ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue V, May 2026

From Microplastics to Nanoplastics: Human Exposure Pathways, Molecular Toxicity, and Emerging Health Risks

Dr. Aruna Bohra

Department of Life Sciences Lachoo Memorial College of Science and Technology, Jodhpur.

DOI: https://doi.org/10.51583/IJLTEMAS.2026.150500059

Received: 22 April 2026; Accepted: 27 April 2026; Published: 28 May 2026

ABSTRACT

The widespread accumulation of plastic waste in the environment has led to the generation of microplastics (MPs; <5 mm) and nanoplastics (NPs; <1 μm), prompting growing concern about their possible effects on human health. (Andrady, 2017; Geyer et al., 2017). Although microplastics are well characterized, nanoplastics have only recently gained attention as a potentially more harmful class because their nanoscale dimensions increase reactivity and permit deeper biological penetration (Gigault et al., 2018; Koelmans et al., 2022; Sharma et al., 2023). This review critically examines recent advancements (2020–2025) in the sources, environmental distribution, exposure pathways, analytical detection, and toxicological effects of micro- and nanoplastics, with a primary focus on nanoplastics (Li et al., 2023; Singh et al., 2025). Comparative evaluation highlights a shift from physical and carrier-based effects of MPs to molecular and cellular toxicity associated with NPs (Yong et al., 2020; Jin et al., 2019). Despite growing evidence of their presence in human tissues, significant uncertainties remain regarding exposure levels and long-term health implications (Leslie et al., 2022; Nihart et al., 2025; Ragusa et al., 2021).

Keywords: Microplastics, Nanoplastics, Human exposure pathways, Molecular toxicity, Environmental distribution

INTRODUCTION

The exponential increase in global plastic production has led to the widespread accumulation of plastic debris across ecosystems (Andrady, 2017). Over time, these materials fragment into microplastics (MPs) and eventually nanoplastics (NPs) through environmental processes such as photodegradation and mechanical abrasion (da Costa et al., 2016; Guo & Wang, 2019).

While MPs have been extensively studied, NPs are emerging as a critical concern due to their nanoscale size and enhanced physicochemical properties (Gigault et al., 2018). Microplastics act as a precursor pool for nanoplastics, yet NPs exhibit greater biological reactivity and the ability to cross cellular membranes, enabling direct interaction with intracellular components (Koelmans et al., 2022). Recent studies have detected plastic particles in human blood and placenta, indicating systemic exposure and raising concerns regarding potential health risks (Leslie et al., 2022; Bhattacharyya et al., 2025).

Sources and Environmental Reservoirs

Micro- and nanoplastics originate from both primary and secondary sources. Secondary particles are formed through degradation of larger plastic debris via ultraviolet radiation, oxidation, and mechanical forces (da Costa et al., 2016; Andrady, 2017; Guo & Wang, 2019). These particles are widely distributed across environmental compartments, including water, soil, air, and sediments (Besseling et al., 2017; Zhang et al., 2020). Due to their smaller size, nanoplastics exhibit higher mobility and persistence, increasing their potential for long-range transport and human exposure (Koelmans et al., 2022; Singh et al., 2025).

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue V, May 2026

Expanded Sources of Nanoplastics

Nanoplastics originate from both primary and secondary sources. Primary nanoplastics include industrial nanopolymers, coatings, and cosmetic formulations, while secondary nanoplastics are generated through the fragmentation of larger plastics driven by ultraviolet radiation, thermal degradation, and microbial activity (Gigault et al., 2018; Lambert & Wagner, 2016). Emerging sources such as tire wear particles, synthetic textiles, food packaging degradation, and indoor dust have also been identified as significant contributors (Kole et al., 2017; Vianello et al., 2019).

Human Exposure Pathways

Human exposure occurs primarily through ingestion, inhalation, and dermal contact (Prata, 2018; Cox et al., 2019; Li et al., 2023). Microplastics are frequently detected in food, drinking water, and airborne particles (Schwabl et al., 2019; Wright & Kelly, 2017). Nanoplastics, however, pose a greater concern due to their ability to penetrate biological barriers such as the intestinal epithelium and alveolar membranes (Koelmans et al., 2022; Sharma et al., 2023). Their presence in human tissues such as placenta and blood further supports systemic exposure and potential bioaccumulation (Leslie et al., 2022; Ragusa et al., 2021; Bhattacharyya et al., 2025). A conceptual overview of nanoplastic pathways in the human body is presented in Figure 1.

