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The Impact of Microplastics on Human Health: An Urgent Public Health Concern

Kerem Kökoğlu,[1] Hamdi Mıhçıokur,[2,3] İbrahim Uyanık[2,3]

[1]Department of Otolaryngology, Erciyes University Faculty of Medicine, Kayseri, Türkiye
[2]Department of Environmental Engineering, Erciyes University Faculty of Engineering, Kayseri, Türkiye
[3]Research and Application Centre for Environmental Problems and Cleaner Production, Erciyes University, Kayseri, Türkiye

ABSTRACT

Microplastics (MPs) have rapidly become one of the most pervasive pollutants in the modern world. Far from being confined to oceans or waste sites, these tiny particles now circulate through the air we breathe, the water we drink, and the food we eat. As everyday plastic items break down over time, they form microscopic fragments that can travel long distances and enter the human body through inhalation or ingestion. Once inside the body, these particles may accumulate in organs and interact with biological systems in ways that scientists are only beginning to understand. This review synthesizes current scientific findings on the formation of MPs, their pathways into and persistence within the human body, and their potential health impacts. Although there is no standardized method for measuring MPs, the main analytical techniques used for biological samples are discussed. Furthermore, the toxicity and environmental impacts of plastic types to which humans are exposed are assessed using the EPI Suite™ program developed by the U.S. Environmental Protection Agency (USEPA). Certain MP types, such as polyethylene and polypropylene, appear more toxic due to their low biodegradability. Although evidence increasingly identifies MPs as a growing public health concern, many questions remain unanswered. Health effects related to gastrointestinal and respiratory health systems are examined, while long-term effects, behavior in human tissues, and associations with chronic diseases—including potential links to cancer—require further multidisciplinary investigation. As global plastic use continues to rise, understanding and mitigating MP exposure will be essential for protecting human health.

Keywords: Cancer, inhibitor, microplastics, migration, one health, toxicity

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Address for correspondence:
İbrahim Uyanık.
Department of Environmental Engineering, Erciyes University Faculty of Engineering, Kayseri, Türkiye
Phone: +90 352 207 66 66 /32806
E-mail: iuyanik@erciyes.edu.tr

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INTRODUCTION

Formation and Environmental Occurrence of MPs

Plastics are versatile polymers characterized by their low density, malleability, and durability, leading to their ubiquity in modern life.[1] In addition to their use in household goods, vehicles, and industrial production processes, they are also produced extensively for single use in all areas of life.[2] Plastic production worldwide is increasing every year and has exceeded 400 million tons annually.[3] Due to problems in plastic waste management and the global recycling rate being around 10%, the degradation and disintegration of plastic polymers lead to the formation of particles called microplastics (MPs), defined as particles ranging from 1 to 5,000 µm.[4]

Microplastics can be formed by the direct breakdown of plastics released into the environment, as well as through environmental factors, such as sunlight, wind, and long-term weathering and aging processes.[5] In addition to the widespread presence and use of plastics in all human environments (homes, offices, industrial parks, etc.), direct exposure also occurs. Fabrics made from plastics such as polyester or polyethylene terephthalate (PET) and shoes made from plastic derivatives such as ethylene-vinyl acetate (EVA) demonstrate that plastics are beginning to surround our bodies.[6,7] Empirical evidence has demonstrated that domestic laundry effluent is a significant source of synthetic microfibers.[8] During the recycling of these plastics, high amounts of MPs are released into receiving water bodies along with washing water.[9] Similarly, studies have identified domestic and industrial wastewater treatment plants as point sources of MPs.[10] Studies conducted in various water sources worldwide have revealed the presence of MPs at high concentrations, particularly in coastal areas.[11] Varying in morphology and composition, MPs can act as vectors for chemical pollutants due to their high surface adsorption capacity.[12]

Studies reported in the literature have demonstrated that the widespread presence of plastics across all environmental media results in the ubiquitous occurrence of MPs.[13] MPs have been detected in air (both indoor and outdoor), on land (including terrestrial environments and landfills), in marine, oceanic, and freshwater environments, and even in the Arctic.[14–17] Although MPs are not considered a conventional air pollution parameter, fiber MPs have been shown to be transported over distances of several kilometers.[18] Due to poor plastic waste management, particularly in rural regions, MP formation and plastic-related environmental impacts are more pronounced, leading to severe consequences such as open burning, open dumping, landfill burial, and waste imports.[19] Consequently, it has been reported that the transition to a circular economic perspective in plastic waste management is quite difficult, and there are significant barriers to achieving a sustainable waste management model.[20]

As a result, MPs are constantly transported across all environmental media (air, soil, and water) by environmental factors.[21] The presence of MPs is not limited to remote areas; they remain in continuous contact along long transport routes. MPs are in constant contact with humans in all areas of life, from seed and medicine packaging or compost used in agricultural fields to serums, syringes, and medications in hospitals.[22] Notably, hypertonic fluids are one of the sources of MPs that directly enter the human body via intravenous routes.[23] Therefore, it is necessary to investigate the pathways of MPs after they enter the human body. Crucial to this investigation is the standardization of analytical methodologies for detecting MPs in biological matrices.

