

Microplastic Cycle in the Environment

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Microplastics have become a pervasive environmental threat, contaminating marine, freshwater, soil, and atmospheric environments. The issue is that, although considerable research has been conducted on soil, marine, and freshwater pollution, the pathways and interconnectedness of microplastic movement between ecosystems and the mechanisms driving this movement have not been thoroughly detailed. This has led to an incomplete understanding of the complex and imperfect cycle formed as microplastics circulate through the environment, despite some research addressing their transport. Understanding the sources, transport mechanisms, and environmental and health impacts of microplastics is essential for developing effective strategies to reduce their release into the environment. This review delves into global plastic and microplastic production, consumption, and pathways, examining their occurrence, transport, raw polymer composition, additives, toxicity, and the cyclical nature of microplastic contamination across ecosystems. By thoroughly reviewing existing literature, this review paper aims to comprehensively understand the incomplete and complex circulation of microplastics in the environment along with their impacts on the environment and human health.

Keywords: Plastics, Microplastics, Microbeads, Biological process, Chemical process.

Introduction

Microplastic increase in the environment is one of the most pressing environmental issues in this 21st century. Microplastics are fragments of any plastic less than 5 mm (0.20 in) in length¹. Due to their persistence and potential adverse effects on ecosystems and human health, microplastics pose a threat and continue to be a global issue to deal with. Through anthropogenic activities such as the breakdown of larger plastic debris, industrial processes, the abrasion of synthetic textiles and tile, and many more, microplastics are released that contaminate marine, freshwater, terrestrial, and atmospheric environments. Microplastics can penetrate the most pristine and isolated regions of the world as they are being discharged into the environment, traveling greater distances through agents or carriers, and are deposited into these remote areas²⁻⁴. According to recent research, certain microplastic particles may be re-emitted into the atmosphere, casting doubt on the notion that plastics that reach the ocean stay restricted to the marine ecosystem. Microplastics can be carried into the atmosphere from the ocean surface by processes such as bubble burst ejection and wave action, which are fueled by wind and sea state turbulence. The global cycle of microplastic pollution is further exacerbated by the land-based transportation of these airborne particles⁵⁻⁷. The amount of plastic produced worldwide has increased exponentially, from 2 million metric tons in 1950 to 280 million tons in 2016. The great majority of plastic products (79%) are thrown out into the environment, where they can break down

and become smaller-sized litter⁸⁻¹¹. Microplastics (MPs) have been found in a variety of environments, including freshwater,¹² benthic sediment,¹³ soil,¹⁴ atmospheres, seawater,¹⁵ beaches sand,¹⁶ and even far-flung places like the polar regions¹⁷ and the Tibet Plateau.¹⁸ Additionally, MPs can be absorbed by a variety of terrestrial and aquatic creatures, including earthworms and snails, as well as plants¹⁹⁻²¹. These organisms include fish and mussels²²⁻²⁴. Therefore, MPs merit careful consideration as they could have a large impact on the Earth's environment. Although substantial research has been conducted on pollution in marine, freshwater, and soil systems, the pathways and interconnectedness of microplastic movement between these ecosystems and the mechanisms driving this movement have not been thoroughly detailed. This neglect indicates a serious knowledge gap about the extent of microplastic contamination and its effects on the ecosystem and public health^{24,25}. A thorough understanding of microplastics' sources, transport processes, and environmental effects is crucial due to the intricate and linked paths of their dissemination. The objective of this study is to clarify the current status of our understanding of microplastic contamination, with a particular emphasis on its transport and circulation between freshwater, marine, terrestrial, and atmospheric systems. We will also examine the kinds and sources of microplastics, their effects on the environment and human health (Table 1), and possible paths of microplastic transport (Fig. 1)^{7,26,27}.

