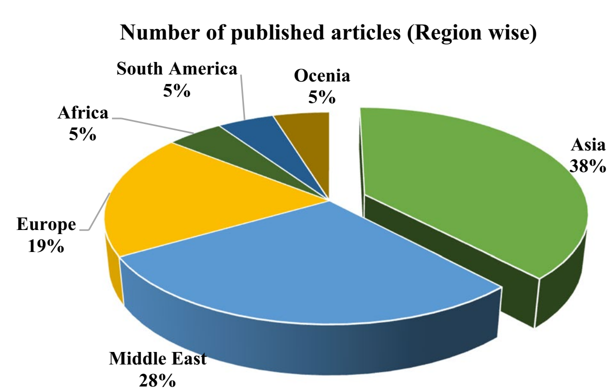


Fig. 4 Region-wise contribution of published paper

Physical and chemical characteristics of microplastics

Microplastics exhibit a diverse range of properties that are distinct and depend on their physical qualities, such as their shape, size, and color.

Color of microplastics found in bottled water

Among the 21 articles that have been published, only 4 of them have mentioned the color of microplastics present in bottled water. The colors observed were blue, white, yellow, and transparent (Table 5). The transparent microplastics

Table 4 Number of published articles found in different journals

Name of journal	Number of published articles	% Share contribution
Science of the Total Environment	3	14
Water Research	3	14
Environmental pollution	2	9
Journal of Water Process Engineering	2	9
Environmental Monitoring and Assessment	2	9
Environmental Science and Pollution Research	1	5
International Journal of Environmental Analytical Chemistry	1	5
International Journal of Environmental Research and Public health	1	5
Analyst	1	5
Frontiers in Environmental Science	1	5
Su Urunleri Dergisi	1	5
Water and Environment Journal	1	5
Journal of Hazardous Materials	1	5
Environmental Engineering Science	1	5
Total (14)	21	100

accounted for the largest proportion among all bottle brands, making up around 66% of the total microplastics (Hossain et al. 2023). Plastics manufacturers incorporate additives and dyes, leading to the varied coloring of microplastics. The color of microplastics can change due to degradation and weathering over time caused by environmental factors. Furthermore, the original purpose and source of the plastic, as well as aging processes, can influence color through alterations in molecular structure (Zhao et al. 2022).

Shape and size of microplastics found in bottled water

These percentages represent the composition of each microplastic shape within bottled water. Fragments were the most prevalent microplastic shape, making up approximately 50% of the total, followed by fibers at around 36% (Fig. 5). Pellets and films have smaller representations, at 7% each, respectively. Mason et al. (2018) observed 65% of microplastic was fragments in bottled water; however, in tap water, fibers (97%) were common shape of microplastics. The data suggest that the primary origin of the microplastic particles is distinct. The result is different from findings of Hossain et al. (2023). The majority of the identified microplastics were in the form of fibers, with films and fragments being the subsequent most common types. Of the total microplastics, approximately 90% consisted of fibers, 7% were fragments, and the remaining 3% were comprised of films and microbeads.

The dimensions of microplastics were quantified in approximately 60% of the articles. The range of microplastic size distribution is broad (Table 5). No microplastics above a size of 5 mm were identified in current review. The study conducted by Hossain et al. (2023) found approximately 94% of the particles had a size less than 0.5 mm, whereas the remaining 6% fell within the size range of 0.5–1 mm. The data of shape and size can be valuable for understanding the distribution of different microplastic forms, which is important in environmental studies and research on the impact of microplastics in various ecosystems.

Abundance of microplastics found in bottled water

Based on the current review, it was found that microplastics, as reported by different authors, were detected in a range of 56 (Almaiman et al. 2021)–100% (Hossain et al. 2023) of the samples that were examined (Table 5). Mason et al. (2018) examined eleven internationally acquired bottled water brands from 19 distinct sites across nine diverse countries to determine the presence of microplastic contamination. Out of the 259 bottles that were examined, 93% exhibited indications of microplastic contamination. After considering the potential contamination, an average of 10.4 microplastic particles larger than 100 µm per liter of processed bottled water were detected. The average number of microplastics identified in bottled water varies from 1.9 ± 4.7 (Almaiman et al. 2021) to 2649 ± 2857 per liter (Oßmann et al. 2018) (Table 5). It showed a wide variation in the quantity of microplastics present in bottled water. Mason et al.(2018) achieved a similar result. The levels of microplastic pollution range from 0 to over 10,000 particles per liter, with 95% of the particles lying between the sizes of 6.5 and 100 µm.

