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The Microplastics and Human Health: Their Sources, and Impact

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Abstract: ***Plastic has been as a revolutionary material in many aspects of our lives, for example, healthcare, food packing, and industry sectors, saving lives, improving life quality and increasing producibility. In the meanwhile, plastic is becoming an insidious and persistent global pollutant in serval different formats. For example, plastic can fragmentates into microplastics, particles less than five millimeters in size, being present across every ecosystem on Earth, from the mountains to the oceans, and even within our bodies. Twenty years after the term "microplastic" was first introduced, rising concerns have been brought to the public and the scientific community continue to unravel the complex and far-reaching consequences of this pervasive contaminant. This review summarizes the current understanding of microplastic pollution, drawing upon foundational and recent peer-reviewed literature to provide an updated perspective on their sources, formation, environmental fate, toxicological effects, and the evolving landscape of remediation and policy.***

Keywords: Microplastics; Environmental Pollution; Human Health; Toxicity; Remediation; Policy.

1. Introduction

Plastic has been as a revolutionary material in many aspects of our lives from packing material of live-saving blood donations to milking containers in the markets. Global plastic production has surged from 1.5 million tonnes in 1950 to 460 million tonnes in 2019, projected to reach 1.2 billion tonnes by 2060 under business-as-usual scenarios (1). Recently, increasing efforts have been implemented to recycle the plastics to reuse. However, only 9% of plastics are recycled, with the remainder landfilled, incinerated, or leaked into the environment, where they persist for centuries due to resistance to biodegradation (2).

The term "microplastic" (MP) was first introduced in 2004 by Thompson et al (3). to describe microscopic plastic fragments accumulating in marine sediments and plankton samples around the UK, with evidence of increasing abundance since the 1960s. This seminal work built on earlier reports of small plastic particles in ocean neuston nets from the 1970s (4, 5). Microplastics, MPs, form through primary manufacturing (e.g., microbeads, pellets) or secondary, for example, macroplastic degradation (macroplastic >5 mm) (6, 7). Over the subsequent two decades, MPs, solid synthetic polymer particles ≤5 mm, have been recognized as a hallmark of anthropogenic pollution, emblematic of the "Anthropocene" or "Plasticene" era (8).

Unfortunately, the contaminations of MPs reach all environmental compartments: oceans (75% of marine litter) (9), freshwater (10), soils (11), atmosphere (12), and even remote polar and mountainous regions (13). Bioaccumulation has been documented in over 1,300 species, from zooplankton to marine mammals, with trophic transfer amplifying risks (14, 15). Human exposure pathways include ingestion via contaminated food (e.g., seafood, salt, water), drink packing (16), inhalation of airborne particles, and dermal contact (1, 17, 18). MPs have been detected in human tissues, including blood, lungs, placenta, breastmilk, and brains, with concentrations rising 50% from 2016 to 2024 (19-22).

Additionally, chemical additives, plasticizers (e.g., phthalates), stabilizers (e.g., Bisphenol A/BPA), flame retardants (e.g., polybrominated diphenyl ethers/PBDEs), and pigments, comprise up to 70% of plastic mass and leach into ecosystems, acting as endocrine disruptors and carcinogens (23). MPs also adsorb persistent organic pollutants (POPs) and heavy metals, vectoring them through food chains (15). For this, efforts (e.g., ban, policy) have been taken to find alternatives of plastics, reduce the plastics already in the environments. In this review, we address sources, distribution, ecological and health impacts, remediation, and policy, emphasizing gaps like nanoplastics and long-term effects.

2. Sources and Types of Microplastics

MPs are heterogeneous, classified by origin, size (micro: 1 μm–5 mm; nano: <1 μm), shape (fibers, fragments, films, beads, foams), and polymer (polyethylene/PE, polypropylene/PP, polystyrene/PS, polyvinyl chloride/PVC, polyethylene terephthalate/PET, polyurethane/PU) (24), for example, PE as shown in Figure 1 as examined by scanning electron microscopy/SEM (25). The major sources of microplastics are paint, plastic pellets, tires, personal care products, synthetic textiles with macro plastic as the leading contributor (13).