While the prevalence of MPs is well documented, specific toxicological modeling of human exposure remains sparse. In preparing this review, research and review publications from the last 10 years were selected from the perspective of each author, including studies on MP formation and occurrence in environmental samples, MP analysis and toxicity in humans, and associated health effects. This review differentiates itself as a case study by applying EPI Suite™ to assess the biopersistence of common polymers. A focused analysis of the mechanisms of respiratory and gastrointestinal degradation is also provided. An interdisciplinary approach was employed to explore the relationship between environmental and medical sciences.

CLINICAL AND RESEARCH CONSEQUENCES

Calculation of Environmental Toxicity of MPs Using EPI Suite™

In this research, the twelve most frequently utilized MPs were analyzed. To gather insights into the toxicological impacts and biodegradability of MPs in the environment, the EPI Suite™ (Estimation Programs Interface) created by the U.S. Environmental Protection Agency (EPA) was employed to assess human toxicity.[24] Biodegradability parameters were evaluated using the BIOWIN module of the software, while toxicity metrics such as effective concentration (EC_{50}) and lethal concentration (LC_{50}) were determined using the ECOSAR module.[25] This program operates based on the principles of Quantitative Structure-Activity Relationships (QSAR), predicting the physical and chemical effects of substances on living organisms according to their molecular characteristics. Unlike basic toxicity screening tools, EPI Suite™ enables a comprehensive assessment of both environmental fate (e.g., partitioning and biodegradation) and toxicological endpoints based on the specific molecular geometry and functional groups of polymers. The integration of BIOWIN™ and ECOSAR™ models provides a standardized regulatory framework developed by the U.S. EPA, ensuring that the predictive data are aligned with internationally recognized environmental safety benchmarks.

Characterization and Detection of MPs in Biological Samples

Numerous studies have analyzed MPs using different methods. Variations in MP extraction processes, as well as in the instrumentation and analytical techniques employed,

Table 1. Comparison of microplastic (MP) analysis methods

Evaluation criteria		Spectroscopic methods		Thermo-analytical methods
Analysis methods	Stereomicroscopy	FTIR spectroscopy	Raman spectroscopy	Py-GC/MS
Chemical analysis	Not possible	Yes	Yes	Yes
Nanoplastic detection	Not possible	Limited	Possible	Possible (mass-based)
Operational complexity	Very low	Moderate	Expertise required	Moderate
Matrix effects	High	Low	Low	Very Low

FTIR: Fourier transform infrared spectroscopy; Py-GC/MS: Pyrolysis gas chromatography-mass spectrometry.

significantly increase the diversity of analyses.[26,27] The analysis of MPs in biological samples is complicated by the difficulty of isolating polymer particles from organic matrices. Because plastics are polymeric organic chemicals, selectively separating them from biological samples that also contain organic material is difficult and may lead to analytical errors.

Separation processes such as digestion, oxidation, or density gradient techniques used to remove the organic matrix from the analyte can result in analyte loss.[28] Therefore, it is essential to avoid the use of overly strong solvents or oxidants during sample separation. Recently, enzymatic digestion has emerged as a particularly suitable pre-separation method for biological samples. This approach has been reported to achieve high digestion efficiency using very low concentrations of trypsin or proteinase K, without analyte loss.[29]

Given the heterogeneity of sample matrices and polymer types, a universal "gold standard" for MP analysis remains elusive. Method selection should be strategically determined based on sample type (e.g., water, sediment, or tissue) and the targeted particle size range. Analytical methods can be broadly divided into two categories: spectroscopic and thermo-analytical approaches.[26,27]

The fundamental distinction in MP characterization lies between particle-based methods, such as Fourier Transform Infrared Spectroscopy (FTIR) or Raman spectroscopy, and mass-based methods, such as pyrolysis gas chromatography/mass spectroscopy (Py-GC/MS). FTIR and Raman analyses report data on a "pieces/liter" or "pieces/m^3" basis, quantifying pollution levels by particle number. Py-GC/MS, on the other hand, provides mass-based values such as μg/L. In the literature, it is debated whether mass-based data are more stable indicators than particle counts for determining ecotoxicological risks. Microscopic techniques are limited by the wavelength of light. FTIR generally experiences signal loss for particles smaller than 20 μm, whereas Raman spectroscopy can detect particles down to 1 μm. Py-GC/MS, in contrast, is size independent.[26,27] The advantages and disadvantages of each method are summarized in Table 1.[26–29]

