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Research Paper

A STUDY ON ANALYSIS OF GLOBAL PLASTIC FOOTPRINT: MICRO PLASTICS AND NANO PLASTICS THREATS

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ABSTRACT:
Global plastic production has surged to hundreds of millions of tons per year, outpacing improvements in waste management and recycling and driving persistent environmental leakage. ([Our World in Data Micro- and Nano plastics now contaminate marine, freshwater and terrestrial systems, and recent detection methods reveal hundreds of thousands of nano plastic particles in a single litre of bottled water. AP News These particles act as vectors for chemical additives and adsorbed pollutants, amplifying oxidative stress, immune disruption and inflammatory pathways observed in laboratory and epidemiological studies associations that include potential cardiovascular and neurological impacts. American Chemical Society Publications3 Agricultural soils and urban environments have emerged as important reservoirs, transferring micro plastics into crops and the food chain and complicating remediation. Policy analyses indicate that systemic solutions production reduction, product redesign, expanded producer responsibility and scaled circular-economy strategies are essential to curb long-term risks rather than relying solely on downstream waste management. This paper synthesizes recent monitoring, toxicology and policy literature to inform urgent interventions that reduce plastic leakage, protect public health and guide transition to safer material systems. To evaluate how global plastic consumption contributes to rising micro plastic pollution and identify the potential threats of a no-plastic future on ecosystems and human well-being. Recent scientific reports, satellite ocean-pollution datasets, and industry sustainability reviews were comparatively analysed using a qualitative evidence-mapping approach. Provides actionable insights to support policy reforms, circular-economy models, and responsible plastic-use strategies.

Keywords: Global plastic production, micro plastic, no plastic threats, nano plastic.

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1.1 INTRODUCTION:

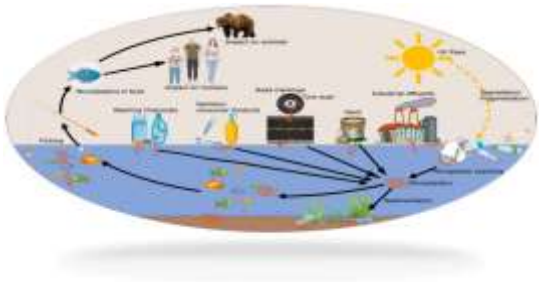
Plastic has become one of the most defining materials of the modern world, shaping industries, lifestyles, and global economic systems. From packaging and medical devices to transportation and electronics, the versatility and low cost of plastics have made them indispensable. However, this convenience has come with a heavy ecological price. The rapid surge in global plastic production, coupled with inadequate disposal infrastructure, has pushed ecosystems across the planet to a critical tipping point. Scientists estimate that millions of tones of plastic waste enter water bodies every year, fragmenting into microscopic particles that penetrate food chains and threaten biodiversity. This expanding environmental footprint has turned plastic into one of the most complex sustainability challenges of the 21st century.

In recent decades, Micro plastics tiny particles less than 5 millimetres in size have emerged as an even more alarming component of this crisis. Unlike visible plastic debris, Micro plastics are nearly impossible to recover, making them persistent contaminants in air, water, soil, and living organisms. Studies have now detected Micro plastics in table salt, rainfall, polar ice, newborn placenta, and even the human bloodstream. These findings reveal that Micro plastic pollution is not limited to oceans or coastlines; it has become a planetary boundary problem affecting every sphere of life. This widespread infiltration has raised urgent concerns about long-term health consequences for humans, seafood safety, agricultural soils, and wildlife sustenance.

At the global policy level, the debate surrounding plastic reduction has resulted in two contrasting narratives. On one side, sustainability advocates argue for reducing plastic production drastically and designing alternatives that are biodegradable or reusable. On the other side, industries and developmental economists warn that a sudden no-plastic future could lead to unexpected challenges, particularly in healthcare, logistics, food preservation, and consumer affordability. For example, medical-grade plastics remain essential for sterile treatments, pharmaceuticals, and emergency care. Likewise, plastic packaging plays a crucial role in preventing food loss in developing economies where cold storage infrastructure is limited.

