

Microplastic Polymers: Sources, Reported Human Health Risks, and Occurrence in Seafood

Seoyun Hwang
The Hill School, Pennyslyvania, USA

Abstract

Microplastics have become a pervasive environmental and public health concern, driven by the proliferation of single-use plastics and rising global plastic production. While the broad effects of microplastics are increasingly documented, polymer-specific understanding remains limited, despite evidence that different polymer types may pose distinct health and environmental risks. This study conducts a meta-analysis of 65 studies from the FCMiNo database, which compiles research on microplastics derived from food-contact materials, to examine the polymers most frequently associated with microplastic contamination, their reported human health risks, and their occurrence in seafood within marine ecosystems. Findings indicate that five polymers—polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), and polyethylene terephthalate (PET)—exhibit distinct chemical properties that shape their industrial applications. Of these, PE, PP, PS, and PET showed widespread distribution across sources including water bottles, take-out containers, salt, and tap water, whereas PVC was detected less frequently and at lower abundance when present. Across polymer types, gastrointestinal disturbances and cellular toxicity emerged as the most commonly reported health concerns. Mussels were also identified as a common vector for microplastic transfer to humans. This review underscores the need for further research into polymer-specific effects to better characterize the risks associated with microplastic exposure.

Keywords

Microplastics, Polymers, Polyethylene (PE), Polypropylene (PP), Polystyrene (PS), Polyvinyl Chloride (PVC), and Polyethylene Terephthalate (PET).

1. INTRODUCTION

Plastic pollution is one of the main causes why human exposure to microplastics has increased in recent years. Microplastics are small plastic particles, less than five millimeters long, which are damaging to both marine and terrestrial organisms in ecosystems (NOAA, 2026). Through an accumulation of various studies and literature documenting the presence of microplastics in the food we eat, the packaging we use, and their effects on our health, there seems to be a clear progression from plastics that enter the environment and end up in human bodies through various food systems, packaging materials, and even the water that we drink.

Prior studies in microplastics have focused on different origins to plastic degradation. For instance, seafood and oceans predominantly have the most research connected to microplastics since they are the primary source from which the effects of plastic pollution can emanate to humans. While seafood does remain the topic that is rigorously backed up by many studies, plastic pollution and its effects reach far beyond the marine ecosystems. The very water that we drink is also a popular source from which microplastics can infiltrate our body. Various studies have detected microplastics in tap water, bottled water, rivers, and groundwater (Koelmans et al., 2019). However, these studies should be strengthened through additional studies on microplastics in bodies of water as well as the development of standardized research methods from sampling, detection, and analysis.

Food processing and packaging, although just recently being studied for microplastics, is another direct vessel that links plastic pollution to humans. Studies show that microplastics are present in all types of common containers that include materials such as polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyethylene terephthalate (PET) (Du et al., 2020). Soil is also a common source of microplastic pollution. Through landfills, greenhouse films, sewage irrigation, and other practices, microplastics are easily introduced to the soil microbiome (Guo et al., 2020). Because soil serves as the growing grounds for many of the crops and plants that humans consume, these microplastics can travel through this system to reach humans.

Ultimately, the various sources of microplastic pollution can lead to serious health problems such as immune system disturbance, neurotoxicity, gastrointestinal disorders, respiratory problems, cancer, and more (Mir et al., 2025; Al Mamun et al., 2023). Thus, it is crucial to improve the research in this area so that we can further develop methods to prevent the detrimental effects of microplastic pollution.

This study examines the occurrence of microplastics released from common plastic-based food-contact materials and their potential impacts on human health. The analysis focuses on five polymers with varying tendencies to generate microplastics: polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), and polyethylene terephthalate (PET). Identifying which polymers are the most common sources of microplastic exposure is important for recognizing potentially harmful food-contact products and developing targeted strategies to reduce human exposure. Examining their associated health risks and occurrence in seafood

can also help inform consumer choices, product design, food-safety standards, and environmental regulations.

Using a meta-analysis of studies included in the Database of Micro- and Nanoplastics from Food Contact Materials (FCMiNo), this study addresses three research questions: (1) Which plastic polymers are most commonly detected in microplastics? (2) What human health risks have been reported? and (3) Which types of seafood contain these particles? The FCMiNo Database maps scientific evidence on micro- and nanoplastics (MNPs) detected in foodstuffs or food simulants that have come into contact with plastic food-contact materials—including food packaging and food-processing equipment—which may serve as sources of microplastic contamination in food (Food Packaging Forum, n.d.). The following sections present the background, methods, results, and discussion of these findings.

2. BACKGROUND

As plastic waste continues to accumulate in oceans and other marine environments, it gradually degrades into fragmented microplastics. Marine animals and organisms consume these particles, which then move through successive trophic levels and eventually reach humans through seafood consumption (Hantoro et al., 2019). Beyond seafood, drinking water represents another significant exposure pathway: studies indicate that bottled water may contain markedly higher concentrations of microplastics than tap water, ranging from 0 to 6,292 particles per liter compared with 0 to 61 particles per liter, respectively (Jin et al., 2021).

Food packaging constitutes a further source of human exposure. Although plastic packaging materials are widely used for food preservation and consumer convenience, these materials may shed small, often undetected microplastic particles into food (Lewańska & Barczyńska, 2025). Such particles have been found to flake off from the interior surfaces of plastic packaging, and it is estimated that humans may ingest as many as 200 of these particles per week through this route alone (Du et al., 2020).

Beyond direct human exposure, microplastics also pose risks to terrestrial ecosystems, particularly agricultural systems that depend on healthy soil conditions (Guo et al., 2020). Once introduced into soil, these particles are highly resistant to degradation and may persist for extended periods, often remaining undetected while continuing to affect soil-dependent plant life (Guo et al., 2020).

(1) Five plastic polymers

As plastics degrade into increasingly smaller particles, they can enter the human body through food, beverages, and food-contact materials. Many commonly consumed foods, particularly seafood, have been found to contain microplastics that are often invisible to the naked eye. Microplastics may also be released from plastic packaging, particularly from widely used single-

use plastic products. Once ingested, these particles may accumulate in cells and tissues, raising concerns about their potential long-term effects on human health.

The digestive system is one of the primary systems potentially affected by microplastic exposure. The presence of these foreign particles in the gastrointestinal tract may disrupt important regulatory processes, including metabolic activity, the gut microbiome, and immune function. Microplastics may also interfere with antioxidant enzyme activity, potentially contributing to oxidative stress and liver damage (Al Mamun et al., 2023). The reproductive system may also be affected, as exposure to polystyrene microplastics (PS-MPs) has been associated with impaired sperm function and ovarian inflammation (Al Mamun et al., 2023). Potential effects on the nervous system are also an emerging concern. For example, microplastic exposure has been associated with increased dopamine levels in zebra mussels and reduced neurotransmission in mice (Al Mamun et al., 2023). In addition, growing evidence suggests that microplastics and nanoplastics may influence processes related to cancer development and progression. Exposure of cell lines to polystyrene nanobeads approximately 50 nm in size has been associated with DNA damage, which could increase the likelihood of genetic mutations and potentially contribute to cancer progression (Mir et al., 2025). Larger PS particles measuring 0.5 and 2 μm have also been shown to alter metabolic processes in colon cells, suggesting a potential association with increased colon cancer risk (Mir et al., 2025).

