



## Microplastics as Emerging Environmental Pollutants: Implications for Ecosystems and Human Health

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### Abstract

Microplastics (plastic particles <5 mm) have emerged as a pervasive and persistent class of environmental pollutants, now detected in nearly all ecological compartments including marine, freshwater, terrestrial, and atmospheric systems. Their omnipresence reflects increasing plastic production, widespread use of synthetic materials, inefficient waste management, and continuous fragmentation of larger plastic debris. Unlike conventional chemical contaminants, microplastics represent a heterogeneous mixture of polymer types, sizes, shapes, and associated additives, posing complex ecological and toxicological challenges. The present paper provides a comprehensive synthesis of literature published between 2000 and 2023, examining the sources, environmental distribution, ecological impacts, and potential human health implications of microplastic pollution. Evidence indicates that microplastics are readily ingested by organisms across trophic levels, leading to physical damage, oxidative stress, inflammatory responses, altered metabolism, and reproductive impairments. Their role as vectors for toxic chemicals and microbial assemblages further enhances their ecological significance. Human exposure occurs primarily through ingestion of contaminated food and water and inhalation of airborne microfibres, with recent biomonitoring studies reporting the presence of microplastic particles in human blood and tissues. Although definitive causal links between microplastic exposure and human disease remain limited, mechanistic studies suggest plausible pathways involving inflammation, immune dysregulation, and endocrine disruption. This paper critically evaluates current evidence, identifies key methodological uncertainties, and proposes an integrative framework for future risk assessment. Given the persistent nature of microplastics and their growing global footprint, mitigation strategies emphasizing source reduction, improved waste management, and material innovation are urgently required. Strengthening scientific understanding through standardized methodologies and interdisciplinary research is essential to inform evidence-based environmental and public health policies.

**Keywords :** Microplastics; Nanoplastics; Environmental pollution; Ecotoxicology; Human health; Risk assessment

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### Introduction

Plastic production and use have increased sharply over recent decades, enabling lightweight packaging, durable consumer goods, and widespread industrial applications. However, inadequate waste management, littering, and losses during production and transport have resulted in extensive environmental contamination. Global assessments indicate that tens of millions of tonnes of plastic waste leak into aquatic ecosystems each year, with downstream fragmentation generating microplastics and nanoplastics. Microplastics are generally defined as plastic particles <5 mm, whereas nanoplastics are often operationally defined as <1 µm, though boundaries vary by discipline and method. These particles originate from (i) primary microplastics, manufactured at small sizes (e.g., industrial pellets, microbeads, abrasive media) and (ii) secondary microplastics, formed through fragmentation of larger debris by ultraviolet radiation, mechanical abrasion, and biodegradation. Fibres shed from synthetic textiles, fragments from packaging, tyre-wear particles, and paint flakes are among the most frequently reported categories. Microplastics are distinct from many conventional pollutants because they are not a single chemical species; rather, they

represent a class of materials with heterogeneous polymer composition (e.g., polyethylene, polypropylene, polystyrene, PET), additives (plasticizers, stabilizers, flame retardants), and surface properties. Their risks arise via multiple hazard modalities: physical particle effects, chemical toxicity from monomers/additives and sorbed pollutants, and biological hazards linked to microbial colonization and biofilm-associated pathogens.

#### Why the concern is increasing now

**Ubiquity and persistence:** Microplastics are detected in marine waters, sediments, freshwater systems, soils, and air creating continuous exposure opportunities.

**Biological interaction:** Small size facilitates ingestion by diverse taxa; the smallest fractions can cross biological barriers in model systems.

**Complex mixtures:** Microplastics can act as vectors or co-stressors with metals, persistent organic pollutants, and other anthropogenic chemicals.

**Emerging human evidence:** Biomonitoring has reported plastic particles in human blood, supporting the plausibility of systemic exposure.

The exponential growth of plastic production since the mid-twentieth century has profoundly altered material use