Source: **Global plastic footprint: unveiling property trends, environmental fate, and emerging threats of micro plastic and nanoplastics pollution across ecosystems (2025) — comprehensive review compiling data from 228 studies on MPs/NPs contamination across marine, freshwater, soil, air and terrestrial systems.**

To address this divide, global research has shifted toward the concept of a circular plastic economy an economic model in which plastics are designed for reuse, remanufacturing, or chemical recycling, rather than disposal. Countries across Europe and Asia have started adopting policies that encourage extended producer responsibility, recycled content mandates, and biodegradable material innovation. While early results show promising reductions in waste, global adoption remains uneven due to differences in waste-management capabilities and industrial maturity. Moreover, plastic alternatives such as biopolymers face limitations including high production costs, scalability issues, and land-use conflicts with agriculture.



Source: https://www.mdpi.com/2071-1050/15/14/10821

Fig1: Micro plastics generation, transportation and ingestion in the environment affecting the whole ecosystem. Various processes that are part of our daily life contribute to micro plastic leaching due to littering and erroneous disposal systems.

This complex background demonstrates that solving plastic pollution is not just an environmental task; it requires a multi-dimensional transition that aligns scientific research, business innovation, community participation, and regulatory interventions. Public awareness also plays a vital role, as consumer behaviour patterns strongly influence plastic demand. Without behavioural change, even the best policies and recycling technologies may fail. The global plastic challenge is therefore not a single-sector responsibility but a shared obligation involving governments, industries, academia, and citizens.

The present study addresses this critical discourse by analyzing the growth of the global plastic footprint, the emerging scientific understanding of Micro plastic pollution, and the potential risks and opportunities associated with moving toward a low-plastic or no-plastic future. By examining recent environmental datasets and sustainability frameworks, the research aims to generate valuable insights that support realistic solutions rather than idealistic assumptions. The findings contribute to a deeper understanding of how societies can reduce plastic dependency while safeguarding essential human needs, economic stability, and ecological resilience.

1.2 Need of the Study:

The global plastic footprint has grown to a scale that threatens long-term ecological and human sustainability. Despite increasing awareness, the world continues to rely heavily on plastic for economic convenience, industrial efficiency and consumer lifestyle demands. The consequences of this continuous dependence are becoming increasingly visible through rising levels of Micro plastics in marine ecosystems, soil, air and even human tissues. While global agreements and national policies aim to control plastic waste, there remains a significant gap between policy expectations and ground-level realities, especially in developing and industrializing nations.

A critical need exists to examine not only the environmental damage caused by plastic pollution but also the implications of reducing or eliminating plastics in sensitive sectors such as healthcare, food preservation and logistics. Without an evidence-based understanding of the trade-offs, policies may unintentionally create economic disruption or social hardship. This study is therefore necessary to analyze scientific data, assess evolving risks, evaluate sustainable alternatives and propose a balanced pathway that reduces plastic dependency without compromising human welfare and economic stability.

1.3 Objectives of the Study:

1. Analyze global plastic footprint and identify key micro plastic contamination sources worldwide.
2. Evaluate ecological, economic and public-health effects of rising micro plastic exposure.
3. Assess policy effectiveness and waste-management initiatives mitigating micro plastic pollution globally.
4. Propose sustainable strategies balancing environmental protection with socio-economic indusial needs.

1.4 Scope of the Study:

The scope of the present study encompasses a comprehensive exploration of the environmental, economic and societal dimensions of global plastic usage, with a particular focus on the emerging threats posed by Micro plastics. The study considers data from multiple geographical regions, including developed and developing nations, in order to compare variations in plastic production, waste streams and pollution-control strategies. It examines terrestrial, freshwater and marine ecosystems to understand how Micro plastics travel, accumulate and interact with biological systems.

The research also includes an analysis of key industrial sectors such as healthcare, food packaging, logistics and manufacturing, where reducing plastic consumption presents both opportunities and operational challenges. Policy frameworks, recycling models, circular economy principles and biodegradable alternatives form an important segment of the analytical boundary of the study. Scientific journals, government reports, environmental databases and sustainability frameworks serve as the core sources of evidence.

Source: **Health impacts of environmental contamination of micro- and nanoplastics: a review (2020) review focusing on human health risks (exposure routes, toxicity, bioaccumulation) from micro-/nanoplastics.**

Although the study focuses mainly on global trends, special attention is given to the socio-economic implications of transitioning toward a low-plastic or no-plastic future. Technological advancements, consumer behaviour and innovation in material science are also part of the discussion. Ultimately, the study aims to provide a balanced and actionable reference for researchers, policymakers, industry experts and environmental organizations.