Five polymers—polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), polyvinyl chloride (PVC), and polystyrene (PS)—are most commonly associated with microplastic pollution, each possessing distinct characteristics and chemical properties that influence how they degrade and where they are used. PE, the most widely produced polymer, is notably flexible and exhibits high heat and moisture resistance, making it common in plastic bags, food packaging, and water pipes (NOAA, 2026).

PP ranks second in prevalence, valued for its cost-effectiveness and combination of strength and flexibility. It is commonly used in Tupperware, woven bags, and laboratory equipment (Soliz et al., 2024). Unlike PE, however, PP performs poorly under high temperatures and is more susceptible to weathering and environmental degradation. PVC follows in frequency and is available in both rigid and flexible forms, depending on the concentration of plasticizers used during production. The rigid form is commonly used in construction materials, doors, and windows, while the flexible form is used in electrical tubing insulation, tubing, and clothing. PET ranks fourth in production and is known for its chemical resistance, recyclability, and high strength-to-weight ratio. However, PET is heat-sensitive and prone to degradation under elevated temperatures. It is commonly found in water bottles, glass fiber composites, and other containers. Finally, PS is a transparent, relatively brittle plastic, making it well suited for foam-based products such as soundproofing panels, instant ramen containers, and insulated walls (Soliz et al., 2024; NOAA, 2026). Table 1 displays the common uses for the five polymers.

Table1. Polymer types and common uses

Plastic type	PE	PP	PS	PVC	PET
Common Uses	Plastic-based food filter bags, rice cooking bags, ice cube bags, nylon teabags, paper cups with PE films, bottle cap, salt, water pipes, shopping bags, detergent bottles, glass bottles, etc.	Single-use beverage cup, infant feeding bottles, take out boxes, plastic-based food filter bags, bottle caps, salt, yoghurt packaging, straws, semi-rigid containers, glass bottles, etc.	Takeout boxes, plastic containers, disposable plastic cups and plates, foam cups and food containers, coffee cup lid, tumbler cup, meat tray, salt, etc.	Water pipes, bottled water, salt, toys, etc.	Bottled water, plastic-based food filter bags, plastic tea bags, plastic packaging, salt, food trays, etc.

These five polymers exhibit distinct properties in strength, flexibility, and resistance to chemicals and heat. These differences shape not only their industrial applications but also, as later sections will show, their varying environmental persistence and associated health risks.

(2) Reported health impacts of microplastics

As plastics degrade into increasingly smaller particles, they can enter the human body through food, beverages, and food-contact materials. Many commonly consumed foods, particularly seafood, have been found to contain microplastics that are often invisible to the naked eye. Microplastics may also be released from plastic packaging, particularly from widely used single-use plastic products. Once ingested, these particles may accumulate in cells and tissues, raising concerns about their potential long-term effects on human health.

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and reduced neurotransmission in mice (Al Mamun et al., 2023). In addition, growing evidence suggests that microplastics and nanoplastics may influence processes related to cancer development and progression. Exposure of cell lines to polystyrene nanobeads approximately 50 nm in size has been associated with DNA damage, which could increase the likelihood of genetic mutations and potentially contribute to cancer progression (Mir et al., 2025). Larger PS particles measuring 0.5 and 2 μm have also been shown to alter metabolic processes in colon cells, suggesting a potential association with increased colon cancer risk (Mir et al., 2025).

3. METHODS

Data were collected from the FCMiNo Database of Micro- and Nanoplastics from Food Contact Materials(<https://foodpackagingforum.org/resources/databases/mino>), an open-access database developed by the Food Packaging Forum that maps scientific evidence on microplastics and nanoplastics released from plastic food-contact articles into food or food simulants. Food-contact articles include food packaging, plastic bottles, reusable containers, cutting boards, tea bags, food pouches, and food-processing equipment (FCMiNo, n.d.).

To identify relevant studies, the FCMiNo database was searched by selecting “plastic” as the primary food-contact material and “micro” as the MNP particle-size category. This search yielded 412 entries representing 76 references. Of these 76 references, 65 articles were included in the analysis. Additional studies outside the database were also consulted to provide broader background information and context.

Data reported in the selected studies were organized by polymer type. Five polymers were examined in greater detail based on their common applications, tendency to generate microplastics, countries in which samples were collected, reported human health impacts, occurrence in seafood, and reported detection of microplastics in soil.

4. RESULTS

(1) Polymer types in Microplastics

While many studies have examined microplastics broadly and reported their abundance across different case studies, sixteen articles specifically investigated the polymer types identified in microplastic samples. Studies by Bai et al. (2022), Zhou et al. (2022), and Du et al. (2020) found that polystyrene (PS) was the most frequently observed polymer in take-out containers, accounting for 43%, 8.5%, and 62% of detected microplastics, respectively. The relatively loose structure and brittle surface of PS containers may contribute to the release of microplastic particles from these products.

In contrast, studies of bottled water reported different polymer compositions. Samandra et al. (2022) found that polypropylene (PP) represented the largest proportion of detected

microplastics, with an observation rate of 88%, followed by polyethylene terephthalate (PET) at 63%. These findings are broadly consistent with Giese et al. (2021), who reported concentrations of 185 ± 52 MPP/L for PP and 32 ± 22 PET-MPP/L for PET. Similarly, Mason et al. (2018) found that PP accounted for the largest share of microplastics detected in bottled water, at 54%. However, Maharjan (2024) and Schymanski et al. (2017) identified PET as the dominant polymer in bottled water. These differences may reflect variation among bottled-water brands, packaging materials, or the use of single-use versus returnable bottles.

The variation across studies is likely related to differences in the types of plastic products examined, as well as differences in sampling and analytical methods. For example, Bai et al. (2022) reported that, in addition to PS, polyethylene (PE) accounted for 14% of detected microplastics, PET for 11%, and PP for 5%. Polyvinyl chloride (PVC) was not reported in that study (Table 1).