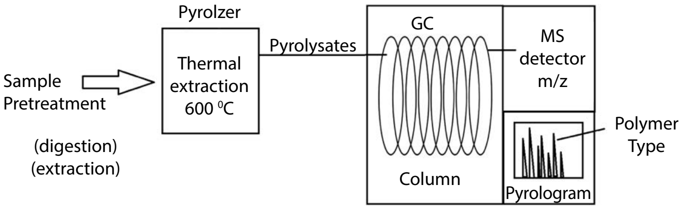

Figure 1. Gas chromatography-mass spectrometry (GC-MS) system equipped with a pyrolyzer.

For the quantitative and qualitative analysis of MPs in biological samples, the PY-GC/MS method is recommended, as it does not require pretreatment and minimizes analyte loss.[30] This method is based on the thermal treatment (pyrolysis) of the sample at high temperatures (600 °C) in an oxygen-free environment, followed by separation of the resulting pyrolysates in a GC column and detection using an MS detector. Qualitative and semi-quantitative analyses can be performed by comparison with GC-MS libraries.[30] Additionally, fully quantitative analyses can be achieved when analyte standards are prepared and appropriate calibrations are performed. The flowchart of the proposed method is shown in Figure 1.

Routes of Human Exposure

Recent studies have identified MPs such as polyvinyl chloride (PVC), polyethylene terephthalate (PET), polypropylene (PP), polyethylene (PE), polystyrene (PS), and polymethyl methacrylate (PMMA) in various human samples, including urine, breast milk, blood, semen, meconium, otitis media fluid, placenta, lung tissue, and heart tissue.[31–33] Therefore, the possible routes of entry into the human body are discussed with respect to ingestion and inhalation.

Ingestion

Microplastic ingestion represents a significant and prevalent pathway for human exposure to these ubiquitous environmental contaminants.[34,35] Humans routinely ingest MPs through various dietary sources, including packaged foods, bottled water, beverages, fruits, fish, sea salt, seafood,

Table 2. Toxicity properties of the most commonly used microplastics (MPs)

Polymer type	LC_{50}/test organism (mg/L)	EC_{50}/test organism (mg/L)	Biodegradability
Polyester (PS)	6.896/Mysid	8.691/green algae	No
Polyethylene (PE)	4.270×10^{-16}/Mysid	6.480×10^{-9}/green algae	No
Polypropylene (PP)	3.111×10^{-16}/Mysid	5.200×10^{-9}/green algae	No
Polyvinyl chloride (PVC)	9.925/Mysid	27.439 /green algae	No
Polyethylene terephthalate (PET)	1031.740/Daphnid	2567.640/green algae	Yes
Polycarbonate (PC)	1.041/Mysid	4.216/green algae	No
Polyurethane (PUR)	131.680/Fish	1.435/green algae	No
Nylon 6 (N-6)	16.420/Mysid	10.095/green algae	No
Nylon 66 (N-66)	10.426/Mysid	6.382/green algae	Yes
Polymethyl methacrylate (PMMA)	0.039/Daphnid	7.892/green algae	No
Styrene-butadiene rubber (SBR)	0.107/Mysid	0.911/green algae	No
Acrylonitrile-butadiene-styrene (ABS)	0.273/Fish	0.157/green algae	No

and agricultural crops.[34,36] Both aquatic ecosystems and agricultural activities serve as pathways through which MPs enter the human food chain.[36,37] Once ingested, MPs are absorbed primarily via transcytosis in enterocytes, with larger particles may be internalized through gaps in the intestinal lining.[38] Evidence indicates the widespread presence of MPs within the human body, as they have been detected in tissues and excreta such as stool, saliva, colon, and placenta.[39,40] Although ongoing research seeks to determine the full extent of health impacts, immediate concerns include long-term accumulation leading to intestinal damage, liver infection, microbial imbalance, and metabolic disorders.[34,35,41]

Inhalation

Humans are chronically exposed to airborne MPs, which are ubiquitous in both indoor and outdoor environments, with indoor settings representing a substantial source due to the amount of time individuals spend indoors.[34,42,43] The presence of MPs in human respiratory samples, including lung tissues, sputum, and the lower airways, has been confirmed in the literature.[44–46] For instance, polymeric particles and fibers have been observed in human lung tissue samples, with particles typically smaller than 5.5 µm and fibers ranging from 8.12 to 16.8 µm.[44] The synthetic fiber industry also represents a significant source of occupational inhalation exposure. The presence of MPs in the respiratory system raises concerns about potential adverse health effects, such as alterations in cellular metabolism, impacts on respiratory diseases, and inflammation.[44,45] Although ingestion was historically considered the primary exposure route, emerging evidence underscores the significance of airborne MP exposure in humans.[35]