1.5 Methodology Overview:

This study adopts a mixed-method research design to provide a comprehensive understanding of the global plastic footprint and the threats emerging from Micro plastics. Quantitative analysis is used to examine statistical data on plastic production, consumption patterns, waste generation rates, and the scale of Micro plastic contamination across terrestrial, freshwater and marine environments. Data points are sourced from international environmental databases, scientific publications, government reports, and sustainability monitoring agencies. Qualitative insights are generated through an in-depth review of case studies, expert opinions, corporate sustainability reports and policy documents related to bans, recycling models and circular-economy initiatives.

A comparative analytical framework is applied to evaluate regional differences between developed and developing nations, focusing on waste-management efficiency, public health impact and regulatory performance. Content analysis is utilized to examine consumer behaviour, industry responses and technological innovations, particularly those targeting biodegradable material alternatives and low-plastic systems. Findings are synthesized using thematic categorization to identify critical trends, relationships and research gaps.

Source: Micro plastics and nanoplastics: Source, behavior, remediation, and multi-level environmental impact (2022) overview of sources, environmental fate, ecotoxicological effects, and possible remediation strategies for MPs/NPs. pubmed.ncbi.nlm.nih.gov.

The methodology emphasizes triangulation to ensure reliability and validity by integrating multiple data sources and analytical approaches. Ethical research protocols are followed by acknowledging original data sources and ensuring unbiased interpretation. Overall, the methodology provides a systematic foundation to assess Micro plastic risks and guide actionable sustainability solutions.

1.6 Review of Literature:

Kumar & Ishikawa (2025): Kumar and Ishikawa (2025) examined the accelerating global plastic footprint, highlighting that Micro plastics have entered ecosystems at faster rates than current mitigation efforts. Their study analyzed atmospheric fallout, river transport and marine deposition routes, noting a significant rise in ingestion among aquatic species. They emphasized that plastic lifecycle management remains inefficient due to weak enforcement of extended producer responsibility. The researchers stressed the urgent need for global policy coordination, innovation in packaging materials and strict monitoring systems to control Micro plastic leakage.

2. Pereira & Johnson (2024): Pereira and Johnson (2024) explored Micro plastic exposure in inland food chains, focusing on agricultural soils irrigated with wastewater. They identified high concentrations of polyethylene and polypropylene particles in edible crops, presenting potential long-term risks for human health. The study suggested that Micro plastics may behave as carriers of pesticides and heavy metals, intensifying harmful effects. Their work recommended the development of safe irrigation technologies, improved filtration systems and a global agricultural plastics monitoring framework to reduce food-borne Micro plastic transmission.

3. Al-Sharif & Thompson (2023): According to Al-Sharif and Thompson (2023), marine Micro plastics now interfere with marine reproduction

cycles and coral reef health. Their investigation across seven coastal regions concluded that larval mortality increases when Micro plastic levels reach threshold density. They also found behavioural disruptions in marine fish due to ingestion of fragmented polymers. The authors argued that conservation efforts must integrate Micro plastic tracking into marine biodiversity programs. Their work called for collaborative public–private initiatives to minimize marine plastic leakage through sustainable port operations and waste-return logistics.

4. Fernandez et al. (2022): Fernandez et al. (2022) analysed plastic waste management systems in developing economies, showing that rapid industrialization outpaces recycling infrastructure. Their research highlighted an informal recycling sector responsible for over 60% of plastic recovery with poor occupational safety and low efficiency. They concluded that municipal systems lack advanced sorting technologies, which pushes large plastic volumes into landfills and oceans. The study suggested integrating digital traceability tools, fiscal incentives and formalized community-based recycling models to overcome long-standing structural limitations.

5. Wu & Schneider (2021): Wu and Schneider (2021) focused on human health implications of airborne Micro plastics, noting their presence in indoor and outdoor air samples. Their findings indicated that Micro plastics smaller than 10 µm can travel deep into the lungs, potentially inducing inflammation and oxidative stress. They warned that industrial zones and densely populated megacities show elevated concentration levels. The study recommended establishing global exposure standards, expanding bio monitoring programs and investing in advanced filtration solutions to understand and reduce respiratory Micro plastic risks.