Table 2. Polymer types observed in microplastics across different types of food-containing plastic containers

MPs Origin	Studies	PE	PP	PS	PVC	PET
Take-out food	Bai et al. (2022)	14%	5%	43%		11%
Bottles in Australia	Samandra et al. (2022)	38%	88%	19%	13%	63%
Liquid after contact from container	Xu et al. (2022)		7.111 ± 1.85 items/100 mL	11.778 ± 2.25 items/100 mL		
Takeaway food containers	Zhou et al. (2022)	0.1%.	2.2%.	8.50%	1.2%.	2.7%.
Bottles	Giese et al. (2021)	25 ± 20 PE-MPP/L	185 ± 52 MPP/L			32 ± 22 PET-MPP/L
After single use plastics are exposed to hot water	Li et al. (2021)	250 micron-sized microplastics (MPs) and 102 million sub-micron-sized particles per milliliter of liquid	7.6 mg of plastic particles after single use			11.6 billion MPs and 3.1 billion nano-sized MPs into a single cup (10 mL) of the beverage

Tap water	Shen et al. (2021)	24%	15%		18%	21%
Bottled water	Maharjan (2024)	31%			6%	44%
Take-out containers	Du et al. (2020)	22%	32%	62%		3%
17 salt samples	Fischer et al. (2019)	88.23%	94.11%	76.47%	41.18%	94.12%
Salt from Taiwan	Lee et al. (2019)	34.90%	39.50%	14%		2.30%
Sea salt, rock salt, or lake salt	Kim et al. (2018)	35%, 26%, 28%	30%, 23%, 47%			30%, 41%, 10%
Bottled water	Mason et al. (2018)	10%	54%			
Returnable plastic bottles	Schymanski et al. (2017)	5%	7%			84%
Tap water in Denmark (~3% were MPs)	Strand et al. (2018)		1.6%	0.8%		0.8%
Sea, lake, and rock/well salt	Yang et al. (2015)	20.5%, 0%, 4.9%	2.3%, 6.8%, 4.9%	n/a	0%, 0%, 2.4%	27.3%, 11.4%, 9.8%

(2) Countries where plastics samples were collected

Many of the studies were conducted in China, with the Czech Republic, Australia, and Iran also frequently represented (Figure 1), and Table 2 presents the list of countries where PE, PP, PS, PVC, and PET were reported. P PE, PP, and PET were reported across a wide range of countries, whereas PS and PVC were less commonly reported. Take-out containers, plastic-based food filter bags, and beverage cups were among the most common food-contact applications associated with these polymers. More specifically, PE was associated with plastic-based food filter bags, rice-cooking bags, ice cube bags, and nylon tea bags. PP was commonly identified in single-use beverage cups, infant feeding bottles, take-out containers, and plastic-based food filter bags. PS was primarily associated with take-out containers and other plastic

food containers, whereas PET was commonly detected in bottled water and plastic-based food filter bags.

Figure 1. Sampling locations for reported microplastics (Note: color indicates how many plastic types (PE, PP, PS, PVC, PET) were reported in each country)

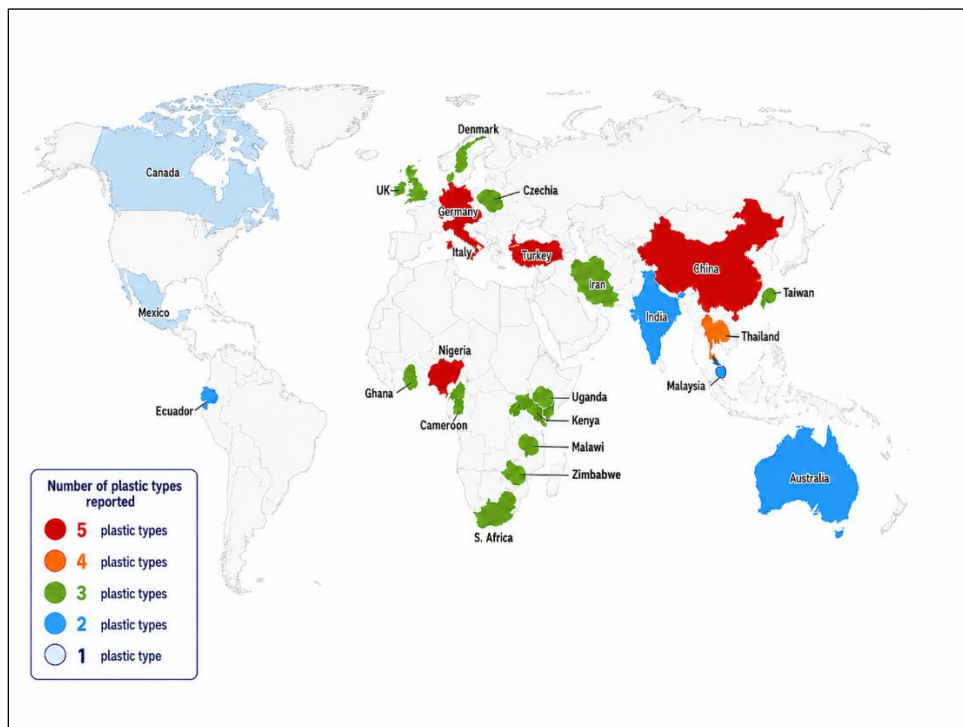


Table 2. Countries where polymer-specific microplastics were sampled

Plastic type	Country
PE	China, Malaysia, India, Thailand, Taiwan, Turkey, United Kingdom, Germany, Italy, Czech Republic, Nigeria, Cameroon, Ghana, Malawi, Zimbabwe, South Africa, Kenya, Uganda, and Ecuador (19 countries)
PP	China, Thailand, Taiwan, Turkey, Iran, United Kingdom, Germany, Italy, Czech Republic, Denmark, Nigeria, Cameroon, Ghana, Malawi, Zimbabwe, South Africa, Kenya, Uganda, Nigeria, Ecuador, and Australia (21 countries)
PS	China, Taiwan, Turkey, Iran, Germany, Italy, Denmark, Nigeria, and Australia (9 countries)
PVC	China, Thailand, Turkey, Germany, Italy, and Nigeria (6 countries)
PET	China, Malaysia, India, Thailand, Turkey, Iran, United Kingdom, Germany, Italy, Denmark, Czech Republic, Ghana, Malawi, Zimbabwe, South Africa, Kenya, Uganda, Nigeria, Cameroon, Mexico, and Canada (21 countries)

(3) Commonly reported health impacts

Based on the data presented in the table, the reported health impacts have generally been associated with microplastics as a whole rather than with specific polymer types. Nevertheless, the frequency and consistency with which these effects have been reported vary across the polymers examined in this study. Gastrointestinal effects were commonly reported for microplastics composed of PE, PP, and PS. Macrophage immune activation and cytokine production, both indicative of inflammatory responses, were reported for PE and PS. Cellular toxicity was reported for PP, while PET was associated with a broader range of toxicological effects, including particle toxicity, oxidative stress and DNA damage, inflammatory lesions, chronic tissue inflammation, and an increased risk of neoplasia. No polymer-specific health effects were identified for PVC in the studies reviewed; however, this should not be interpreted as evidence that PVC is non-toxic, as the broader microplastics literature has reported adverse health effects associated with particles that may contain PVC. Table 3 summarizes the reported health impacts by polymer type.