CONCLUSIONS – HEALTH EFFECTS ASSOCIATED WITH MP EXPOSURE

Toxicity of Common Plastic Types

Polyethylene and polypropylene stand out for their high toxicity due to their very low LC_{50} and EC_{50} values (Table 2). Furthermore, polyethylene terephthalate and Nylon 66 (N-66) MPs are more biodegradable than other plastic types; therefore, prioritizing these materials may be more appropriate when considering alternatives. Additionally, MPs have the potential to adsorb other pollutants, allowing them to enter living organisms and exert synergistic toxic effects. Weathered plastics are continuously transported in the environment and act as vectors for pollutants due to the contaminants they adsorb or are exposed to.[47] Because these plastics are hydrophobic, they generally exhibit a high adsorption capacity and may accumulate in lipid-rich tissues. Studies have also explored the use of plastics or weathered MPs as adsorbents, as reported by Osman et al.[48] Consequently, when MPs adsorb pollutants, their potential to transport additional contaminants into the body, beyond the MPs themselves, is considerably high.

Gastrointestinal Health

Microplastic exposure to the human gastrointestinal system is a growing concern, as humans are estimated to ingest significant amounts of MPs weekly, with particles detected in various human biological samples, including feces, saliva, sputum, lungs, liver, and breast milk.[49] Once ingested, these MPs can enter the human body and translocate to the lymphatic and circulatory systems, accumulating in various organs.[50] Indeed, MPs have been detected in human colectomy specimens and have also been identified in human blood and even brain tissue, with increasing concentrations reported over time.[51–54] Current evidence suggests that MPs are not easily excreted from the body after ingestion, leading to their accumulation in human tissues and organs, with particularly high concentrations observed in the colon and liver.[35,55] While the exact long-term impacts are still under investigation, these findings highlight the pervasive nature of MPs within the human body and their potential interactions with the gastrointestinal system.

Once ingested, MPs may accumulate in the gastrointestinal tract, leading to significant disruption of the gut microbiome.[56] This disruption often manifests as dysbiosis, characterized by alterations in the diversity and composition of beneficial bacteria and a potential increase in harmful bacterial population.[56,57] Studies indicate that MP exposure can negatively affect functional pathways and metabolic activity of the gut microbiota, contributing to oxidative stress, inflammation, and compromised intestinal barrier function.[57–59] Alterations to the gut microbiome may trigger a range of health problems, including digestive disorders and widespread inflammation. These changes can influence gut health, and, consequently, the rest of the body through its connections with the brain and the immune system.[56,60]

The liver and gastrointestinal tract serve as the primary sites for nutrient absorption and metabolic detoxification. MPs disrupt the gut-liver axis by triggering oxidative stress, inflammation, and programmed cell death (apoptosis).[61] These particles may further interfere with hepatic glucose and lipid regulation and exert indirect effects on the gut-brain axis by altering the intestinal microbiota.[61] Zhang et al.[62] reported in a meta-analysis that MPs can cause hepatocellular injury, oxidative stress, and elevated inflammatory markers, as well as increased liver enzyme levels and decreased antioxidants, such as superoxide dismutase, catalase, and glutathione peroxidase, in animal models. Jin et al.[63] reported that MPs induce cellular toxicity in an in vitro human intestinal cell model. Ozsoy et al.[64] demonstrated the presence of MPs in stomach cells from 26 cadavers.

Respiratory Health

Microplastics have been detected in sputum, bronchoalveolar lavage fluid, and lung tissue. These findings highlight direct exposure routes and the accumulation of MPs within the human respiratory system.[31,45,46]

Evidence from both in vitro and in vivo models indicates that MPs may impair respiratory function. These effects are characterized by pulmonary inflammation, metabolic alterations at the cellular level, and dysregulation of proteins associated with apoptosis.[46] Airborne MPs are increasingly recognized as emerging contributors to respiratory diseases and may significantly influence their onset and progression.[65] Specifically, MP fibers can trigger alveolar macrophages and airway epithelial cells to produce pro-inflammatory cytokines, potentially resulting in chronic airway inflammation.[66] Collectively, these findings highlight the potential for broad respiratory health implications associated with MP exposure.[67]

According to Paplińska-Goryca et al.,[66] MP stimulation elicits distinct responses in the airway epithelial cells of patients with obstructive lung diseases compared to healthy controls. This differential response is associated with Th2-mediated inflammation, altered stress response pathways, and potential carcinogenic processes. Epithelial cells from patients with asthma and chronic obstructive pulmonary disease (COPD) are more susceptible to damage from MP fiber exposure. Anuar et al.[68] demonstrated that polyethylene MPs may adversely affect airway function by enhancing tissue contractile responses, mimicking pathophysiological features observed in asthma, chronic cough, and chronic obstructive pulmonary disease.