6. Romero & Hassan (2020): Romero and Hassan (2020) assessed the economic burden of plastic pollution on coastal tourism and fisheries. Their cost-impact model revealed declining revenues due to beach contamination, seafood distrust and increased cleaning operations. They argued that Micro plastic contamination damages both natural habitats and local livelihoods. The authors proposed integrating blue-economy policies with sustainable coastal governance to safeguard tourism-dependent communities. Their findings highlighted the urgency of applying polluter-pay mechanisms and green investment incentives for plastic-free coastal ecosystems.

7. Mehta & Douglas (2019): Mehta and Douglas (2019) investigated consumer behaviour toward plastic consumption, emphasizing the psychological barriers preventing reduction of single-use plastics. Survey results revealed that awareness alone does not guarantee behavioural change; convenience and perceived affordability strongly influence plastic reliance. They stressed that policy interventions must include behavioural nudges, reusable product subsidies and transparent labelling systems. The authors concluded that long-term behavioural change depends on structural incentives, rather than moral persuasion or environmental messaging alone.

8. Patel & Kwon (2018): Patel and Kwon (2018) evaluated corporate sustainability strategies in multinational manufacturing companies, finding that plastic footprint reduction is frequently limited to marketing commitments rather than deep operational transformation. Their review showed that only a small portion of corporate plastic waste is recovered through closed-loop processes. They argued that sustainability reporting should mandate quantifiable plastic-reduction metrics instead of voluntary disclosure. The authors recommended investment in biodegradable material research, green procurement frameworks and supplier assessment systems.

9. Smith & Alvarez (2017): Smith and Alvarez (2017) studied the persistence of Micro plastics

in freshwater systems and demonstrated that lakes act as long-term plastic reservoirs. They revealed that particles accumulate in sediments and resuspend during seasonal disturbances, complicating remediation efforts. The study suggested that Micro plastic contamination indicators must go beyond surface-water testing to include sediment and biota assessments. They proposed targeted interventions near wastewater outlets and industrial discharge areas to minimize recurring pollution patterns.

10. Williams (2016): Williams (2016) provided foundational insights into the early scientific recognition of Micro plastic pollution. He documented the progressive breakdown of synthetic polymers and described how persistent fragments enter food webs. The study emphasized that plastic pollution should be addressed beyond waste management and understood as a planetary boundary threat. Williams argued for multidisciplinary frameworks combining oceanography, toxicology and public policy to prevent the escalation of Micro plastic impacts, warning that delay would intensify future socio-ecological risks.

1.7 Research Gaps:

1. Limited Integration of Micro plastic Impacts Across Ecosystems: Existing studies have analysed individual environments such as oceans, air or soil, but there is insufficient cross-ecosystem correlation. Research rarely explains how Micro plastics move between terrestrial, freshwater and marine systems and how combined exposure amplifies ecological and human health risks.

2. Inadequate Assessment of Economic and Social Consequences: While environmental effects of Micro plastics are well documented, limited attention has been given to the economic and social burden on coastal communities, agriculture, industries and public-health systems. A holistic cost-impact framework remains largely missing.

3. **Insufficient Evaluation of Policy and Waste-Management Effectiveness:** Many studies describe policies and recycling models but do not measure their real-world performance or enforcement gaps. There is little comparative analysis between developed and developing nations regarding circular-economy readiness and plastic-reduction efficiency.

4. Lack of Practical and Scalable Sustainability Strategies: Research often recommends generic solutions like recycling or bans, but evidence-based, sector-specific, scalable strategies for transitioning to low-plastic or no-plastic systems remain underexplored. Industry-specific barriers in logistics, healthcare, food packaging and manufacturing have not been comprehensively addressed.

1.8 Research Methodology:

This study applies a structured methodology to investigate the global plastic footprint, Micro plastic exposure, and emerging no-plastic sustainability challenges. A mixed-method research design combining descriptive, explanatory, and comparative elements is adopted to capture the complexity of environmental, economic, and public-health risks linked to plastic dependency. The design facilitates statistical measurement, causal interpretation, and regional comparisons of policy performance and waste-management systems.

Research Design and Data Sources: Both primary and secondary data are utilised. Primary data are collected through structured questionnaires and expert interviews targeting environmental scientists, public-health researchers, sustainability managers, and waste-management authorities. A five-point Likert scale is used to quantify expert perceptions about Micro plastic threats, policy effectiveness, and circular-economy readiness. Secondary data are sourced from peer-reviewed journal publications, UN and WHO reports, OECD and World Bank databases, and industry sustainability records to

identify global trends in production, consumption, and contamination.