Tabel 3. Polymer-specific human health risks across microplastic exposure

Plastic type	Human health impacts
PE	Gastrointestinal issues, macrophage immune activation and cytokine production
PP	Gastrointestinal issues, Cellular toxicity
PS	Gastrointestinal issues, macrophage immune activation and cytokine production
PVC	N/A
PET	Particle toxicity, oxidative stress, inflammatory lesions, chronic inflammation, and increase risk of neoplasia, tissue inflammation

(4) Microplastics occurrence in seafood

Across the studies included in this discussion, PP, PS, and PET were the polymers strongly associated with seafood contamination, although PE and PVC were also detected in limited numbers. Mussels, specifically *M. galloprovincialis*, *M. edulis*, and *M. chilensis*, were reported to be contaminated with all the polymers in this study. PE, PP, PS, and PET were further identified in green lipped mussels from New Zealand. Fish also represented a source of microplastic contamination as Icefish was detected to have PE, PP, PS, and PET polymers. PET was additionally found in barramundi fillet and PS was detected in other coastal animals like scallops and fish.

Table 4. Reported seafoods associated with the polymers discussed

Plastic type	Seafood
PE	Mussels (<i>M. galloprovincialis</i> , <i>M. edulis</i> , <i>M. chilensis</i>), Icefish, green lipped mussels
PP	Mussels (<i>M. galloprovincialis</i> , <i>M. edulis</i> , <i>M. chilensis</i>), Icefish, green lipped mussels
PS	Coastal animals like scallops and fish, Mussels (<i>M. galloprovincialis</i> , <i>M. edulis</i> , <i>M. chilensis</i>), Icefish, green lipped mussels
PVC	Mussels (<i>M. galloprovincialis</i> , <i>M. edulis</i> , <i>M. chilensis</i>)
PET	Barramundi fillet, Mussels (<i>M. galloprovincialis</i> , <i>M. edulis</i> , <i>M. chilensis</i>), Icefish, green lipped mussels

5. DISCUSSION

This study demonstrates clear differences in the frequency of polymer types based on their material properties and common applications. PVC was identified in only a limited number of studies included in this analysis, and when present, it generally represented a very small proportion of the detected microplastics compared with other polymers (Samandra et al., 2022; Zhou et al., 2022; Shen et al., 2021; Maharjan, 2024; Fischer et al., 2019; Yang et al., 2015). This pattern may partly reflect the applications of PVC, which is more commonly used in products such as pipes and infrastructure than in many food-contact materials.

PP, which is frequently used in bottle caps, was a dominant polymer in several studies examining microplastics in bottled water, including those by Samandra et al. and Lee et al. It was also detected in multiple studies of sea salt but was generally less abundant in studies of take-out containers. Schymanski et al. reported a different pattern, which may partly reflect their focus on returnable plastic bottles rather than single-use bottles, as the materials and construction of these products differ.

PS showed a contrasting pattern. Although it was identified in some studies of sea salt, it was particularly prevalent among microplastics detected in take-out containers and was less frequently reported in studies of plastic bottles or water more generally (Bai et al., 2022; Xu et al., 2022; Zhou et al., 2022; Du et al., 2020). The relatively brittle structure of PS may make it more susceptible to fragmentation and the release of microplastic particles from food containers. PET, in contrast, was detected at moderate to high levels in studies of both single-use and returnable plastic water bottles and generally occurred at lower levels in take-out containers (Bai et al., 2022; Samandra et al., 2022; Zhou et al., 2022; Giese et al., 2021; Li et al., 2021; Shen et al., 2021; Maharjan, 2024; Du et al., 2020; Schymanski et al., 2017; Strand et al., 2018). Across the studies reviewed, PET was frequently identified as the dominant polymer associated with plastic bottles, excluding bottle caps.

PE emerged as one of the most widely reported polymers across the studies reviewed. Its use in a broad range of products, including plastic-based food-filter bags, detergent bottles, and other packaging materials, may help explain its widespread detection in microplastics found in take-out containers, bottled water, salt, and tap water.

With respect to health impacts, the findings suggest that reported effects vary across polymer types, although these differences may reflect both actual toxicological variation and uneven research attention. PET appears to have the broadest range of documented health effects among the polymers examined, whereas the limited evidence for PVC should be interpreted as a research gap rather than evidence of safety. Much of the current literature on microplastic toxicity relies on experimental studies involving animals or cell models. Greater attention to the chemical characteristics of individual polymers and their polymer-specific effects is therefore needed to better understand potential risks to human health. Further research in this area could help inform public health guidance, product-safety standards, and policies aimed at reducing microplastic exposure.

With respect to seafood, microplastic contamination was reported across a wide range of marine species, with PP, PS, and PET among the polymers most frequently associated with contamination in the studies reviewed. Mussels appeared to be particularly affected, as multiple species were found to contain all five polymers examined in this study. This pattern may be related to their filter-feeding behavior, through which they continuously process large volumes of water and can accumulate suspended microplastic particles. The detection of multiple polymer types in green-lipped mussels, icefish, barramundi fillets, scallops, and other coastal fish further indicates that microplastics are distributed across diverse marine species and feeding groups.

The presence of microplastics in commonly consumed seafood also raises concerns about dietary exposure in humans. However, variation in polymer types among species may reflect differences in habitat, feeding behavior, geographic location, and the availability of plastic debris in the surrounding environment. These findings indicate that seafood can serve both as an indicator of marine microplastic pollution and as a potential pathway for human exposure.

6. CONCLUSION

This meta-analysis demonstrates the pervasive presence of microplastics across common sources of human exposure, including bottled water, take-out containers, various types of salt, tap water, and other food-contact materials. Among the five polymers examined, polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyethylene terephthalate (PET) were frequently reported across studies, whereas polyvinyl chloride (PVC) was generally detected less often and in lower quantities. These polymers were identified across a wide range of countries and seafood species, further illustrating the widespread distribution of microplastics.

Several potential health effects, including gastrointestinal disturbances, cellular toxicity, and oxidative stress, were reported in association with different polymer types. However, many of these effects were examined in relation to microplastics more broadly rather than being clearly

attributable to individual polymers. Although none of the studies included in this analysis specifically examined soil, soil may represent an additional pathway of microplastic exposure and warrants further investigation.

Future research should adopt more standardized sampling, detection, and reporting methods to improve comparability across studies. Studies should also expand geographic coverage, examine a broader range of food and environmental exposure pathways, and more clearly distinguish health effects associated with specific polymer types. Such efforts would strengthen understanding of polymer-specific risks and provide a more robust evidence base for public health guidance, food-safety standards, and policies aimed at reducing microplastic exposure.