The abundance of microplastics in bottled water is attributed to multiple sources. The components consist of raw substances, the surrounding air, as well as equipment and

Table 5 Physical and chemical characteristics of microplastics

Sn	Color	Shape (dominant)	Size	Abundance	Polymer types	References
1	–	Irregular fragments	–	–	Polypropylene (PP)	Li et al. (2022)
2	–	Fragments (bottled mineral water) Fiber (bottled natural waters)	–	Identified in 43 (86%) out of 50 bottle brands 12.6 ± 1.6 particles/Liter	Polyethylene is the most prevalent (33%), followed by polypropylene (31%), polyethylene terephthalate (25%), and polyamid (11%)	Altunışık (2023)
3	–	Fragment film and pellet/granule		Detected in 92% of sample	Polyethylene (PE), polyvinyl chloride (PVC), polyethylene terephthalate (PET) and polydimethyl siloxane (PDMS)	Ibeto et al. (2021)
4	–	Fragment (93%) and fiber (7%)	–	Detected in 81.8% of the tested brands The mean concentration is around 8.5 ± 10.2 particles per liter	PET, PS, and PP	Makhdoumi et al. (2021)
5	–	–	–	Microplastics range from 2649 ± 2857 per liter in single use PET bottles	PET in plastic bottle Polyethylene or styrene-butadiene-copolymer in glass bottle	Oßmann et al. (2018)
6		Fiber and fragments	0.025–5 mm	2–23 particles/bottle	11 types of MPs (polypropylene, polystyrene, polyethylene, polyethylene terephthalate, polyurethane, polyvinyl chloride, polyamide, polyacrylic acid, polyacrylamide, polyethylene vinyl acetate, and cellulose)	Zhou et al. (2021)
7		Fragments	Modal size 1 µm	The average concentration of microplastics with a size of 50 µm or larger in the samples ranged from 8 to 50 particles per liter. Microplastics of a size smaller than 50 µm were identified at concentrations ranging from 1570 to 17,817 particles per liter	–	Tse et al. (2022)

Table 5 (continued)

Sn	Color	Shape (dominant)	Size	Abundance	Polymer types	References
8	–	–	–	Identified in each and every sample The average microplastic content was 5.42 per liter (656.8 μg/L 632.9)	–	Zuccarello et al. (2019)
9	–	–	91.3% of the particles that were identified had a size ranging from 1 to 10 μm	The mean concentration of microplastics in water samples was 1496.7 ± 1452.2 particles per liter (ranging from 199.8 to 6626.7 particles per liter)	Polyethylene terephthalate (PET)	Taheri et al. (2023)
10	Transparent	Fragments	About 31% of bottled water brands were made up of particles with diameters between 100 and 300 μm	The particle concentration varied between 8 and 22 particles per liter, with an average of 11.7 ± 4.6 particles per liter	Polyethylene terephthalate (PET) and polypropylene (PP)	Praveena et al. (2022)
11	–	–	Microplastics ranging from 5 to 20 μm in size (major)	391microplastics per liter (average)	–	Nacaratte et al. (2023)
12			77 ± 22 μm (average)	Recorded in 94% of the samples The average concentration of microplastics in a liter of bottled water was 13 ± 19, with a range of 0 to 80 microplastics per liter	PP, PET, PA and PE	Samandra et al. (2033)
13	–	–	25–500 μm	Microplastics were detected in 17 out of 30 samples The mean concentration of the identified microplastic particles was 1.9 ± 4.7 per liter	Polyethylene (PE-38%), followed by polystyrene (PS-25%), and polyethylene terephthalate (PET-22%)	Almaiman et al. (2021)
14	Microplastics were separated into 8 color categories, with the transparent group making up about sixty-six percent of the total	Fibers (90%)	94% of the microplastics were less than 0.5 mm in size	The mean concentration of microplastics ranged from 14 ± 6.8 to 56 ± 23 particles per liter, with an average of 35 ± 19 particles per liter (all brands)	There are four distinct types of polymers, namely low-density polyethylene (LDPE), high-density polyethylene (HDPE), ethylene vinyl acetate (EVA), and polyethylene terephthalate (PET). Among them, LDPE and HDPE were the most prevalent	Hossain et al. (2023)