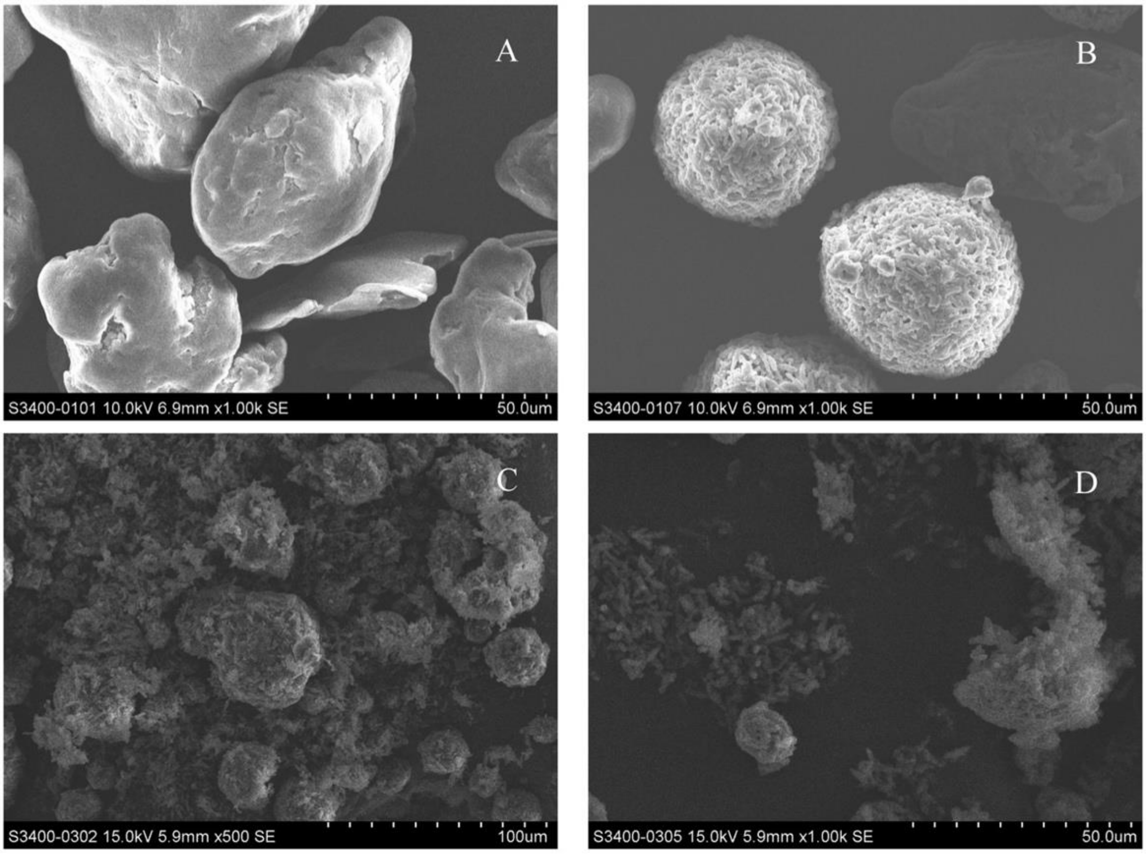

Figure 1. Scanning electron microscopy imaging of PE microplastics. Adapted from Lai et al. (25), Front Microbial, CC BY 4.0.

2.1 Primary Sources

MPs come from many different sources: industrial and manufacturing produce pre-production pellets (nurdles) and powders leak during transport and handling, contributing contamination to oceans (26); flakes from recycling processes also add to this (27); personal care and cosmetics: microbeads in exfoliants and toothpastes historically released via wastewater (14); paints and abrasives: road markings, marine coatings, and blasting media abrade, releasing PS and acrylic particles (28, 29); agricultural applications: coated fertilizers and mulch films fragment, contributing MPs to soils (30).

2.2 Secondary Sources

There are several secondary sources due to wear of product during use, breakdown of large items and waste management. Degradation of Macroplastics: UV-induced photodegradation, thermo-oxidation, and mechanical forces (waves, wind) fragment macro items like bags, bottles, and fishing gear (31). PE fragments in months under UV, but complete mineralization takes centuries. Textile and tire abrasion: synthetic fibers can shed MPs each wash (35,000 fibers/load) (32). Tire wear particles are often rubber-polymer hybrids with 10-20% entering oceans (33). Landfills and open dumping from waste management and litter leak MPs via leachate and wind; urban runoff transports 80-90% of land-based MPs to aquatic systems (34); fishing nets and ropes abrade contributes 10-20% of marine MPs (35). COVID-19 increased emissions from personal protective equipment/PPE, with masks releasing >1,500 fibers each (36). Emerging sources include 3D printing wastes and bioplastics, which fragment similarly (37).