References

- Bai, C.-L., Liu, L.-Y., Guo, J.-L., Zeng, L.-X., & Guo, Y. (2022). Microplastics in take-out food: Are we over taking it? *Environmental Research*, 215. <https://doi.org/10.1016/j.envres.2022.114390>
- Du, F., Cai, H., Zhang, Q., Chen, Q., & Shi, H. (2020). Microplastics in take-out food containers. *Journal of Hazardous Materials*, 399. <https://doi.org/10.1016/j.jhazmat.2020.122969>
- Fischer, M., Goßmann, I., & Scholz-Böttcher, B. M. (2019). Fleur de sel—an interregional monitor for microplastics mass load and composition in european coastal waters? *Journal of Analytical and Applied Pyrolysis*, 144. <https://doi.org/10.1016/j.jaap.2019.104711>
- Food Packaging Forum (n.d.) FCMiNo Database. <https://foodpackagingforum.org/resources/databases/mino>
- Giese, A., Kerpen, J., Weber, F., & Prediger, J. (2021). A preliminary study of microplastic abrasion from the screw cap system of reusable plastic bottles by raman microspectroscopy. *ACS ES&T Water*, 1(6), 1363-1368. <https://doi.org/10.1021/acsestwater.0c00238>
- Guo, J.-J., Huang, X.-P., Xiang, L., Wang, Y.-Z., Li, Y.-W., Li, H., Cai, Q.-Y., Mo, C.-H., & Wong, M.-H. (2020). Source, migration and toxicology of microplastics in soil. *Environment International*, 137. <https://doi.org/10.1016/j.envint.2019.105263>
- Hantoro, I., Löhr, A. J., Van Belleghem, F. G. A. J., Widianarko, B., & Ragas, A. M. J. (2019). Microplastics in coastal areas and seafood: Implications for food safety. *Food Additives & Contaminants: Part a*, 36(5), 674-711. <https://doi.org/10.1080/19440049.2019.1585581>
- Jin, M., Wang, X., Ren, T., Wang, J., & Shan, J. (2021). Microplastics contamination in food and beverages: Direct exposure to humans. *Journal of Food Science*, 86(7), 2816-2837. <https://doi.org/10.1111/1750-3841.15802>
- Kim, J.-S., Lee, H.-J., Kim, S.-K., & Kim, H.-J. (2018). Global pattern of microplastics (MPs) in commercial food-grade salts: Sea salt as an indicator of seawater MP pollution. *Environmental Science & Technology*, 52(21), 12819-12828. <https://doi.org/10.1021/acs.est.8b04180>
- Koelmans, A. A., Mohamed Nor, N. H., Hermesen, E., Kooi, M., Mintenig, S. M., & De France, J. (2019). Microplastics in freshwaters and drinking water: Critical review and assessment of data quality. *Water Research*, 155, 410-422. <https://doi.org/10.1016/j.watres.2019.02.054>
- Lee, H., Kunz, A., Shim, W. J., & Walther, B. A. (2019). Microplastic contamination of table salts from taiwan, including a global review. *Scientific Reports*, 9. <https://doi.org/10.1038/s41598-019-46417-z>
- Lewanska, M., & Barczynska, R. (2025). Microplastics from food packaging: Polymer degradation pathways, environmental distribution, and effects on the human gastrointestinal tract. *Polymers*, 17(21), 2923. <https://doi.org/10.3390/polym17212923>
- Li, D., Yang, L., Kavanagh, R., Xiao, L., Shi, Y., Kehoe, D. K., Sheerin, E. D., Gun'ko, Y. K., Boland, J. J., & Wang, J. J. (2021). Sampling, identification and characterization of

- microplastics release from polypropylene baby feeding bottle during daily use. *Journal of Visualized Experiments*, (173). <https://doi.org/10.3791/62545>
- Maharjan, K. K. (2024). Microplastic pollution in bottled water: A systematic review. *International Journal of Environmental Science and Technology*, 22, 1283-1296. <https://doi.org/10.1007/s13762-024-05807-1>
- Mamun, A. A., Prasetya, T. A. E., Dewi, I. R., & Ahmad, M. (2023). Microplastics in human food chains: Food becoming a threat to health safety. *Science of the Total Environment*, 858. <https://doi.org/10.1016/j.scitotenv.2022.159834>
- Mason, S. A., Welch, V. G., & Neratko, J. (2018). Synthetic polymer contamination in bottled water. *Frontiers in Chemistry*, 6. <https://doi.org/10.3389/fchem.2018.00407>
- Mir, M. A., Ali Khan, M. A., Banik, B. K., Hasnain, S. M., Alzayer, L., Andrews, K., & Abba, S. I. (2025). Microplastics in food products: Prevalence, artificial intelligence based detection, and potential health impacts on humans. *Emerging Contaminants*, 11(2), 100477. <https://doi.org/10.1016/j.emcon.2025.100477>
- Samandra, S., Mescall, O. J., Plaisted, K., Symons, B., Xie, S., Ellis, A. V., & Clarke, B. O. (2022). Assessing exposure of the Australian population to microplastics through bottled water consumption. *Science of the Total Environment*, 837. <https://doi.org/10.1016/j.scitotenv.2022.155329>
- Schymanski, D., Goldbeck, C., Humpf, H.-U., & Fürst, P. (2018). Analysis of microplastics in water by micro-Raman spectroscopy: Release of plastic particles from different packaging into mineral water. *Water Research*, 129, 154-162. <https://doi.org/10.1016/j.watres.2017.11.011>
- 7 different types of plastic. (n.d.). A&C Plastics. Retrieved July 28, 2026, from <https://www.acplasticsinc.com/resource/7-different-types-of-plastic/>
- Shen, M., Zeng, Z., Wen, X., Ren, X., Zeng, G., Zhang, Y., & Xiao, R. (2021). Presence of microplastics in drinking water from freshwater sources: The investigation in Changsha, China. *Environmental Science and Pollution Research*, 28, 42313-42324. <https://doi.org/10.1007/s11356-021-13769-x>
- Strand, J., Feld, L., Murphy, F., Mackevica, A., & Hartmann, N. B. (2018). Analysis of microplastic particles in Danish drinking water (Scientific Report from DCE – Danish Centre for Environment and Energy No. 291). Aarhus University, DCE – Danish Centre for Environment and Energy. <http://dce2.au.dk/pub/SR291.pdf>
- Soliz, D. L., Paniagua González, G., Muñoz-Arnanz, J., Bravo-Yagüe, J. C., Fernández Hernando, P., & Garcinuño Martínez, R. M. (2024). Identification and morphological characterization of different types of plastic microparticles. *Heliyon*, 10(11), e30749. doi:10.1016/j.heliyon.2024.e30749
- National Oceanic and Atmospheric Administration (NOAA). (2026). What are microplastics? Retrieved July 28, 2026, from <https://oceanservice.noaa.gov/facts/microplastics.html>
- Xu, X., Guo, J., Gao, Y., Xue, Y., Shi, X., Zhang, L., Zhang, Q., & Peng, M. (2022). Leaching behavior and evaluation of zebrafish embryo toxicity of microplastics and phthalates in take-away plastic containers. *Environmental Science and Pollution Research*, 30, 21104-21114. <https://doi.org/10.1007/s11356-022-23675-5>

- Yang, D., Shi, H., Li, L., Li, J., Jabeen, K., & Kolandhasamy, P. (2015). Microplastic pollution in table salts from china. *Environmental Science & Technology*, 49(22), 13622-13627.
<https://doi.org/10.1021/acs.est.5b03163>
- Zhou, X., Wang, J., & Ren, J. (2022). Analysis of microplastics in takeaway food containers in china using fpa-ftir whole filter analysis. *Molecules*, 27(9).
<https://doi.org/10.3390/molecules27092646>