The main findings and conclusions can be summarized as follows:

- Polyethylene and polypropylene were identified as high-toxicity risks based on EPI Suite™ prediction (LC_{50}/EC_{50} values), whereas PET and Nylon 66 were highlighted as safer and more biodegradable alternatives.
- Hydrophobic MPs act as chemical vectors by adsorbing environmental pollutants and facilitating their transport into lipid-rich tissues.
- Ingested particles can translocate beyond the gastrointestinal tract into the lymphatic and circulatory systems, accumulating in organs such as the liver, blood, and brain.
- MP-induced gut dysbiosis disrupts the intestinal-hepatic axis, contributing to oxidative stress, liver injury, and metabolic disorders, including insulin resistance.
- Inhaled fibers stimulate pro-inflammatory cytokine production, with significantly higher risks of damage in patients with asthma and COPD.

Knowledge Gaps and Future Research Directions

Human exposure routes to MPs are not yet fully understood. Therefore, further studies are needed to elucidate their effects on various organs or tissues after entering the human body. Additionally, research focusing on the long-term effects of MPs, as well as their behavior and degradation within human tissues, is required. Although associations between certain plastic types or the presence of MPs and various cancers have been reported, more in-depth studies are necessary to establish causal relationships.

Microplastics are now known to be ubiquitous in the environment; therefore, it appears that they may have serious impacts on human health. Humans are in constant contact with plastics in daily lives, and because plastics eventually decompose into MPs, human exposure via air, water, and food is inevitable. In addition to affecting the respiratory and digestive systems, the effects of MPs on other systems of the human body, particularly vital organs such as the brain and heart via the bloodstream, need to be investigated. While some waste management strategies emphasize waste prevention and reduction through hierarchical approaches, it is hypothesized that legislative restrictions on plastic production could play a critical role in mitigating MP exposure.

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REFERENCES

1. Millican JM, Agarwal S. Plastic pollution: a material problem? Macromolecules 2021;54(10):4455-69. [CrossRef]
2. Laitala K, Klepp IG, Haugrønning V, Throne-Holst H, Strandbakken P. Increasing repair of household appliances, mobile phones and clothing: Experiences from consumers and the repair industry. J Clean Prod 2021;282:125349. [CrossRef]
3. Pilapitiya PNT, Ratnayake AS. The world of plastic waste: A review. Clean Mater 2024;11:100220. [CrossRef]
4. Cai Z, Li M, Zhu Z, Wang X, Huang Y, Li T, et al. Biological Degradation of Plastics and Microplastics: A Recent Perspective on Associated Mechanisms and Influencing Factors. Microorganisms 2023;11(7):1661. [CrossRef]
5. Ren Z, Gui X, Xu X, Zhao L, Qiu H, Cao X. Microplastics in the soil-groundwater environment: Aging, migration, and co-transport of contaminants - A critical review. J Hazard Mater 2021;419:126455. [CrossRef]
6. Kim L, Kim D, Kim SA, Kim H, Lee TY, An YJ. Are your shoes safe for the environment? - Toxicity screening of leachates from microplastic fragments of shoe soles using freshwater organisms. J Hazard Mater 2022;421:126779. [CrossRef]
7. Ali A, Qamer S, Shahid M, Tomkova B, Khan MZ, Militky J, et al. Micro- and Nanoplastics Produced from Textile Finishes: A Review. Langmuir 2024;40(34):17849-67. [CrossRef]
8. Wang C, Song J, Nunes LM, Zhao H, Wang P, Liang Z, et al. Global microplastic fiber pollution from domestic laundry. J Hazard Mater 2024;477:135290. [CrossRef]
9. Çolakoğlu EB, Uyanık İ. Plastic waste management in recycling facilities: Intentionally generated MPs as an emerging contaminant. Waste Manag 2024;181:79-88. [CrossRef]
10. Cavazzoli S, Murari F, Donegà M, Tirler W, Andreottola G. Microplastic removal and environmental emissions from municipal wastewater treatment plants. J Clean Prod 2025;521:146267. [CrossRef]
11. Luo W, Su L, Craig NJ, Du F, Wu C, Shi H. Comparison of microplastic pollution in different water bodies from urban creeks to coastal waters. Environ Pollut 2019;246:174-82. [CrossRef]
12. Wang J, Guo X, Xue J. Biofilm-Developed Microplastics As Vectors of Pollutants in Aquatic Environments. Environ Sci Technol 2021;55(19):12780-90. [CrossRef]
13. Lim X. Microplastics are everywhere - but are they harmful? Nature 2021;593(7857):22-5. [CrossRef]
14. Yakushev E, Gebruk A, Osadchiev A, Pakhomova S, Lusher A, Berezina A, et al. Microplastics distribution in the Eurasian Arctic is affected by Atlantic waters and Siberian rivers. Communications Earth & Environment 2021;2(1):23. [CrossRef]
15. Bharath KM, Muthulakshmi A, Natesan U. Microplastic contamination around the landfills: Distribution, characterization and threats: A review. Curr Opin Environ Sci Health 2023;31(2):100422. [CrossRef]
16. Zhai X, Zheng H, Xu Y, Zhao R, Wang W, Guo H. Characterization and quantification of microplastics in indoor environments. Heliyon 2023;9(5):e15901. [CrossRef]
17. Jaikumar IM, Tomson M, Meyyazhagan A, Balamuralikrishnan B, Baskaran R, Pappuswamy M, et al. A comprehensive review of microplastic pollution in freshwater and marine environments. Green Anal Chem 2025;12(1):100202. [CrossRef]