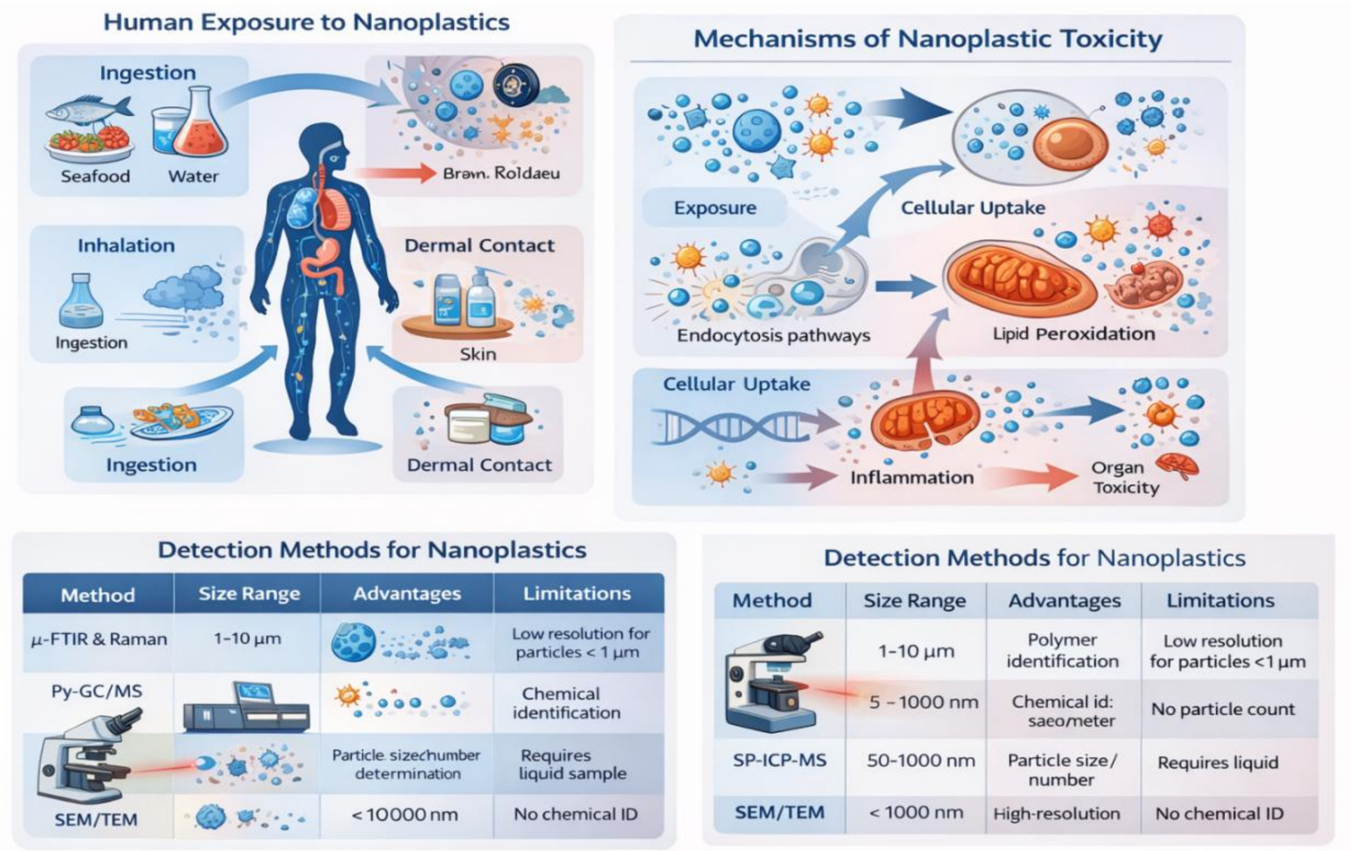

Fig. 1: Pathways of Nanoplastics from environmental sources to human exposure, distribution, cellular interaction, and associated health effects.

Comparative Toxicity: Microplastics vs Nanoplastics

Microplastics primarily induce physical effects such as tissue irritation and localized inflammation and can act as vectors for chemical contaminants (Wright & Kelly, 2017; Rochman et al., 2019). In contrast, nanoplastics demonstrate enhanced cellular uptake via endocytosis and can interact directly with proteins, lipids, and DNA (Yong et al., 2020). These interactions lead to oxidative stress, mitochondrial dysfunction, and genotoxic effects, indicating a shift toward molecular-level toxicity (Jin et al., 2019; Koelmans et al., 2022). A comparative summary of microplastics and nanoplastics is provided in **Table 2.**

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue V, May 2026

Parameter	Microplastics (MPs)	Nanoplastics (NPs)
Size	<5 mm	<1 µm
Origin	Primary & secondary	Mainly secondary (fragmentation)
Surface Area	Lower	Very high
Mobility	Moderate	High
Environmental Persistence	High	Very high
Biological Uptake	Limited	High (cellular/internal)
Cellular Interaction	Minimal	Direct interaction with biomolecules
Toxicity Type	Physical, inflammatory	Molecular, oxidative, genotoxic
Barrier Penetration	Limited	Can cross biological barriers
Detection Methods	FTIR, Raman	AFM-IR, NTA, advanced microscopy
Role as Pollutant Carrier	Yes	Enhanced due to high reactivity
Evidence Availability	Extensive	Emerging
Risk Level	Moderate	Potential High

Table 2: Comparative analysis of Microplastics and Nanoplastics highlighting differences in size, behaviour, toxicity and detection methods.