Appendix I. Studies for meta-analysis

- Ajaj, A., J'Bari, S., Ononogbo, A., Buonocore, F., Bear, J. C., Mayes, A. G., & Morgan, H. (2021). An insight into the growing concerns of styrene monomer and poly(styrene) fragment migration into food and drink simulants from poly(styrene) packaging. *Foods*, 10(5), Article 1136. <https://doi.org/10.3390/foods10051136>
- Alak, G., Köktürk, M., & Atamanalp, M. (2021). Evaluation of different packaging methods and storage temperature on MPs abundance and fillet quality of rainbow trout. *Journal of Hazardous Materials*, 420, Article 126573. <https://doi.org/10.1016/j.jhazmat.2021.126573>
- Bai, C.-L., Liu, L.-Y., Guo, J.-L., Zeng, L.-X., & Guo, Y. (2022). Microplastics in take-out food: Are we over taking it? *Environmental Research*, 215, 114390. <https://doi.org/10.1016/j.envres.2022.114390>
- Braun, U., Altmann, K., Herper, D., Knefel, M., Bednarz, M., & Bannick, C. G. (2021). Smart filters for the analysis of microplastic in beverages filled in plastic bottles. *Food Additives & Contaminants: Part A*, 38(4), 691–700. <https://doi.org/10.1080/19440049.2021.1889042>
- Cella, C., La Spina, R., Mehn, D., Fumagalli, F., Ceccone, G., Valsesia, A., & Gilliland, D. (2022). Detecting micro- and nanoplastics released from food packaging: Challenges and analytical strategies. *Polymers*, 14(6), 1238. <https://doi.org/10.3390/polym14061238>
- Chen, S., Li, Y., Mawhorter, C., & Legoski, S. (2021). Quantification of microplastics by count, size and morphology in beverage containers using Nile Red and ImageJ. *Journal of Water and Health*, 19(1), 79–88. <https://doi.org/10.2166/wh.2020.171>
- Da Costa Filho, P. A., Andrey, D., Eriksen, B., Peixoto, R. P., Carreres, B. M., Ambühl, M. E., Descarrega, J. B., Dubascoux, S., Zbinden, P., Panchaud, A., & Poitevin, E. (2021). Detection and characterization of small-sized microplastics ($\geq 5 \mu\text{m}$) in milk products. *Scientific Reports*, 11(1), Article 24046. <https://doi.org/10.1038/s41598-021-03458-7>
- Dalmau-Soler, J., Ballesteros-Cano, R., Ferrer, N., Boleda, M. R., & Lacorte, S. (2022). Microplastics throughout a tap water supply network. *Water and Environment Journal*, 36(2), 292–298. <https://doi.org/10.1111/wej.12766>
- Dawson, A. L., Li, J. Y. Q., & Kroon, F. J. (2022). Plastics for dinner: Store-bought seafood, but not wild-caught from the Great Barrier Reef, as a source of microplastics to human consumers. *Environmental Advances*, 8, 100249. <https://doi.org/10.1016/j.envadv.2022.100249>
- Diaz-Basantes, M. F., Conesa, J. A., & Fullana, A. (2020). Microplastics in honey, beer, milk and refreshments in Ecuador as emerging contaminants. *Sustainability*, 12(14), Article 5514. <https://doi.org/10.3390/su12145514>
- Du, F., Cai, H., Zhang, Q., Chen, Q., & Shi, H. (2020). Microplastics in take-out food containers. *Journal of Hazardous Materials*, 399, Article 122969. <https://doi.org/10.1016/j.jhazmat.2020.122969>
- Fadare, O. O., Okoffo, E. D., & Olasehinde, E. F. (2021). Microparticles and microplastics contamination in African table salts. *Marine Pollution Bulletin*, 164, Article 112006. <https://doi.org/10.1016/j.marpolbul.2021.112006>

- Fischer, M., Goßmann, I., & Scholz-Böttcher, B. M. (2019). Fleur de Sel—An interregional monitor for microplastics mass load and composition in European coastal waters? *Journal of Analytical and Applied Pyrolysis*, 144, Article 104711. <https://doi.org/10.1016/j.jaap.2019.104711>
- Gerhard, M. N., Schymanski, D., Ebner, I., Esselen, M., Stahl, T., & Humpf, H.-U. (2022). Can the presence of additives result in false positive errors for microplastics in infant feeding bottles? *Food Additives & Contaminants: Part A*, 39(1), 185–197. <https://doi.org/10.1080/19440049.2021.1989498>
- Giese, A., Kerpen, J., Weber, F., & Prediger, J. (2021). A preliminary study of microplastic abrasion from the screw cap system of reusable plastic bottles by Raman microspectroscopy. *ACS ES&T Water*, 1(6), 1363–1368. <https://doi.org/10.1021/acsestwater.0c00238>
- Hernandez, L. M., Xu, E. G., Larsson, H. C. E., Tahara, R., Maisuria, V. B., & Tufenkji, N. (2019). Plastic teabags release billions of microparticles and nanoparticles into tea. *Environmental Science & Technology*, 53(21), 12300–12310. <https://doi.org/10.1021/acs.est.9b02540>
- Ibeto, C. N., Enyoh, C. E., Ofomatah, A. C., Oguejiofor, L. A., Okafocha, T., & Okanya, V. (2023). Microplastics pollution indices of bottled water from South Eastern Nigeria. *International Journal of Environmental Analytical Chemistry*, 103(19), 8176–8195. <https://doi.org/10.1080/03067319.2021.1982926>
- Kankanige, D., & Babel, S. (2020). Smaller-sized micro-plastics (MPs) contamination in single-use PET-bottled water in Thailand. *Science of the Total Environment*, 717, Article 137232. <https://doi.org/10.1016/j.scitotenv.2020.137232>
- Kedzierski, M., Lechat, B., Sire, O., Le Maguer, G., Le Tilly, V., & Bruzard, S. (2020). Microplastic contamination of packaged meat: Occurrence and associated risks. *Food Packaging and Shelf Life*, 24, Article 100489. <https://doi.org/10.1016/j.fpsl.2020.100489>
- Kim, J.-S., Lee, H.-J., Kim, S.-K., & Kim, H.-J. (2018). Global pattern of microplastics (MPs) in commercial food-grade salts: Sea salt as an indicator of seawater MP pollution. *Environmental Science & Technology*, 52(21), 12819–12828. <https://doi.org/10.1021/acs.est.8b04180>
- Kim, S., Jo, E. H., & Choi, S. (2022). Microplastic release from damaged commercial teabags. *Membrane and Water Treatment*, 13(1), 21–28. <https://doi.org/10.12989/mwt.2022.13.1.021>
- Lee, E.-H., Lee, S., Chang, Y., & Lee, S.-W. (2021). Simple screening of microplastics in bottled waters and environmental freshwaters using a novel fluorophore. *Chemosphere*, 285, Article 131406. <https://doi.org/10.1016/j.chemosphere.2021.131406>
- Lee, H., Kunz, A., Shim, W. J., & Walther, B. A. (2019). Microplastic contamination of table salts from Taiwan, including a global review. *Scientific Reports*, 9(1), Article 10145. <https://doi.org/10.1038/s41598-019-46417-z>
- Li, D., Sheerin, E. D., Shi, Y., Xiao, L., Yang, L., Boland, J. J., & Wang, J. J. (2022). Alcohol pretreatment to eliminate the interference of micro additive particles in the identification of microplastics using Raman spectroscopy. *Environmental Science & Technology*, 56(17), 12158–12168. <https://doi.org/10.1021/acs.est.2c01551>