3. Environmental Distribution and Fate

MPs are transported by hydrodynamics, winds, and biota, leading to heterogeneous and wide distribution.

3.1 Marine Ecosystems

Concentrations in surface waters vary from shoreline, sea surface, sea ice, deep sea water to deep sea sediment, with hotspots in gyres (e.g., Great Pacific Garbage Patch: 1.8 trillion pieces) (38). Buoyant MPs (PE, PP) float while denser ones (PVC) sink. Biofouling alters buoyancy, enabling vertical mixing (39). Ocean currents redistribute MPs globally, with 99% eventually sinking (40).

3.2 Freshwater and Terrestrial Systems

The levels of MPs vary across the systems as well: rivers: Rhine (0.89/m3), Seine (3-108/m^3) (41, 42); lakes: Great Lakes (0.05-32/m^3) (43), Taihu (3.4-25.8/L) (44); soils from farmlands 0.03-6.7% by weight from sludge application (45, 46). It has been reported soil containing only a concentration of 0.1% by soil weight considered as the polluted soil (47). In atmosphere, there is a concentration of up to 60 fibers/m^3, deposited in remote areas (48).

4. Toxicity and Ecological Impacts

MPs exert both physical (ingestion, entanglement) and chemical (leaching, adsorption) effects. Physically, MPs block digestive tracts, and reduce energy intake (49). In Daphnia, 1-5 μm PS beads cause immobilization (50). Abrasion damages gills and epithelia in fish (51). MPs also result in reduced reproduction in copepods (52) and growth inhibition in algae (53). When it comes to nanoplastics, they internalize in cells, altering membrane integrity (54).

The additives in MPs also cause physical and other damages. Di(2-ethylhexyl) phthalate (DEHP) causes endocrine disruption (55); BPA induces oxidative stress (56); PBDEs bioaccumulate affects thyroid function (57).

Further, MPs sorb pollutants (e.g., PCBs) and metals (e.g., Cd, Pb) like a sponge, desorbing in guts (58) via reactive oxygen species/ROS generation, genotoxicity, inflammation (59). Additionally, MPs cause altered microbial communities (60); nutrient cycling disruption (61). At a large scale, biodiversity loss is predicted in hotspots (62).

5. Human Exposure Pathways

MPs have been reported in many parts of human body, from hair, saliva, sputum, blood, breast milk, liver, kidney, colon, placenta, saphenous vein tissue, lung, spleen, bronchoalveolar lavage fluid, feces, and meconium (13). MPs come into human bodies via serval pathways, with annual intake: 39,000-121,000 MPs via diet/air, plus 4,000-90,000 from water (63).

Ingestion is on major source, for example, via seafood, bivalves, and fish, which could be amplified via bioaccumulation as illustrated in Figure 2 (64); salt: 11 to 193 MPs items/kg (65); water: Tap (3.57 MPs/L), bottled (325 MPs/L) (66); produce: MPs in vegetables from soil uptake (67) ; others: honey (40-660 fibers/kg), beer (12-109 particles/L) (68).