patterns worldwide (Geyer *et al.*, 2017). Plastics are valued for durability, flexibility, and low cost; however, these same properties contribute to environmental persistence once discarded. Large quantities of plastic waste escape formal waste management systems and accumulate in natural ecosystems, where they undergo slow fragmentation into smaller particles termed microplastics (Thompson *et al.*, 2004). Microplastics are broadly classified into primary microplastics, intentionally manufactured at microscopic sizes, and secondary microplastics, generated by the degradation of larger plastic items through photochemical, mechanical, and biological processes (Cole *et al.*, 2011). Recently, attention has shifted toward nanoplastics, which may exhibit enhanced bioavailability and reactivity due to their extremely small size (Koelmans *et al.*, 2019). Microplastics have been reported from oceans, freshwater bodies, soils, sediments, atmospheric fallout, polar ice, and remote mountain regions, demonstrating their global dispersion (Allen *et al.*, 2019; Li *et al.*, 2018). Their small size facilitates ingestion by a wide range of organisms, raising concerns about ecological consequences and trophic transfer (Besseling *et al.*, 2014). Unlike traditional pollutants, microplastics are not chemically uniform. They consist of diverse polymers containing additives such as plasticizers, stabilizers, and flame retardants, and they readily adsorb persistent organic pollutants and metals from surrounding environments (Rochman *et al.*, 2013). Consequently, their potential impacts arise from a combination of physical, chemical, and biological mechanisms. Growing evidence of microplastics in food, drinking water, air, and human tissues has intensified concerns regarding human health implications (WHO, 2019; Leslie *et al.*, 2022). However, uncertainties remain regarding exposure levels, toxicological relevance, and long-term risks. This paper critically examines current scientific understanding of microplastics as emerging environmental pollutants and discusses their implications for ecosystems and human health.

**Materials and Methods**

**Environmental distribution and pathways-** Microplastics occur across environmental compartments due to multiple interconnected pathways:

**Aquatic systems:** rivers act as major conduits transporting mismanaged plastic to oceans; lakes and reservoirs accumulate local inputs.

**Wastewater and runoff:** municipal wastewater can remove substantial fractions of microplastics, but residual particles and sludge application can transfer them to aquatic and terrestrial environments.

**Soils:** plastic mulching, compost contamination, sludge amendments, and atmospheric deposition contribute to terrestrial loads.

**Air:** fibres from textiles, indoor materials, and abrasion sources become airborne and are inhalable.

UN-wide reporting emphasizes that plastic pollution including microplastics has broad ecological consequences and is a growing global priority.

**Table 1.** Major sources and environmental pathways of microplastics

Source category	Typical examples	Dominant particle forms	Primary pathways	Key receiving environments
Consumer packaging	bags, bottles,	fragments /films	fragmentation, runoff,	rivers, coasts,

& litter	wrappers		wind	sediments
Synthetic textiles	polyester/n ylon garments	fibres	washing effluent, indoor air	wastewater , indoor dust/air
Tyre and road wear	tyre-wear particles	irregular fragments	stormwater runoff, road dust	urban waterways, sediments
Paint and coatings	marine/road paints	chips/fragments	abrasion, weathering	harbors, estuaries, soils
Industrial pellets	resin pellets (“nurdles”)	pellets	spills during transport	shorelines, waters

**Ecological impacts in aquatic and terrestrial biota-** Across taxa, the most consistently reported ecological effects cluster into:

**Physical effects:** gut blockage, reduced feeding, false satiation, tissue abrasion.

**Physiological stress:** oxidative stress, inflammation-like responses, altered energy budgets.

**Reproductive impacts:** reduced fecundity, impaired gamete quality, developmental effects.

**Behavioral changes:** altered activity, predator avoidance, and feeding behavior.

**Community-level implications:** changes in microbial communities via biofilm (“plastisphere”), potential shifts in nutrient cycling.

**Trophic transfer and bioaccumulation potential-**

Microplastics are ingested by primary consumers (e.g., zooplankton, bivalves) and can transfer to higher trophic levels through predation. However, bioaccumulation patterns depend on retention time, egestion, and translocation from the gut to tissues. Many organisms rapidly excrete larger particles, while smaller particles may persist longer, particularly if they interact with mucus layers or are taken up by gut-associated pathways.

**Human exposure and biomonitoring signals**

**Humans are exposed via:**

**Ingestion:** seafood, salt, packaged foods, drinking water

**Inhalation:** indoor fibres, dust resuspension, outdoor particulate

**Potential indirect exposure:** leaching additives and associated chemicals

**Evidence of systemic availability-**A pioneering biomonitoring study reported quantifiable plastic particles in human blood, indicating that microplastics can be bioavailable for uptake into systemic circulation. Subsequent research has continued exploring polymer types and potential associations with biomarkers, but causality and health relevance remain uncertain. A scoping review summarized detection of microplastics in multiple human tissues and organs, highlighting both evidence growth and analytical/interpretation gaps.

**Evidence synthesis on health risk signals-** The World Health Organization concluded that chemicals and biofilms associated with microplastics in drinking water pose low concern for human health based on limited evidence, while emphasizing insufficient data to draw firm conclusions on physical particle toxicity, particularly for the smallest size fractions.