Analytical Challenges and Detection Methods

Detection of microplastics is commonly achieved using FTIR and Raman spectroscopy (Koelmans et al., 2022). However, nanoplastics remain difficult to detect due to their small size and low concentrations. Emerging techniques such as AFM-IR and nanoparticle tracking analysis are improving detection capabilities, yet the lack of standardized methodologies continues to limit comparability across studies (Shukla et al., 2024).

Mechanisms of Toxicity

Nanoplastics induce reactive oxygen species (ROS) production, leading to oxidative stress and inflammatory responses (Lu et al., 2018; Hirt & Body-Malapel, 2020; Thapliyal et al., 2025). They can also cause DNA damage and chromosomal instability, raising concerns regarding genotoxicity (Jin et al., 2019; Liu et al., 2025). Plastic-associated chemicals such as bisphenols and phthalates can disrupt endocrine function, with nanoplastics enhancing their bioavailability (Winiarska et al., 2024; Rochman et al., 2019). Additionally, nanoplastics have been shown to cross physiological barriers and accumulate in organs such as the liver and brain (Mattsson et al., 2017; Koelmans et al., 2022). Nanoplastics also act as carriers for co-contaminants such as heavy metals, persistent organic pollutants (POPs), and antibiotics, resulting in synergistic toxicity and increased bioavailability (Rochman et al., 2019; Guo et al., 2020).

Evidence from Human Studies

Recent studies have confirmed the presence of micro- and nanoplastics in human tissues, including blood, placenta, and feces (Leslie et al., 2022; Ragusa et al., 2021; Schwabl et al., 2019). Emerging epidemiological evidence suggests possible associations between microplastic exposure and cardiovascular diseases,

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue V, May 2026

inflammation, and metabolic disorders (Otorkpa et al., 2024; Sharma et al., 2023). Furthermore, inhalation of airborne microplastics has been linked to respiratory stress and lung inflammation, particularly in occupational settings (Prata, 2018; Dris et al., 2016). However, causal relationships remain unclear due to limitations in exposure quantification and variability in particle characteristics (Koelmans et al., 2022; EFSA, 2021).

Dose and Risk Assessment

Traditional mass-based metrics used for microplastics may not adequately reflect nanoplastic toxicity. Parameters such as particle number and surface area are more relevant for assessing risk (Koelmans et al., 2022). However, variability in particle characteristics and lack of standardized methods contribute to uncertainty in risk assessment (Singh et al., 2025).

Vulnerable Populations

Fetuses, infants, and occupationally exposed individuals are particularly vulnerable due to higher exposure levels and physiological sensitivity (Bhattacharyya et al., 2025).

Research Priorities

A significant limitation in current nanoplastic research is the reliance on laboratory conditions that may not accurately reflect environmentally relevant exposure levels. Many studies employ high concentrations and pristine particles, potentially overestimating toxicity compared to aged and weathered nanoplastics encountered in real-world scenarios. Future research should emphasize standardized detection methods, long-term epidemiological studies, and realistic exposure assessments (WHO, 2019; EFSA, 2021).

CONCLUSION

Nanoplastics are emerging as a critical concern in environmental health due to their nanoscale size, high reactivity, and ability to penetrate biological systems. Compared to microplastics, which primarily induce physical and carrier-mediated effects, nanoplastics exhibit enhanced cellular uptake and molecular-level interactions, leading to oxidative stress, inflammation, and potential genotoxic and endocrine-disrupting effects (Koelmans et al., 2022; Yong et al., 2020). The detection of plastic particles in human tissues such as blood and placenta highlights the reality of systemic exposure and raises concerns regarding long-term health implications (Leslie et al., 2022; Ragusa et al., 2021). However, uncertainties persist due to limited real-world exposure data and lack of standardized analytical methods. Future research should prioritize realistic exposure assessments, long-term epidemiological studies, and harmonized detection techniques. Addressing nanoplastic pollution will require coordinated scientific efforts and policy interventions focused on reducing plastic production and improving waste management to mitigate potential risks to human health.