18. Evangeliou N, Grythe H, Klimont Z, Heyes C, Eckhardt S, Lopez-Aparicio S, et al. Atmospheric transport is a major pathway of microplastics to remote regions. Nat Commun 2020;11(1):3381. [CrossRef]

19. Mihai F-C, Gündoğdu S, Markley LA, Olivelli A, Khan FR, Gwinnett C, et al. Plastic Pollution, Waste Management Issues, and Circular Economy Opportunities in Rural Communities. Sustainability 2022;14(1):20. [CrossRef]

20. Debnath B, Bari AM, Ali SM, Ahmed T, Ali I, Kabir G. Modelling the barriers to sustainable waste management in the plastic-manufacturing industry: an emerging economy perspective. Sustain Anal Model 2023;3:100017. [CrossRef]

21. Inobeme A, Shahnawaz M, Adetunji CO, Mathew JT, Adetuyi BO, Popoola OA, et al. Primary microplastic: source, uses, transportation from land to marine environment. Muthu SS, ed. Microplastic Pollution. Singapore: Springer; 2021.p.23-33. [CrossRef]

22. Braun M, Mail M, Heyse R, Amelung W. Plastic in compost: Prevalence and potential input into agricultural and horticultural soils. Sci Total Environ 2021;760:143335. [CrossRef]

23. Çağlayan U, Gündoğdu S, Ramos TM, Syberg K. Intravenous hypertonic fluids as a source of human microplastic exposure. Environ Toxicol Pharmacol 2024;107:104411. [CrossRef]

24. United States Environmental Protecton Agency. Estimation Programs Interface Suite™ for Microsoft® Windows. United States Environmental Protection Agency, Washington, DC, USA. https://www.epa.gov/tsca-screening-tools/epi-suitetm-estimation-program-interface Accessed Jan 21, 2026.

25. Oğuz M, Mihçiokur H. Environmental risk assessment of selected pharmaceuticals in Turkey. Environ Toxicol Pharmacol 2014;38(1):79-83. [CrossRef]

26. Elert AM, Becker R, Duemichen E, Eisentraut P, Falkenhagen J, Sturm H, et al. Comparison of different methods for MP detection: What can we learn from them, and why asking the right question before measurements matters? Environ Pollut 2017;231(Pt 2):1256-64. [CrossRef]

27. Rani M, Ducoli S, Depero LE, Prica M, Tubić A, Ademovic Z, et al. A Complete Guide to Extraction Methods of Microplastics from Complex Environmental Matrices. Molecules 2023;28(15):5710. [CrossRef]

28. Zhang S, Yang X, Gertsen H, Peters P, Salánki T, Geissen V. A simple method for the extraction and identification of light density microplastics from soil. Sci Total Environ 2018;616-617:1056-65. [CrossRef]

29. Courtene-Jones W, Quinn B, Murphy F, Gary SF, Narayanaswamy BE. Optimisation of enzymatic digestion and validation of specimen preservation methods for the analysis of ingested microplastics. Analytical Methods 2017;9(9):1437-45. [CrossRef]

30. Lv L, Yan X, Feng L, Jiang S, Lu Z, Xie H, et al. Challenge for the detection of microplastics in the environment. Water Environ Res 2021;93(1):5-15. [CrossRef]