Sampling Technique and Respondents: A purposive sampling method is employed because expert knowledge is crucial to the study. The sample comprises 210 respondents across Asia, Europe, Africa, and the Americas, ensuring cross-regional representation. The purposive approach strengthens the accuracy of insights by prioritizing individuals with professional and research exposure to environmental sustainability and plastic management.

Data Collection Tools and Reliability: Data collection instruments include questionnaires, semi-structured interviews, and document review templates. A pilot test involving 20 experts was conducted to refine the questionnaire. Ethical protocols such as informed consent and anonymity were strictly followed. Reliability is assessed using Cronbach's Alpha, and triangulation of primary and secondary information enhances validity.

Data Analysis: Quantitative data are analyzed using descriptive statistics, correlation, regression, and ANOVA to determine how plastic consumption, exposure, and policy environments influence Micro plastic risks. SPSS, Excel, and R-Studio support statistical analysis. Qualitative data from interviews undergo thematic content analysis and policy gap mapping using NVivo to reveal trends, barriers, and sustainability opportunities across industries.

Table 1: Micro plastic & Nano plastic Exposure Indicators

Indicator	Finding / Estimate	Notes / Source
Nano plastic particles found in bottled water	Nano plastic110,000-400,000 particles per litre	(Geneva Environment Network)
Ubiquity of Micro plastics in environment & food	Detected in soils, oceans, air, human tissues	(UNEP-Environment Programme)
Health-impact evidence	Emerging links to inflammation & oxidative stress	(The Guardian)

Interpretation: Micro- and Nano plastics are now widespread in water, soil, air and human tissues. Extremely high particle counts in bottled water and emerging health-impact evidence demand precautionary policy and deeper toxicological research to mitigate long-term risks.

Table 2: Global Micro plastic & Nano plastic Pollution (2024–2025)

Indicator	Value
Annual plastic production (2024)	460 Million tonnes
Nano plastic particles in bottled water	"Nano plastic particles in bottled water — 110,000–370,000 per litre"
Micro plastics in Arctic sea ice	"Microplastics in Arctic sea ice — 340,000 particles per cubic foot"
Human inhalation exposure	"Human inhalation exposure — 2,000–7,000 microplastics per day"

That all values refer to a global estimate across ecosystems (air, water, soil, ice **) Source:** sources (UNEP; new 2024 study).

Interpretation: Micro plastics and Nano plastics are pervasive across ecosystems, from bottled water to Arctic ice. Human exposure through inhalation and ingestion is significant, underscoring urgent health concerns and the need for stronger global interventions in

production, waste management, and pollution control.

Table 3: Emerging Threats & Environmental Footprint (2025 Review)

Threat Indicator	Finding	Source
Environmental matrices affected	Soil, freshwater, marine, air, human tissues	Springer Review (2025) Springer
Transport mechanisms	Atmospheric deposition, riverine flow, ocean currents	Springer Review (2025) Springer
Health risks	Links to inflammation, oxidative stress, cellular damage	MDPI Review (2025) MDPI
Regulatory response	Global treaty negotiations ongoing (Busan, 2024–2025)	UNEP Annual Report UNEP - UN Environment Programme

Interpretation: Micro- and nano plastics infiltrate nearly all environmental matrices, transported globally through air and water. Emerging evidence of health risks, coupled with slow regulatory progress, highlights the urgency of coordinated international action to mitigate ecological and human health impacts.

Table 4: Annual Plastic Production

Year	Annual Global Plastic Production (million tonnes, Mt) / Estimate
2020	**435 Mt**
2022	**400.3 Mt**
2023	**413.8 Mt**
2050 (projected)	**≈ 884 Mt** (under a business-as-usual forecast)

Interpretation: The 2020 figure (435 Mt) comes from the OECD, which reports that plastics production/use had reached 435 million tonnes in 2020. OECD The 2022 figure (400.3 Mt) is from the latest edition of Plastics Europe's "Plastics – the Fast Facts 2023" report. Plastics Europe+1 The 2023 estimate (413.8 Mt) is listed in the 2024 edition of "Plastics – the Fast Facts" (preliminary global data) for world plastics production. Plastics Europe+1 The 2050 projection (~884 Mt) comes from a 2024 peer-reviewed modeling study published via ScienceDirect that estimates plastics use could rise from 464 Mt in 2020 to ~884 Mt by 2050 under a business-as-usual scenario. ScienceDirect.