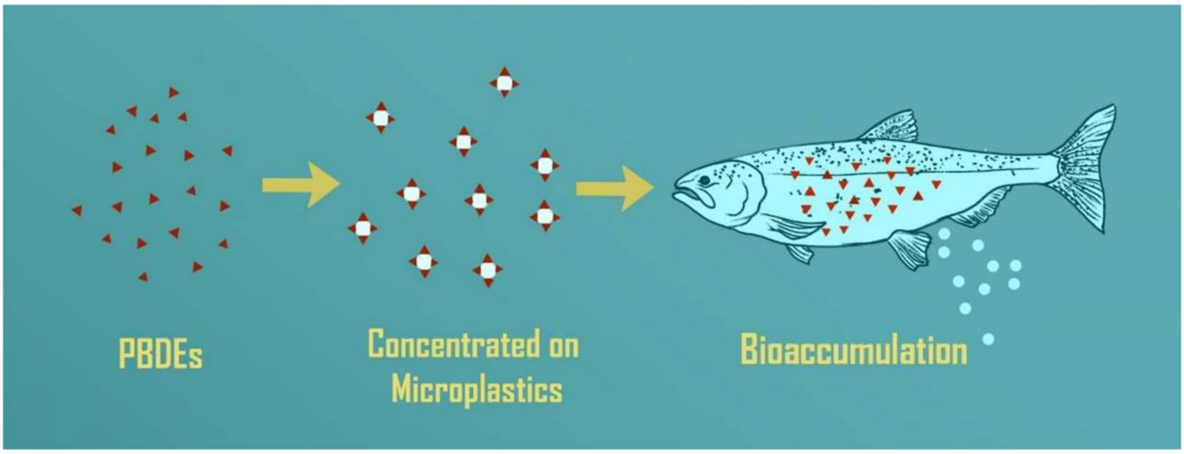

Figure 2. Illustration showing persistent organic pollutant sorption and accumulation over time, using flame-retardant compounds (polybrominated diphenyl ethers (PBDEs)) as example, via microplastic ingestion in fish. From (64) which adapted from Wardrop et al., 2016. Licensed under Creative Commons Attribution (CC BY)

Another pathway is inhalation and dermal. Indoor air could contain 9.8 MPs/m³, with outdoor around 1.42 MPs/m³ (69). Both polymeric particles and fibres were observed in lung tissue samples with varying size from smaller than 5.5 um to up to 16.8 um. The most frequently determined polymers were polyethylene and polypropylene. (70). Dermal pathway, cosmetics transfer additives through the absorbing (71), (72).

6. Health Impacts on Humans

MPs translocate to many organs and bodily fluids systems, causing systemic effects (73); oxidative stress: ROS from PS and MPs damage DNA as illustrated in Figure 3 (74); inflammation: cytokine release in lung cells (Dong et al., 2020); genotoxicity: micronuclei formation (72).