31. Jenner LC, Rotchell JM, Bennett RT, Cowen M, Tentzeris V, Sadofsky LR. Detection of microplastics in human lung tissue using μFTIR spectroscopy. Sci Total Environ 2022;831:154907. [CrossRef]

32. Montano L, Giorgini E, Notarstefano V, Notari T, Ricciardi M, Piscopo M, et al. Raman Microspectroscopy evidence of microplastics in human semen. Sci Total Environ 2023;901:165922. [CrossRef]

33. Kökoğlu K, Mıhçıokur H, Uyanık I, Öztürk D, Yıldız H, Taş OB, et al. Microplastic presence in the fluid of otitis media with effusion. Int J Pediatr Otorhinolaryngol 2025;196:112501. [CrossRef]

34. Emenike EC, Okorie CJ, Ojeyemi T, Egbemhenghe A, Iwuozor KO, Saliu OD, et al. From oceans to dinner plates: The impact of microplastics on human health. Heliyon 2023;9(10):e20440. [CrossRef]

35. Li Y, Tao L, Wang Q, Wang F, Li G, Song M. Potential Health Impact of Microplastics: A Review of Environmental Distribution, Human Exposure, and Toxic Effects. Environ Health (Wash) 2023;1(4):249-57. [CrossRef]

36. Hore M, Bhattacharyya S, Roy S, Sarkar D, Biswas JK. Human exposure to dietary microplastics and health risk: A comprehensive review. Environ Contam Toxicol 2024;262(1):14. [CrossRef]

37. Zhang X, Yin Z, Xiang S, Yan H, Tian H. Degradation of Polymer Materials in the Environment and Its Impact on the Health of Experimental Animals: A Review. Polymers (Basel) 2024;16(19):2807. [CrossRef]

38. Prata JC. Microplastics and human health: Integrating pharmacokinetics. Crit Rev Env Sci Tec 2023;53(16):1489-511. [CrossRef]

39. Winiarska E, Jutel M, Zemelka-Wiacek M. The potential impact of nano- and microplastics on human health: Understanding human health risks. Environ Res 2024;251(Pt 2):118535. [CrossRef]

40. Zhao S, Yao L, Zhu L, Dong J, LeBlanc GA, An L. Growing concerns over ingested microplastics in humans. Carbon Research 2025;4(1):1. [CrossRef]

41. Wang YF, Wang XY, Chen BJ, Yang YP, Li H, Wang F. Impact of microplastics on the human digestive system: From basic to clinical. World J Gastroenterol 2025;31(4):100470. [CrossRef]