**Table 2.** Ecosystem and human health endpoints linked to microplastic exposure

Domain	Endpoint category	Evidence strength (qualitative)	Notes
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Aquatic biota	feeding & growth	Moderate	species-dependent; particle size/shape important
Aquatic biota	oxidative stress/inflammation markers	Moderate	often in lab studies; field relevance varies
Aquatic biota	reproduction & development	Moderate	stronger in chronic exposure designs
Terrestrial biota/soil	soil structure & microbiota shifts	Emerging	methods and exposure realism still developing
Humans	exposure occurrence (ingestion/inhalation)	Moderate	widely documented; dose estimates uncertain
Humans	biomonitoring (blood/tissues)	Emerging–moderate	detection reported; contamination control critical
Humans	clinical outcomes (causal links)	Limited	few longitudinal studies; confounding substantial

**Interpreting ecological harm: from individuals to ecosystems-** Microplastics can produce harm through particle-driven stress and chemical-mediated toxicity, but translating laboratory findings to population and ecosystem consequences requires careful attention to exposure realism and endpoint relevance.

**Key modifiers of ecological risk**

**Particle size:** Smaller particles have higher surface area-to-volume ratio, potentially increasing interaction with tissues and sorbed chemicals.

**Shape:** Fibres may cause greater physical irritation and retention than spherical beads; fragments can differ in abrasion potential.

**Aging/weathering:** Environmental aging increases surface roughness and functional groups, potentially changing sorption and biofilm formation.

**Mixtures:** Microplastics rarely occur alone; organisms face simultaneous exposures to metals, pesticides, pharmaceuticals, and nutrient stress.

**The “plastisphere” and microbial interactions-** Plastics in the environment often host complex microbial biofilms. This colonization can:

Alter sinking/floating behavior (changing where particles accumulate)

Modify exposure by creating a biologically active interface  
Potentially carry pathogens or antibiotic resistance genes (evidence is still evolving and context-dependent)

These microbial interactions are a major research frontier because they bridge pollution chemistry, microbial ecology, and disease ecology.

**Human exposure:** why risk quantification is still hard

Even with increasing biomonitoring signals, three issues limit clear risk conclusions:

Measurement challenges and contamination risk

Microplastics are ubiquitous in laboratories (air, clothing, consumables). Without rigorous blanks, clean-air protocols, and polymer confirmation, false positives are possible.

Dose metric uncertainty

Toxicology studies may report dose by mass, particle count, or surface area. These are not interchangeable and can produce different hazard interpretations. For example, a low mass of nanoplastics can represent a very high particle count.

**Linking exposure to health outcomes**

**Strong clinical inference usually requires:-** Prospective cohorts or repeated measures over time

Standardized exposure assessment

Control of confounders (smoking, occupational dust, diet patterns, socioeconomic factors)

Mechanistic biomarkers aligned with plausible pathways (oxidative stress, immune perturbation)

Plausible mechanisms for human health effects Based on toxicological plausibility (primarily from experimental systems) and emerging human detection studies, several mechanisms are considered plausible:

Oxidative stress and inflammation: particle surface reactivity, macrophage activation, epithelial irritation

Barrier disruption: gut or lung epithelial tight junction alteration in models

**Immune modulation:** chronic exposure may contribute to low-grade inflammation

**Chemical co-exposure:** additives (e.g., plasticizers) and sorbed pollutants might contribute to endocrine or metabolic perturbation, though separating “plastic particle” effects from chemical effects is challenging

At the same time, authoritative assessments caution that current evidence especially for drinking-water exposure—does not yet support strong claims of harm, underscoring the need for better data rather than speculation.

**A practical evidence-to-risk framework**

To move from “presence” to “risk,” studies and regulators can align around:

**Standardized sampling/QA-QC:** field blanks, lab blanks, clean-air handling, polymer confirmation.

Harmonized reporting: size bins, shapes, polymer types, and both particle count and mass.

**Exposure realism:** environmentally relevant concentrations; chronic low-dose scenarios; mixture contexts.

**Ecologically meaningful endpoints:** reproduction, survival, growth, and behavior in realistic conditions.

Human relevance: inhalation-focused studies (indoor microfibrils), dietary patterns, and vulnerable groups (children, occupationally exposed workers).

**Uncertainty accounting:** transparent limitations and sensitivity analysis.

**Mitigation implications-** Given the broad environmental footprint of plastics, the most reliable mitigation steps are upstream:

- Reduce plastic use where avoidable; redesign products for durability and reuse
- Improve waste collection, sorting, and recycling infrastructure
- Upgrade wastewater and stormwater management to reduce particle emissions
- Encourage textile innovations to reduce fibre shedding and support filtration strategies
- Policy instruments targeting problematic single-use plastics and microplastic sources

UNEP communications emphasize the scale and persistence of plastic pollution and the need for system-level action.