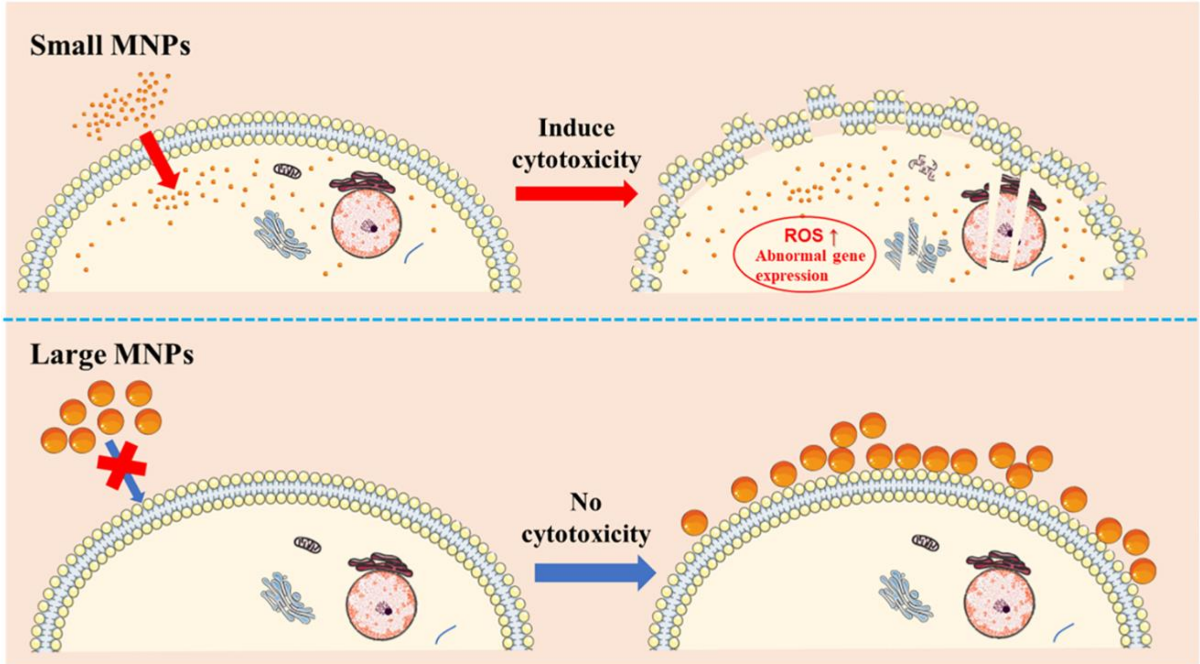

Figure 3. Schematic image showing the correlation between cellular uptake and cytotoxicity, as a function of particle size. From Uptake, ROS production, and cytotoxicity of polystyrene MNPs (size-dependent). Ruan et al, PLOS ONE (2023). Licensed under Creative Commons Attribution (CC BY)

The effects differs among organs: (1)respiratory, fibrosis and cancer risk from inhaled fiber (75); gastrointestinal, dysbiosis and barrier leakage (76); gardiovascular, thrombosis and hypertension from vascular inflammation (77); reproductive, sperm reduction and fetal anomalies (78); neurological, brain accumulation, linked to depression/Alzheimer's (14); epidemiology, associations with CVD, infertility (79). Further, additives have been linked to harmful health effects: Phthalates (reproductive toxicity), BPA (cancer) (80). As such the MPs have broad impacts to human health and its environments as summarized in Figure 4. Individuals with preexisting disease: those with inflammatory bowel disease, chronic obstructive pulmonary disease, cardiovascular disease, or compromised immunity may have impaired clearance and heightened susceptibility to MP-induced inflammation.

Further, there are vulnerable populations who would be riskier to MPs. Infants and children, early-life exposures are elevated due to mouthing behaviors, higher dietary intake per body weight, and greater gut permeability. MP detection in infant feces at higher concentrations than adults underscore this vulnerability. Developmental toxicity concerns include neurocognitive impacts and immune system imprinting. Pregnant individuals and fetuses, placental transfer of MPs suggests potential fetal exposure. Disruption of placental barrier function and nutrient transport, along with endocrine effects from additive leachates, may have implications for growth and development.

Occupational groups, workers in textiles, synthetic fiber production, waste sorting/recycling, and polymer manufacturing may experience inhalation exposures orders of magnitude above the general population. Historical cases of polymer-associated lung disease highlight the need for occupational surveillance (81).