This review seeks to address this gap by examining global plastic and microplastic production, consumption, and pathways, focusing on their occurrence, transport, raw polymer composi-

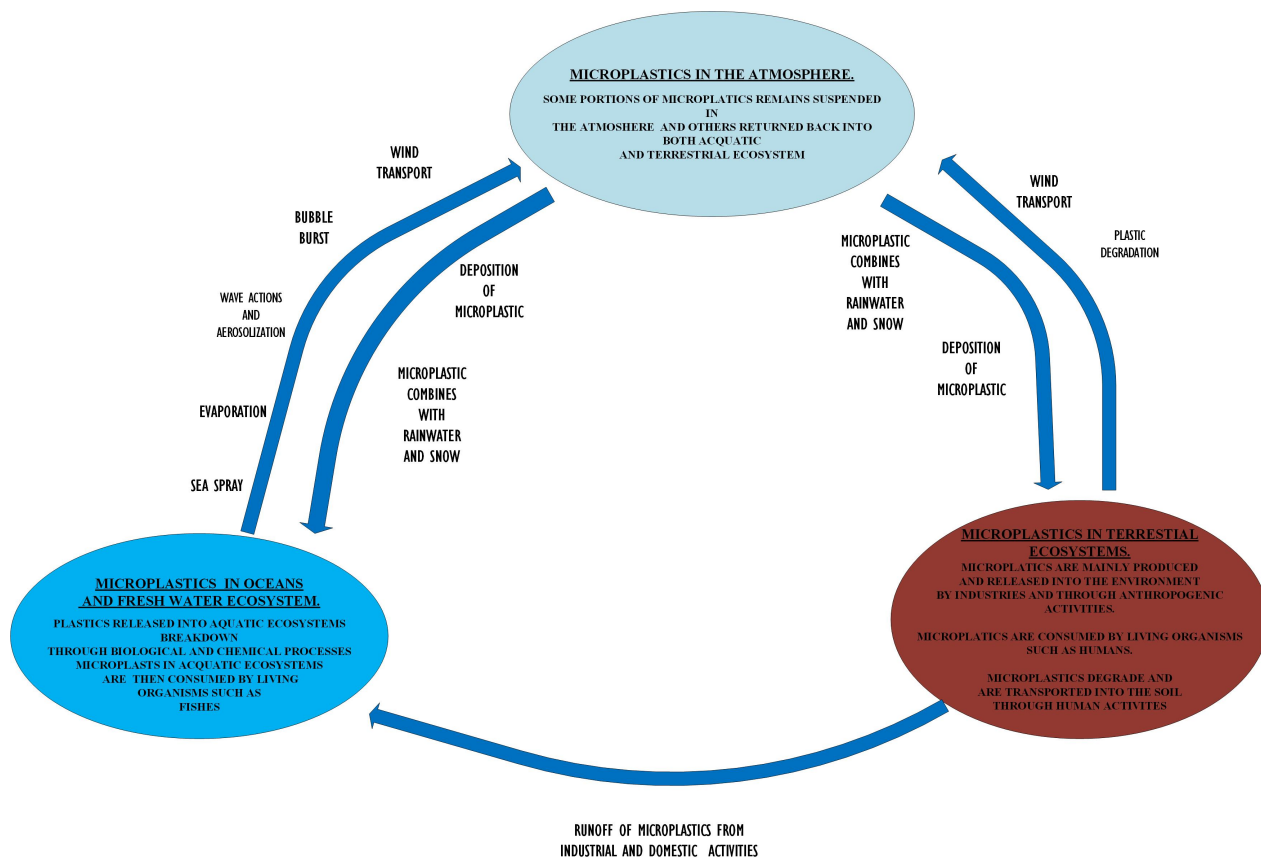


Fig. 1 A brief description of the cycle of Microplastic in the environment through various media and mechanisms.

tion, additives, toxicity, and the cyclical nature of microplastic contamination across different ecosystems. Through a comprehensive review of existing literature, this analysis aims to provide a detailed understanding of the incomplete and complex circulation of microplastics in the environment.

Types, Occurrences, and Sources of Microplastics

The term “microplastics” is used to differentiate smaller or minute plastics from larger plastic waste, such as plastic bottles or bigger pieces of plastic. Two classifications of microplastics are currently recognized: primary and secondary. Primary microplastics are deliberately produced to be small, such as microbeads used in cosmetics and personal care products, while secondary microplastics result from the breakdown of larger plastic items. Secondary microplastics are the most common type found in the environment²⁸. Primary microplastics include any plastic fragments or particles that are already 5.0 mm in size or less before entering the environment.¹ These include microfibers from clothing, microbeads, plastic glitter²⁹, and plastic pellets (also known as nurdles)^{10,30}. Secondary microplastics arise from the degradation of larger plastic products through