Table 5 (continued)

Sn	Color	Shape (dominant)	Size	Abundance	Polymer types	References
15	–	Fibers (62.8%) followed by fragments	6.5–20 µm dominant	140 ± 19 per Liter in single-use plastic-bottled water 52 ± 4 per Liter in glass-bottled water Plastic bottles had a significantly higher microplastic quantity than glass-bottled water	PET, PE, PP, and PA were dominant Major polymers detected for ≥ 50 µm particles: PE, PET, PP, and PA	Kankanige and Babel (2020)
16		Fragments	Small (50–500 µm) and very small (1–50 µm)	14 ± 14 particles per liter in single-use plastic bottles	Few micro-PET detected in single-use plastic	Schymanski et al. (2018)
17	Blue (57%)	Fiber (91%)	0.1–1 mm (71%)	mean of 7.35 ± 9.66 microplastics per liter	PET	Yozukmaz (2022)
18	White/yellow colour 51%	Pellet forms 35.3%	< 100 µm dominant microplastics (60.2%)	Average concentration 63.9 ± 38.9 microplastics per liter	–	Ravanbakhsh et al. (2022)
19	–	Films	Majority of microplastics in bottled water (67.85 ± 8.40%) and tap water (75.50%) were found to be within the size range of 10–50 µm	The mean microplastic concentration in bottled water was 72.32 ± 44.64 per liter, which was greater than the concentration found in tap water (49.67 ± 17.49 per liter)	Cellulose and PVC	Li et al. (2023)
20	–	–	–	Average 96 particles/Liter	Polyethylene terephthalate (PET) and/or polyurethane (36.1%) > polyamide > polyvinylchloride	Nizamali et al. (2023)
21	–	–	–	Varied in size between 1 and 30 µm found in all samples	polypropylene or polyethylene terephthalate	Parveen et al. (2022)