REFERENCES

1. Andrady, A. L. (2017). The plastic in microplastics: A review. *Marine Pollution Bulletin*, *119*, 12–22.
2. Besseling, E., et al. (2017). Effects of microplastic on ecosystems. *Environmental Science & Technology, 51*, 12336–12343.
3. Bhattacharyya, S., et al. (2025). Nanoplastics in human systems. *Environmental Science & Technology*.
4. Cai, L., et al. (2017). Characterization of microplastics in indoor dust. *Environmental Pollution, 221*, 141–149.
5. Cox, K. D., et al. (2019). Human consumption of microplastics. *Environmental Science & Technology*, *53*, 7068–7074.
6. Da Costa, J. P., et al. (2016). Microplastics in the environment. *Marine Pollution Bulletin, 113*, 5–15.
7. Dris, R., et al. (2016). Synthetic fibers in the atmosphere. *Environmental Science & Technology*, *50*, 339–344.
8. European Food Safety Authority. (2021). Microplastics in food. *EFSA Journal*.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue V, May 2026

9. Gewert, B., et al. (2015). Degradation of plastics. *Marine Pollution Bulletin, 85*, 352–364.
10. Geyer, R., et al. (2017). Production, use, and fate of all plastics ever made. *Science Advances, 3*, e1700782.
11. Gigault, J., et al. (2018). Current opinion: What is a nanoplastic? *Environmental Pollution, 235*, 1030–1034.
12. Guo, X., & Wang, J. (2019). The chemical behaviors of microplastics in marine environment: A review. *Marine Pollution Bulletin, 142*, 1–10.
13. Guo, X., et al. (2020). Interaction of microplastics with pollutants. *Journal of Hazardous Materials, 400*, 123–456.
14. Hernandez, L. M., et al. (2017). Plastic weathering and degradation. *Environmental Science & Technology*.
15. Hirt, N., & Body-Malapel, M. (2020). Immunotoxicity and intestinal effects of microplastics. *Environmental Science & Technology*.
16. Jin, Y., et al. (2019). Toxic effects of microplastics. *Environmental Pollution*.
17. Koelmans, A. A., et al. (2022). Microplastics and nanoplastics in the environment: Risk assessment. *Nature Reviews Materials*.
18. Kole, P. J., et al. (2017). Wear and tear of tyres: A stealthy source of microplastics. *International Journal of Environmental Research and Public Health*.
19. Lambert, S., & Wagner, M. (2016). Formation of microscopic particles during the degradation of different polymers. *Science of the Total Environment*.
20. Leslie, H. A., et al. (2022). Discovery and quantification of plastic particle pollution in human blood. *Environment International*.
21. Li, D., et al. (2023). Human exposure pathways of microplastics and nanoplastics. *Environmental Research*.
22. Liu, G., et al. (2025). Nanoplastics and DNA damage. *Journal of Hazardous Materials*.
23. Lu, L., et al. (2018). Oxidative stress induced by nanoplastics. *Environmental Science: Nano*.
24. Mattsson, K., et al. (2017). Brain accumulation of nanoplastics. *Environmental Science & Technology*.
25. Nihart, A. J., et al. (2025). Human exposure to nanoplastics: A review. *Environmental Research Letters*.
26. Otorkpa, E., et al. (2024). Health impacts of nanoplastics. *Science of the Total Environment*.
27. Prata, J. C. (2018). Airborne microplastics: Consequences to human health? *Environmental Pollution*.
28. Ragusa, A., et al. (2021). Plasticenta: First evidence of microplastics in human placenta. *Environment International*.
29. Rochman, C. M., et al. (2019). Microplastics as vectors for environmental contaminants. *Nature Ecology & Evolution*.
30. Schwabl, P., et al. (2019). Detection of microplastics in human stool. *Annals of Internal Medicine*.
31. Sharma, S., et al. (2023). Nanoplastics toxicity in biological systems. *Environmental Research*.
32. Shukla, S., et al. (2024). Detection challenges of nanoplastics. *Analytical Chemistry*.
33. Singh, N., et al. (2025). Environmental transport of microplastics and nanoplastics. *Environmental Science & Technology*.
34. Thapliyal, P., et al. (2025). Reactive oxygen species mechanisms in nanoplastic toxicity. *Chemosphere*.
35. Vianello, A., et al. (2019). Simulating human exposure to indoor airborne microplastics. *Environmental Science & Technology*.
36. Winiarska, K., et al. (2024). Endocrine disruption caused by nanoplastics. *Toxicology Letters*.
37. Wright, S. L., & Kelly, F. J. (2017). Plastic and human health: A micro issue? *Environmental Science & Technology*.
38. Yong, C. Q. Y., et al. (2020). Nanoplastics and their interactions with biological systems. *Environmental Pollution*.
39. Zhang, Q., et al. (2020). Distribution of microplastics in the environment. *Water Research*.