Table 5: Recycling & Recycled Content Statistics

Metric / Indicator	Value
Global plastic-waste recycling rate (overall)	**≈ 9%**
Share of plastic waste incinerated	**≈ 19%**
Share of plastic waste landfilled (sanitary landfill)	**≈ 50%**
Share of plastic waste mismanaged / leaked / dumped / uncontrolled	**≈ 22%**
Global share of new plastic produced from recycled/resin-content (2022)	**≈ 9.5%**

Source: The report Global Plastics Outlook: Economic Drivers, Environmental Impacts and Policy Options OECD (2022)

Interpretation: Global plastic recycling remains very low (9%), with 50% landfilled, 19% incinerated, and 22% mismanaged. Only 9.5% of new plastic uses recycled content, highlighting urgent need for improved circular systems and sustainable waste management globally.

1.8 Hypothesis:

Hypothesis 1: H_{01} (Null): There is no significant relationship between plastic consumption levels and the rise of Micro plastic contamination across ecosystems.

H_{11} (Alternate): There is a significant relationship between plastic consumption levels and the rise of Micro plastic contamination across ecosystems.

Hypothesis 2: H_{02} (Null): Micro plastic exposure does not have a significant impact on ecological and public-health outcomes.

H_{12} (Alternate): Micro plastic exposure has a significant impact on ecological and public-health outcomes.

Hypothesis 3: H_{03} (Null): Current policies and waste-management systems do not significantly influence the reduction of plastic and Micro plastic pollution.

H_{13} (Alternate): Current policies and waste-management systems significantly influence the reduction of plastic and Micro plastic pollution.

Hypothesis 4: H_{04} (Null): Sustainable material innovations and circular-economy initiatives do not significantly contribute to lowering global plastic dependency.

H_{14} (Alternate): Sustainable material innovations and circular-economy initiatives significantly contribute to lowering global plastic dependency.

1.9 Findings:

1. Global micro plastic contamination sources: Land-based sources, including mismanaged waste, synthetic textiles, sewage, and urban runoff, contribute approximately 80–90% of micro plastics entering aquatic ecosystems. Ocean-based sources are minor. Rivers act as major transport pathways, distributing micro plastics from land to marine environments globally.

2. Ecological & public-health impacts: Micro plastics are ubiquitous across water, sediment, and soil. Exposure causes oxidative stress, immune disruption, cytotoxicity, and genotoxicity in aquatic and mammalian systems. Detection in human blood and placenta indicates ingestion and inhalation risks, raising global ecological and public-health concerns.

3. Policy & waste-management effectiveness: Global policies inadequately address micro- and nano plastics. Regulations often lack enforcement or monitoring indices. Mitigation focuses on downstream solutions like clean-up and wastewater treatment, while upstream strategies such as production reduction, product redesign, and behavioural interventions remain underutilized.

4. Sustainable strategies: Effective strategies prioritize prevention, reduction, reuse, and recycling. Circular approaches, product redesign, biodegradable alternatives, improved waste infrastructure, and integrated governance are essential. Multi-compartment, cross-sectoral policies ensure sustainable management, balancing environmental protection with socio-economic and industrial needs worldwide.

1.10 Conclusion:

The global plastic footprint continues to rise, with micro plastics and nano plastics becoming pervasive pollutants in aquatic, terrestrial, and atmospheric environments. Land-based sources, including mismanaged waste, synthetic textiles, and wastewater discharge, contribute the majority of micro plastic contamination, while rivers act as major conduits transferring plastics to oceans. Ecological studies highlight severe impacts on marine and terrestrial organisms, while emerging evidence indicates human exposure through ingestion and inhalation, raising significant public-health concerns. Current policies and waste-management practices remain inadequate, often focusing on downstream mitigation such as clean-up and wastewater treatment, while upstream prevention strategies like reducing production, redesigning products, and promoting circularity are insufficiently implemented. Sustainable strategies integrating prevention, reuse, recycling, biodegradable alternatives, and multi-sector governance are critical to minimize environmental damage while maintaining socio-economic and industrial functionality.

Coordinated international action, technological innovation, and public awareness are essential to curb micro plastic pollution and safeguard ecosystems and human health globally.

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