Only studies with clearly described methodologies, contamination control, and polymer identification techniques (e.g., FTIR, Raman spectroscopy) were included (Hartmann *et al.*, 2019). Data were synthesized using a qualitative weight-of-evidence approach emphasizing environmental relevance, consistency across studies, and methodological rigor (GESAMP, 2015).

Results

**Sources and environmental distribution-** Microplastics originate from diverse anthropogenic sources, including degradation of packaging materials, textile fibers released during washing, tire wear particles, industrial pellets, and cosmetic products (Dris *et al.*, 2016; Windsor *et al.*, 2019). Rivers act as major transport pathways, conveying land-based plastics to marine ecosystems (Li *et al.*, 2018).

Microplastics are now ubiquitous in marine surface waters and sediments, freshwater systems, soils, and the atmosphere, indicating continuous cycling between environmental compartments (Allen *et al.*, 2019; UNEP, 2023).

**Ecological impacts on aquatic organisms-** Numerous laboratory and field studies demonstrate ingestion of microplastics by aquatic organisms ranging from zooplankton to fish (Cole *et al.*, 2011; Besseling *et al.*, 2014). Ingested microplastics can cause gastrointestinal blockage, reduced feeding efficiency, oxidative stress, inflammation, and impaired reproduction (Alimba & Faggio, 2019).

Chronic exposure experiments suggest that sublethal effects may accumulate, potentially influencing population dynamics and ecosystem functioning (Wright & Kelly, 2017).

**Terrestrial ecosystem effects-** In terrestrial environments, microplastics enter soils through agricultural mulching, sewage sludge application, and atmospheric deposition (Windsor *et al.*, 2019). Evidence indicates that microplastics can alter soil structure, microbial communities, and invertebrate health, potentially affecting nutrient cycling and plant growth (Rochman *et al.*, 2013).

**Trophic transfer-** Microplastics can be transferred across trophic levels when predators consume contaminated prey (Besseling *et al.*, 2014). Although bioaccumulation is inconsistent due to particle egestion, smaller particles may persist longer in tissues, increasing ecological relevance (Koelmans *et al.*, 2019).

**Human exposure and biomonitoring-** Human exposure occurs mainly via ingestion of contaminated food and drinking water and inhalation of airborne microfibrils (WHO, 2019). Microplastics have been detected in seafood, bottled water, salt, fruits, vegetables, and indoor air (Dris *et al.*, 2016; Koelmans *et al.*, 2019).

### Discussion

The toxicity of microplastics is influenced by particle size, shape, polymer composition, aging, and associated chemicals (Hartmann *et al.*, 2019). Fibrous microplastics often cause greater physical damage than spherical particles, while aged plastics exhibit enhanced chemical sorption capacity (Rochman *et al.*, 2013). Microplastics also serve as substrates for microbial colonization, forming the so-called plastisphere, which may facilitate pathogen transport and alter biogeochemical processes (GESAMP, 2015). Although epidemiological evidence linking microplastics to human disease remains limited, mechanistic studies suggest plausible pathways involving oxidative stress, inflammation,

immune modulation, and endocrine disruption (Wright & Kelly, 2017; WHO, 2019).

### Conclusion

Microplastics are globally distributed environmental pollutants with demonstrated ecological impacts and increasing evidence of human exposure. While current data do not yet allow definitive conclusions regarding human health risks, the weight of evidence supports precautionary action, improved waste management, and continued scientific investigation (WHO, 2019). Microplastics and nanoplastics have become pervasive, multimedia contaminants with documented interactions across ecosystems and growing evidence of human exposure. Ecological research indicates that microplastics can cause physical and physiological stress in organisms, with potential population-level implications under chronic exposure, especially when combined with other stressors. Human evidence is advancing from exposure documentation toward biomonitoring in internal matrices, but robust causal links to health outcomes remain limited. Authoritative evaluations, including those by the World Health Organization, currently indicate low concern for certain pathways (e.g., chemical and microbial hazards in drinking-water) while emphasizing substantial research gaps for particle toxicity and nano-scale effects. Future progress depends on standardized measurement, exposure-realistic ecotoxicology, and well-designed human studies. Meanwhile, prevention-oriented policies reducing plastic leakage at source represent the most defensible strategy to limit long-term ecological and potential human-health burdens.

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