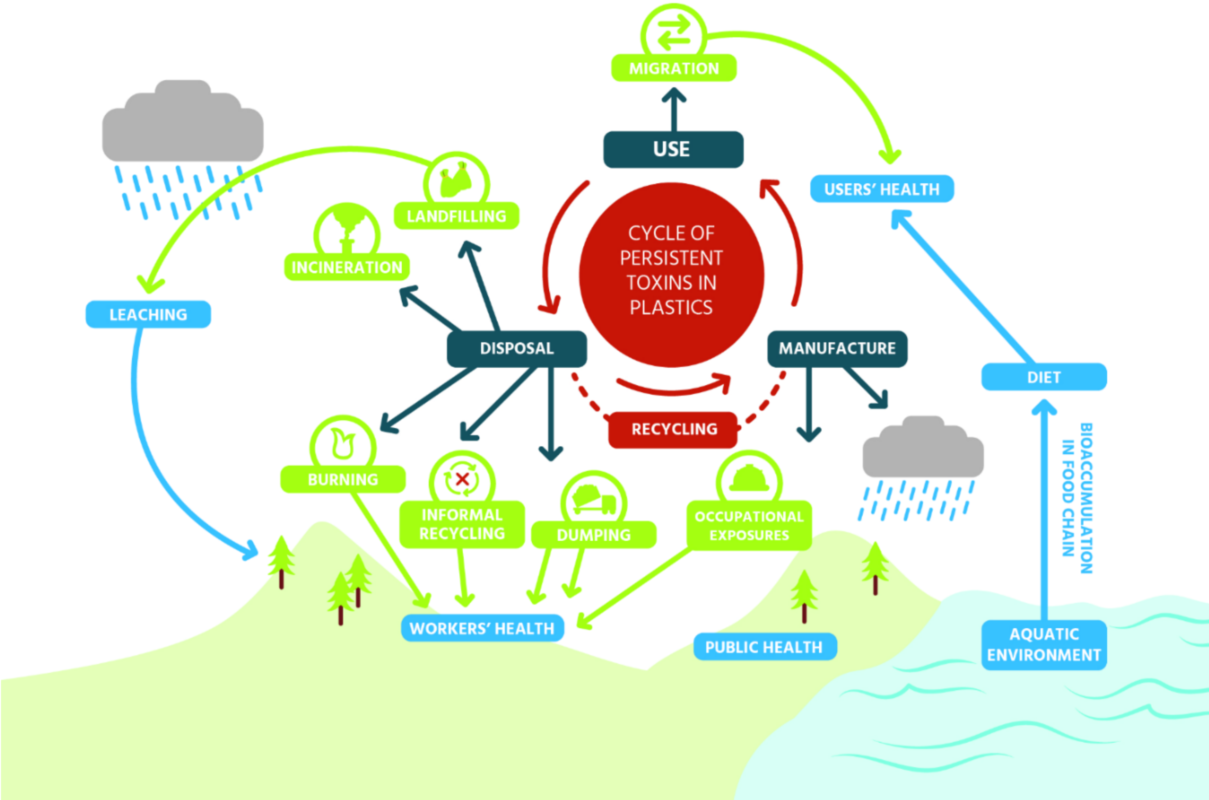

Figure 4. Schematic overview of the human and environmental health impacts of the plastics life cycle. From (82) PLOS Biology. 2021. Licensed under the Creative Commons Attribution License (CC BY)

7. Remediation and Mitigation Strategies

There are several ways to manage to cut the plastic into the environment: (1) reducing plastic consumption: this involves promoting reusable alternatives to single-use plastics and fostering a circular economy model where plastic products are designed for durability, reuse, and recyclability.

(2) improved waste management: expanding and improving waste collection and recycling infrastructure globally is crucial to prevent plastic from entering the environment; (3) product design: redesigning products to minimize the release of microplastics during their lifecycle is a critical upstream solution. This includes developing textiles that shed fewer fibers and tires with lower abrasion rates.

Physical/Chemical methods are included: filtration, sand filters, coagulation/flocculation: Alum/Fe salts aggregate MPs; adsorption with biochar; advanced oxidation with photocatalysis; electrocoagulation (83, 84). It is also obveriosus that these approaches are in high efficiency but energy-intensive, sludge MP concentration.

Biodegradation has made significant progress: bacteria (Pseudomonas, Bacillus) degrade PE/PS; fungi (Aspergillus), enzymes: PETase from Ideonella sakaiensis and engineered variants (85, 86). It is noticeable that biofilms on MPs enhance degradation but may vector pathogens (87).

In the meanwhile, bans have been in place. There are more and more places, plastics bags have been banned from markets with paper bags as a replacement. Globally there are also many initiatives: UN Plastics Treaty targets MP reductions. Public policies have been to make to encourage for reduce/reuse/recycle.

8. Future Directions and Conclusion

For better understanding of the MPs, efforts would be put on: AI modeling for risk (88); standardized methods (89); circular economy (biodegradables with LCA) (90). MPs represent a defining challenge of the Anthropocene, with emissions doubling by 2040 risking widespread harm (13). Integrated solutions—prevention, remediation, policy—are imperative to safeguard ecosystems and health. The past two decades of research have firmly established microplastics as a pervasive and persistent global pollutant with the potential for significant ecological and human health impacts. While our understanding of the sources, transport, and effects of microplastics has grown immensely, critical knowledge gaps remain, particularly concerning the long-term health consequences of human exposure and the ecological impacts of nanoplastics.

Addressing this multifaceted challenge requires a concerted effort from scientists, policymakers, industry, and the public. Continued research is essential to refine risk assessments, develop effective remediation technologies, and inform evidence-based policy. However, the existing body of evidence is already sufficient to warrant a precautionary approach and immediate action to reduce our reliance on plastics and prevent their release into the environment. The transition to a more sustainable and circular plastic economy is not just an environmental imperative but a crucial step in safeguarding the health of our planet and ourselves. The ongoing negotiations for a global plastics treaty offer a tangible opportunity for the international community to collectively address this pressing issue and pave the way for a future with less plastic pollution.

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