- Li, D., Yang, L., Kavanagh, R., Xiao, L., Shi, Y., Kehoe, D. K., Sheerin, E. D., Gun'ko, Y. K., Boland, J. J., & Wang, J. J. (2021). Sampling, identification and characterization of microplastics release from polypropylene baby feeding bottle during daily use. *Journal of Visualized Experiments*, (173), Article e62545. <https://doi.org/10.3791/62545>
- Li, J., Green, C., Reynolds, A., Shi, H., & Rotchell, J. M. (2018). Microplastics in mussels sampled from coastal waters and supermarkets in the United Kingdom. *Environmental Pollution*, 241, 35–44. <https://doi.org/10.1016/j.envpol.2018.05.038>
- Liu, G., Wang, J., Wang, M., Ying, R., Li, X., Hu, Z., & Zhang, Y. (2022). Disposable plastic materials release microplastics and harmful substances in hot water. *Science of the Total Environment*, 818, 151685. <https://doi.org/10.1016/j.scitotenv.2021.151685>
- Madejski, G. R., Ahmad, S. D., Musgrave, J., Flax, J., Madejski, J. G., Rowley, D. A., DeLouise, L. A., Berger, A. J., Knox, W. H., & McGrath, J. L. (2020). Silicon nanomembrane filtration and imaging for the evaluation of microplastic entrainment along a municipal water delivery route. *Sustainability*, 12(24), Article 10655. <https://doi.org/10.3390/su122410655>
- Maharjan, K. K. (2025). Microplastic pollution in bottled water: A systematic review. *International Journal of Environmental Science and Technology*, 22(2), 1283–1296. <https://doi.org/10.1007/s13762-024-05807-1>
- Makhdoumi, P., Amin, A. A., Karimi, H., Pirsaeheb, M., Kim, H., & Hossini, H. (2021). Occurrence of microplastic particles in the most popular Iranian bottled mineral water brands and an assessment of human exposure. *Journal of Water Process Engineering*, 39, Article 101708. <https://doi.org/10.1016/j.jwpe.2020.101708>
- Mason, S. A., Welch, V. G., & Neratko, J. (2018). Synthetic polymer contamination in bottled water. *Frontiers in Chemistry*, 6, Article 407. <https://doi.org/10.3389/fchem.2018.00407>
- Mazlan, N. A., Lin, L., & Park, H. E. (2022). Microplastics in the New Zealand environment. *Processes*, 10(2), 265. <https://doi.org/10.3390/pr10020265>
- Mei, T., Wang, J., Xiao, X., Lv, J., Li, Q., Dai, H., Liu, X., & Pi, F. (2022). Identification and evaluation of microplastics from tea filter bags based on Raman imaging. *Foods*, 11(18), 2871. <https://doi.org/10.3390/foods11182871>
- Nalbone, L., Cincotta, F., Giarratana, F., Ziino, G., & Panebianco, A. (2021). Microplastics in fresh and processed mussels sampled from fish shops and large retail chains in Italy. *Food Control*, 125, Article 108003. <https://doi.org/10.1016/j.foodcont.2021.108003>
- Oßmann, B. E., Sarau, G., Holtmannspötter, H., Pischetsrieder, M., Christiansen, S. H., & Dicke, W. (2018). Small-sized microplastics and pigmented particles in bottled mineral water. *Water Research*, 141, 307–316. <https://doi.org/10.1016/j.watres.2018.05.027>
- Ouyang, X., Hu, Y., & Li, G. (2022). Integrated sample-pretreatment strategy for separation and enrichment of microplastics and primary aromatic amines in the migration of teabag. *Journal of Separation Science*, 45(4), 929–937. <https://doi.org/10.1002/jssc.202100893>
- Park, I., Yang, W., & Lim, D.-K. (2022). Current status of organic matters in bottled drinking water in Korea. *ACS ES&T Water*, 2, 738–748. <https://doi.org/10.1021/acsestwater.1c00435>

- Parveen, N., Ranjan, V. P., Chowdhury, S., & Goel, S. (2022). Occurrence and potential health risks due to trihalomethanes and microplastics in bottled water. *Environmental Engineering Science*, 39(6), 523–534. <https://doi.org/10.1089/ees.2021.0295>
- Pratesi, C. B., A. L. Santos Almeida, M. A., Cutrim Paz, G. S., Ramos Teotonio, M. H., Gandolfi, L., Pratesi, R., Hecht, M., & Zandonadi, R. P. (2021). Presence and quantification of microplastic in urban tap water: A pre-screening in Brasilia, Brazil. *Sustainability*, 13(11), Article 6404. <https://doi.org/10.3390/su13116404>
- Praveena, S. M., Shamsul Ariffin, N. I., & Nafisyah, A. L. (2022). Microplastics in Malaysian bottled water brands: Occurrence and potential human exposure. *Environmental Pollution*, 315, 120494. <https://doi.org/10.1016/j.envpol.2022.120494>
- Ravanbakhsh, M., Ravanbakhsh, M., Jamali, H. A., Ranjbaran, M., Shahsavari, S., & Jaafarzadeh Haghighi Fard, N. (2023). The effects of storage time and sunlight on microplastic pollution in bottled mineral water. *Water and Environment Journal*, 37(2), 206–217. <https://doi.org/10.1111/wej.12829>
- Rbaibi Zipak, S., Muratoglu, K., & Buyukunal, S. K. (2022). Evaluation of microplastic presence in yogurt production process. *Kafkas Üniversitesi Veteriner Fakültesi Dergisi*, 28(5), 633–641. <https://doi.org/10.9775/kvfd.2022.27871>
- Renzi, M., & Blašković, A. (2018). Litter & microplastics features in table salts from marine origin: Italian versus Croatian brands. *Marine Pollution Bulletin*, 135, 62–68. <https://doi.org/10.1016/j.marpolbul.2018.06.065>
- Samandra, S., Mescall, O. J., Plaisted, K., Symons, B., Xie, S., Ellis, A. V., & Clarke, B. O. (2022). Assessing exposure of the Australian population to microplastics through bottled water consumption. *Science of the Total Environment*, 837, 155329. <https://doi.org/10.1016/j.scitotenv.2022.155329>
- Schymanski, D., Goldbeck, C., Humpf, H.-U., & Fürst, P. (2018). Analysis of microplastics in water by micro-Raman spectroscopy: Release of plastic particles from different packaging into mineral water. *Water Research*, 129, 154–162. <https://doi.org/10.1016/j.watres.2017.11.011>
- Schymanski, D., Humpf, H.-U., & Fürst, P. (2020). Determination of particle abrasion through milling with five different salt grinders—A preliminary study by micro-Raman spectroscopy with efforts towards improved quality control of the analytical methods. *Food Additives & Contaminants: Part A*, 37(8), 1238–1252. <https://doi.org/10.1080/19440049.2020.1748724>
- Scircle, A., & Cizdziel, J. V. (2020). Detecting and quantifying microplastics in bottled water using fluorescence microscopy: A new experiment for instrumental analysis and environmental chemistry courses. *Journal of Chemical Education*, 97(1), 234–238. <https://doi.org/10.1021/acs.jchemed.9b00593>
- Shen, M., Zeng, Z., Wen, X., Ren, X., Zeng, G., Zhang, Y., & Xiao, R. (2021). Presence of microplastics in drinking water from freshwater sources: The investigation in Changsha, China. *Environmental Science and Pollution Research*, 28(31), 42313–42324. <https://doi.org/10.1007/s11356-021-13769-x>
- Shruti, V. C., Pérez-Guevara, F., Elizalde-Martínez, I., & Kuttralam-Muniasamy, G. (2020). First study of its kind on the microplastic contamination of soft drinks, cold tea and energy