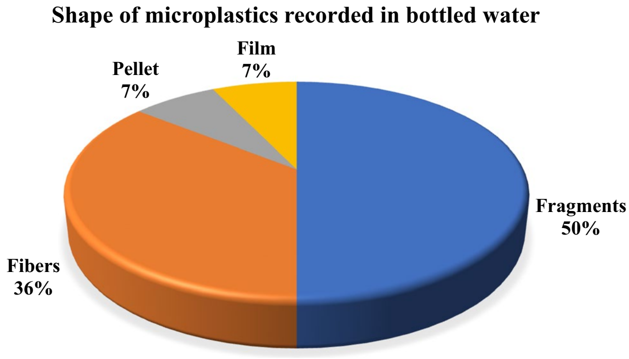


Fig. 5 Shape and size of microplastics found in bottled water

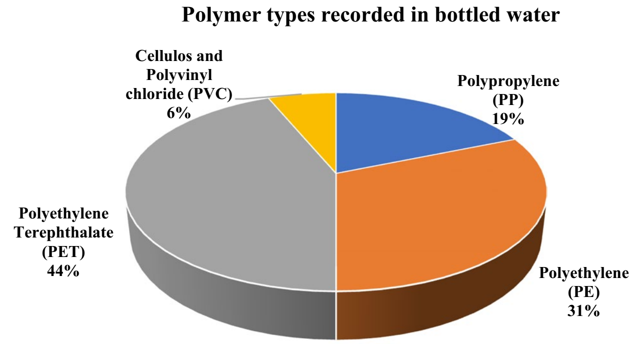


Fig. 6 Types of polymers recorded in bottled water

containers (Li et al. 2022) and leaching from packaging materials (Ibeto et al. 2021; Zhou et al. 2021; Kankanige and Babel 2020; Schymanski et al. 2018) that produce minute plastic particles. The contamination is originating, to some extent, from either the packaging or the bottling process itself (Mason et al. 2018). Other causes of microplastic found in bottled water is direct sunlight and longer storage time (Ravanbakhsh et al. 2022). Moreover, subjecting the bottles to mechanical stress can enhance the number of microplastics released into the water. The structural integrity of polymers in PET bottles and the release of microplastics are primarily affected by environmental factors such as sunlight exposure and the age of the bottles. Regardless of its form, source, and commercial brands, bottled water contains hundreds to thousands of microplastics per liter that are contaminated (Taheri et al. 2023). Zuccarello et al. (2019) found a significant correlation between the presence of microplastics in bottled mineral waters and both the pH level of the water and the density of plastic used in the bottle. The concentration of microplastics per liter and the size of microplastics were significantly influenced by the thickness of the plastic. The mineral water brand most heavily contaminated by microplastics was the one that utilized bottles manufactured from substandard plastic material.

Types of polymers recorded in bottled water

Figure 6 represents the composition of each polymer type found in bottled drinking water. Polyethylene Terephthalate (PET) is the most prevalent polymer, making up approximately 44% of the polymers, followed by polyethylene (31%) and cellulose, and polyvinyl chloride has the smallest representation at around 6%. The finding aligns with the results reported by Oßmann et al. (2018) and Schymanski et al. (2018), which indicated that PET was the most common polymer found in PET bottled water and the reason is that most of the plastic bottles are made by Polyethylene Terephthalate (PET) (Almaiman et al. 2021). Polyethylene is another polymer detected in plastic bottles (Fig. 6) because the majority of the caps were composed primarily of high-density polyethylene (HDPE), which may account for the presence of polyethylene (PE) fragments in the samples. A recent study conducted by Winkler et al. (2019) revealed that repeatedly opening and shutting bottle caps can release particles into the water. The study conducted by Mason et al. (2018) suggested that the caps represent a substantial contributor to microplastic pollution. They found that the presence of microplastic contamination in glass bottles was considerably less compared to plastic bottles of the same brand and water source. This indicates that the primary source of contamination is the packaging material itself.

Estimated daily intake (EDI)

It is a vital measurement to evaluate a population, or individual' s drink intake per day. It is necessary to determine exposure to microplastic pollutants to human health and to aid in establishing dietary guidelines for public health policy. According to Samandra et al. (2033), Australians are projected to encounter approximately 400 microplastics per year as a result of consuming bottled water. The estimated daily intake of microplastics per individual was found to be 2.63 particles, resulting in annual consumption of 960 particles per person (Hossain et al. 2023). According to Zhou et al. (2021), the estimated daily intakes for adults and children were projected to be 0.274 and 0.600 microplastics per kilogram per day, respectively. The pollution risk indices suggest that there is a moderate level of pollution risk associated with microplastics in bottled water. The estimated daily intake was generally minimal, indicating little harm from everyday consumption. However, it indicates that children have a larger intake of microplastics than adults (Ibeto et al. 2021). Praveena et al. (2022) predicted dietary intake for adults, which ranged from 0.068 to 0.19 particle/kg/day, while the dietary intake for children was between 0.089 and 0.25 particle/kg/day. Almaiman et al. (2021) concluded that the amount of dietary consumption of microplastics from drinking water in Saudi Arabia is minimal and does not constitute a risk to users in Saudi Arabia. Ravanbakhsh et al. (2022) calculated that adult had a daily intake (EDI) of 2.1 microplastics per kilogram per day. In contrast, children and infants had EDIs of 6.4 and 9.6 microplastics per kilogram per day, respectively. Infants exhibited higher levels of microplastic exposure compared to both children and adults. The study conducted by Li et al. (2023) showed the estimated daily intake of microplastics (EDI) through bottled water and tap water was nearly double for newborns compared to adults, despite adults consuming a greater quantity of microplastics.

Conclusion

The study addresses the global concern of microplastic contamination in bottled drinking water, aiming to explore recent global developments in microplastic research. The findings indicate a growing trend in published articles, with China and Iran leading contributions. The study contributes valuable insights into global research trends, geographic concentrations, physical characteristics, polymer types, and estimated daily intake related to microplastic contamination in bottled water. However, it emphasizes a critical research gap in understanding the health risks associated with microplastic exposure, highlighting the need for further investigation. Most research used a snapshot technique rather than a seasonal variation to investigate microplastic pollution. It needs to look at a longer-term study of the same brand of bottled water.

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Declarations

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

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