natural weathering processes after entering the environment¹. Both types are known to persist in the environment at high levels, particularly in aquatic and marine ecosystems, where they cause water pollution. Thirty-five percent of all ocean microplastics come from textiles/clothing, primarily due to the erosion of polyester, acrylic, or nylon-based clothing, often during the washing process³¹. Microplastics (MP) are categorized by their morphology, including size and shape, using the standardized size and color sorting (SCS) system. This categorization aims to standardize and facilitate the comparison of study results worldwide. Shapes, colors, and texture are used to determine whether a suspected item is an MP³². MPs vary in shape from irregular to spherical and long-thin fibers. Plastic pellets present tablet-like, oblong, cylindrical, spherical, and disk shapes, mostly spherical to ovoid with rounded ends³³. One of the most common sources of microplastics is discarded plastic products, such as bags, bottles, and packaging materials. When these plastics break down, they release small particles that can end up in the soil and water. Additionally, microplastics can also come from synthetic fibers in clothing that are shed during washing and drying processes³⁴. Primary sources include household sewage discharge, polymeric particles from cosmetic and cleaning products, feedstocks used

to manufacture plastic products, and plastic pellets or powders used for air blasting³⁵. Progressive fragmentation of larger plastic items under atmospheric conditions, e.g., by mechanical degradation and UV light exposure, contributes to the entrance of significant amounts of microplastics into the environment³⁶. This increases plastic debris availability for ingestion by various organisms, highlighting the emergence of further environmental hazards³⁷. Wastewater treatment plants are also a major source of microplastic release^{38,39}. While large plastic particles are efficiently removed during wastewater treatment, microplastics often bypass the treatment units, entering and accumulating in the aquatic environment⁴⁰. Notably, many water treatment plants are located near the ocean and seawater, thus becoming a significant source of microplastic release. For instance, in mainland China, about 1,873 wastewater plants (56%) out of 3,340, with a treatment capacity of $78 \times 10^6 \text{ m}^3/\text{day}$, are located in coastal regions where their effects can be directly or indirectly discharged into aquatic ecosystems⁴¹. Additionally, MP fibers can be produced due to mechanical wear or damage to textile clothing and bedding, including pillows, blankets, and curtains. In the sun, photooxidation and thermal effects of drying clothes can easily promote the decomposition and degradation of these textiles, causing the release of microfibrils⁴². These fibrous MPs can then be broken into smaller-sized fine items through wind shear or wear and other environmental factors⁴³. The sources of microplastics, the kinds of microplastics they produce, and the release of these microplastics into the environment are all displayed in the table below (Table. I)⁴⁴.

Transport Mechanisms of Microplastics

Sea and ocean are viewed as microplastic sinks, whereas freshwaters and terrestrial environments are the main sources. Indeed, early research found that microplastic litter reaching oceans by rivers contains particles found in soils⁴⁵. This implies that freshwaters and soils are also sinks of microplastics, as evidenced by high concentrations in some terrestrial and freshwater areas⁴⁶. This shows that there is transport of microplastics from one ecosystem to another through various media and mechanisms (Fig.1). In this section, we will review the various mechanisms for the transport of microplastics from one ecosystem to another and their harmful impact.

Transport of Microplastics from Terrestrial ecosystem into Aquatic ecosystem

There are various mechanisms by which microplastics move from the land into water bodies. These include the following:

1. **Flooding and Erosions:** Flooding events, influenced by factors like excessive rainfall, artificial irrigation, and increased flow rates, significantly expedite the transport of

microplastics (MPs) from land into water bodies. These events increase flow velocities in rivers and streams, dislodging and transporting accumulated microplastics from terrestrial sources such as littered areas, agricultural fields with plastic mulches, and urban environments with plastic debris. The higher volume of water during flooding mobilizes larger quantities of microplastics that have settled on land, which are then carried into nearby water bodies through runoff. Erosion of river banks and beds during floods further contributes to this transport by releasing microplastics adsorbed to soil particles and sediment into aquatic ecosystems. Artificial irrigation in agriculture also plays a role, causing localized flooding or runoff that can transport microplastics from soils, particularly those contaminated by plastic agricultural materials⁴⁷.