- drinks—Future research and environmental considerations. *Science of the Total Environment*, 726, Article 138580. <https://doi.org/10.1016/j.scitotenv.2020.138580>
- Singh, T. (2021). Generation of microplastics from the opening and closing of disposable plastic water bottles. *Journal of Water and Health*, 19(3), 488–498. <https://doi.org/10.2166/wh.2021.025>
- Sobhani, Z., Lei, Y., Tang, Y., Wu, L., Zhang, X., Naidu, R., Megharaj, M., & Fang, C. (2020). Microplastics generated when opening plastic packaging. *Scientific Reports*, 10(1), Article 4841. <https://doi.org/10.1038/s41598-020-61146-4>
- Song, K., Ding, R., Sun, C., Yao, L., & Zhang, W. (2021). Microparticles and microplastics released from daily use of plastic feeding and water bottles and plastic injectors: Potential risks to infants and children in China. *Environmental Science and Pollution Research*, 28(42), 59813–59820. <https://doi.org/10.1007/s11356-021-14939-7>
- Strand, J., Feld, L., Murphy, F., Mackevica, A., & Hartmann, N. B. (2018). *Analysis of microplastic particles in Danish drinking water* (Scientific Report No. 291). Aarhus University, DCE – Danish Centre for Environment and Energy. <http://dce2.au.dk/pub/SR291.pdf>
- Su, Y., Hu, X., Tang, H., Lu, K., Li, H., Liu, S., Xing, B., & Ji, R. (2022). Steam disinfection releases micro(nano)plastics from silicone-rubber baby teats as examined by optical photothermal infrared microspectroscopy. *Nature Nanotechnology*, 17, 76–85. <https://doi.org/10.1038/s41565-021-00998-x>
- Taheri, S., Shoshtari-Yeganeh, B., Pourzamani, H., & Ebrahimpour, K. (2023). Investigating the pollution of bottled water by the microplastics (MPs): The effects of mechanical stress, sunlight exposure, and freezing on MPs release. *Environmental Monitoring and Assessment*, 195, Article 62. <https://doi.org/10.1007/s10661-022-10697-2>
- Tse, Y.-T., Chan, S. M.-N., & Sze, E. T.-P. (2022). Quantitative assessment of full size microplastics in bottled and tap water samples in Hong Kong. *International Journal of Environmental Research and Public Health*, 19(20), 13432. <https://doi.org/10.3390/ijerph192013432>
- Winkler, A., Fumagalli, F., Cella, C., Gilliland, D., Tremolada, P., & Valsesia, A. (2022). Detection and formation mechanisms of secondary nanoplastic released from drinking water bottles. *Water Research*, 222, Article 118848. <https://doi.org/10.1016/j.watres.2022.118848>
- Winkler, A., Santo, N., Ortenzi, M. A., Bolzoni, E., Bacchetta, R., & Tremolada, P. (2019). Does mechanical stress cause microplastic release from plastic water bottles? *Water Research*, 166, Article 115082. <https://doi.org/10.1016/j.watres.2019.115082>
- Xu, X., Guo, J., Gao, Y., Xue, Y., Shi, X., Zhang, L., Zhang, Q., & Peng, M. (2023). Leaching behavior and evaluation of zebrafish embryo toxicity of microplastics and phthalates in take-away plastic containers. *Environmental Science and Pollution Research*, 30(8), 21104–21114. <https://doi.org/10.1007/s11356-022-23675-5>
- Yang, D., Shi, H., Li, L., Li, J., Jabeen, K., & Kolandhasamy, P. (2015). Microplastic pollution in table salts from China. *Environmental Science & Technology*, 49(22), 13622–13627. <https://doi.org/10.1021/acs.est.5b03163>

- Zhou, G., Wu, Q., Tang, P., Chen, C., Cheng, X., Wei, X.-F., Ma, J., & Liu, B. (2023). How many microplastics do we ingest when using disposable drink cups? *Journal of Hazardous Materials*, 441, 129982. <https://doi.org/10.1016/j.jhazmat.2022.129982>
- Zhou, X., Wang, J., & Ren, J. (2022). Analysis of microplastics in takeaway food containers in China using FPA-FTIR whole filter analysis. *Molecules*, 27(9), Article 2646. <https://doi.org/10.3390/molecules27092646>
- Zhou, X.-J., Wang, J., Li, H.-Y., Zhang, H.-M., Hua-Jiang, & Zhang, D. L. (2021). Microplastic pollution of bottled water in China. *Journal of Water Process Engineering*, 40, Article 101884. <https://doi.org/10.1016/j.jwpe.2020.101884>
- Ziino, G., Nalbone, L., Giarratana, F., Romano, B., Cincotta, F., & Panebianco, A. (2021). Microplastics in vacuum packages of frozen and glazed icefish (*Neosalanx* spp.): A freshwater fish intended for human consumption. *Italian Journal of Food Safety*, 10(4), Article 9974. <https://doi.org/10.4081/ijfs.2021.9974>
- Zuccarello, P., Ferrante, M., Cristaldi, A., Copat, C., Grasso, A., Sangregorio, D., Fiore, M., & Oliveri Conti, G. (2019). Exposure to microplastics (<10 µm) associated to plastic bottles mineral water consumption: The first quantitative study. *Water Research*, 157, 365–371. <https://doi.org/10.1016/j.watres.2019.03.091>

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