42. Rindelaub JD, Miskelly GM. Inhalable microplastics and plastic additives in the indoor air of chemical laboratories. J Expo Sci Environ Epidemiol 2025;35:785-91. [CrossRef]
43. Vianello A, Jensen RL, Liu L, Vollertsen J. Simulating human exposure to indoor airborne microplastics using a Breathing Thermal Manikin. Sci Rep 2019;9(1):8670. [CrossRef]
44. Amato-Lourenço LF, Carvalho-Oliveira R, Júnior GR, Dos Santos Galvão L, Ando RA, Mauad T. Presence of airborne microplastics in human lung tissue. J Hazard Mater 2021;416:126124. [CrossRef]
45. Baeza-Martínez C, Olmos S, González-Pleiter M, López-Castellanos J, García-Pachón E, Masiá-Canuto M, et al. First evidence of microplastics isolated in European citizens' lower airway. J Hazard Mater 2022;438:129439. [CrossRef]
46. Baeza-Martínez C, Garcia-Pachon E, Bayo J. Environmental Microplastics and the Lung. Arch Bronconeumol 2023;59(6):352-3. English, Spanish. [CrossRef]
47. Sheng Y, Ye X, Zhou Y, Li R. Microplastics (MPs) Act as Sources and Vector of Pollutants-Impact Hazards and Preventive Measures. Bull Environ Contam Toxicol 2021;107(4):722-9. [CrossRef]
48. Osman D, Uyanık İ, Mıhçıokur H, Özkan O. Evaluation of ciprofloxacin (CIP) and clarithromycin (CLA) adsorption with weathered PVC microplastics. J Environ Sci Health A Tox Hazard Subst Environ Eng 2023;58(5):498-505. [CrossRef]
49. Dong H, Wang X, Niu X, Zeng J, Zhou Y, Suona Z, et al. Overview of analytical methods for the determination of microplastics: Current status and trends. TrAC Trends in Anal Chem 2023;167:117261. [CrossRef]
50. Daud A, Astuti RDP. Detection of exposure to microplastics in humans: A systematic review. Open Access Maced J Med Sci 2021;9(F):275-80. [CrossRef]
51. Ibrahim YS, Tuan Anuar S, Azmi AA, Wan Mohd Khalik WMA, Lehata S, Hamzah SR, et al. Detection of microplastics in human colectomy specimens. JGH Open 2020;5(1):116-21. [CrossRef]
52. Campen M, Nihart A, Garcia M, Liu R, Olewine M, Castillo E, et al. Bioaccumulation of Microplastics in Decedent Human Brains Assessed by Pyrolysis Gas Chromatography-Mass Spectrometry. Res Sq 2024:rs.3.rs-4345687. Update in: Nat Med 2025;31(4):1114-9.
53. Li B, Li M, Du D, Tang B, Yi W, He M, et al. Characteristics and influencing factors of microplastics entering human blood through intravenous injection. Environ Int 2025;198(12):109377. [CrossRef]
54. Nihart AJ, Garcia MA, El Hayek E, Liu R, Olewine M, Kingston JD, et al. Bioaccumulation of microplastics in decedent human brains. Nat Med 2025;31(4):1114-9. [CrossRef]
55. Niu H, Liu S, Jiang Y, Hu Y, Li Y, He L, et al. Are Microplastics Toxic? A Review from Eco-Toxicity to Effects on the Gut Microbiota. Metabolites 2023;13(6):739. [CrossRef]
56. Bora SS, Gogoi R, Sharma MR, Anshu, Borah MP, Deka P, et al. Microplastics and human health: unveiling the gut microbiome disruption and chronic disease risks. Front Cell Infect Microbiol 2024;14:1492759. [CrossRef]
57. Hirt N, Body-Malapel M. Immunotoxicity and intestinal effects of nano- and microplastics: a review of the literature. Part Fibre Toxicol 2020;17(1):57. [CrossRef]
58. Qiao J, Chen R, Wang M, Bai R, Cui X, Liu Y, et al. Perturbation of gut microbiota plays an important role in micro/nanoplastics-induced gut barrier dysfunction. Nanoscale 2021;13(19):8806-16. [CrossRef]
59. Tu P, Xue J, Niu H, Tang Q, Mo Z, Zheng X, et al. Deciphering Gut Microbiome Responses upon Microplastic Exposure via Integrating Metagenomics and Activity-Based Metabolomics. Metabolites 2023;13(4):530. [CrossRef]
60. Nugrahapraja H, Sugiyo PWW, Putri BQ, Huang L, Hafza N, Götz F, et al. Effects of microplastic on human gut microbiome: detection of plastic-degrading genes in human gut exposed to microplastics-preliminary study. Environments 2022;9(11):140. [CrossRef]
61. Zhou L, Ran L, He Y, Huang Y. Mechanisms of microplastics on gastrointestinal injury and liver metabolism disorder (Review). Mol Med Rep 2025;31(4):98. [CrossRef]
62. Zhang Y, Yuan J, Mao T. Impact of microplastics exposure on liver health: A comprehensive meta-analysis. Comp Biochem Physiol C Toxicol Pharmacol 2025;288:110080. [CrossRef]
63. Jin T, Liu Y, Lyu H, He Y, Sun H, Tang J, et al. Plastic takeaway food containers may cause human intestinal damage in routine life usage: Microplastics formation and cytotoxic effect. J Hazard Mater 2024;475:134866. [CrossRef]
64. Özsoy S, Gündogdu S, Sezigen S, Tasalp E, Ikiz DA, Kideys AE. Presence of microplastics in human stomachs. Forensic Sci Int 2024;364:112246. [CrossRef]
65. Vasse GF, Melgert BN. Microplastic and plastic pollution: impact on respiratory disease and health. Eur Respir Rev 2024;33(172):230226. [CrossRef]
66. Paplińska-Goryca M, Misiukiewicz-Stępień P, Wróbel M, Mycroft-Rzeszotarska K, Adamska D, Rachowka J, et al. The impaired response of nasal epithelial cells to microplastic stimulation in asthma and COPD. Sci Rep 2025;15(1):4242. [CrossRef]
67. Chartres N, Cooper CB, Bland G, Pelch KE, Gandhi SA, BakenRa A, et al. Effects of Microplastic Exposure on Human Digestive, Reproductive, and Respiratory Health: A Rapid Systematic Review. Environ Sci Technol 2024;58(52):22843-64. [CrossRef]
68. Anuar NAS, Pang LY, Selvam SB, Gibbins CN, Nee TK. Polyethylene microplastics adversely affect airway patency. LSMB 2022;6(1):93. [CrossRef]