2. **Landfill Leachate:** Microplastics (MPs) are transported from landfills into water bodies through landfill leachate, which often contains dissolved and suspended microplastics from degraded plastic waste. These MPs originate from various sources within the landfill, including solid waste and wastewater treatment plant residuals such as sludge and fat, oil, and grease⁴⁸. Plastic waste in landfills undergoes abrasive activities, breaking down into secondary microplastics, while MPs also enter from primary sources, such as products directly disposed of in the landfill. Wastewater, a significant collection point for MPs, contributes to this process, as MPs can become entrapped in fat, oil, grease, and solid sludge during treatment. Upon disposal in landfills, these materials increase the abundance of MPs in landfill leachate, which can seep into groundwater and surface water bodies, transporting MPs from the landfill into these water bodies^{25,49}.
3. **Wind Transport:** In coastal and marine environments, wind can carry lightweight microplastics from beaches, roadsides, or other exposed surfaces and deposit them directly into water bodies. Although there isn't enough data to support the transport of microplastics into these water bodies, direct observations and research studies reinforce it.
4. **Sewage and Wastewater Discharge:** Microplastics (MPs) are transported from land into water bodies primarily through sewage and wastewater discharge. Wastewater treatment plants (WWTPs) often fail to filter out all small plastic particles, allowing MPs to enter water bodies through their effluents. Additionally, untreated sewage discharges can directly release MPs into rivers and oceans. Major sources of MPs include personal care products, cleansing agents, synthetic discharge, air blast media, industrial raw materials, and poor waste management systems^{50,51}. WWTPs receive MPs from various domestic and

| Sources | Types of Microplastics Present | Occurrence, Generation, and Release into the Environment |
|---|--|--|
| Textiles | <ul style="list-style-type: none"> • Polyester • Nylon • Acrylic • Polyethylene • Polyurethane | Microfibers are released from natural fabrics like cotton and wool and synthetic materials like polyester, nylon, and acrylic during use or washing. These fibers reach rivers and seas, where they are ingested by marine organisms like fish. Due to their extensive use in textiles, microfibers are the most prevalent type of microplastics in marine environments. |
| Paints and Finishes | <ul style="list-style-type: none"> • Acrylic • Polyurethane • Polyvinyl chloride (PVC) • Polystyrene • Polyethylene • Polypropylene | Microplastics included in most paints and finishes can leak into the environment during application or removal. These particles can enter the air, streams, or soil, potentially affecting nearby ecosystems and human health through inhalation. |
| Industrial Processes | <ul style="list-style-type: none"> • Polyethylene (PE) • Polypropylene (PP) • Polyvinyl chloride (PVC) • Polyethylene terephthalate (PET) • Polystyrene (PS) • Nylon • Acrylic polymers | Microplastics are generated as waste products during manufacturing processes such as the fabrication of plastic or the cutting and grinding of plastic materials. These are then released into air or waterbodies near industrial sites, negatively impacting ecosystems and human health. |
| Cosmetics and Personal Care Products | <ul style="list-style-type: none"> • Polyethylene (PE) • Polypropylene (PP) • Nylon • Polyethylene terephthalate (PET) • Polymethyl methacrylate (PMMA) • Polyurethane (PU) | Microbeads and other microplastics are often used as abrasives or exfoliants in products like body wash, toothpaste, and face scrubs. These tiny particles escape filtration by wastewater treatment plants and end up in waterways and seas. |
| Plastic Packaging, Containers, and Tire Wear | <ul style="list-style-type: none"> • Polyethylene (PE) • Polypropylene (PP) • Polyethylene terephthalate (PET) • Polystyrene (PS) • Polyvinyl chloride (PVC) • Nylon • Acrylic polymers | Single-use plastics such as food containers, water bottles, and plastic bags fragment into smaller pieces over time due to exposure to sunlight and other environmental factors. These fragments become hard-to-remove microplastics. Tire wear releases microscopic rubber fragments containing microplastics, which can wash into streams or become airborne, affecting the environment and public health. |

Table 1 Sources, types, and occurrences of microplastics in the environment.

industrial sources, including textiles, city dust, tire shedding, plastic pellet fragments, road paint, and other plastic-based items. These MPs are drained through wastewater

during washing processes and eventually make their way to WWTPs⁵². Once in the WWTPs, these MPs can pass through treatment processes and be discharged into wa-

ter bodies, further contributing to the pollution of rivers, oceans, and other surface waters.

5. **Direct Deposition:** Ocean-based sources of marine litter include materials lost or discarded from various activities such as fishing vessels, aquaculture facilities, merchant ships, recreational boats, offshore oil or gas platforms, and military operations. Cargo loss from merchant ships can significantly contribute to plastic pollution in the marine environment^{24,53–55}. Although the dumping of plastic waste at sea has been prohibited since 1988, evidence suggests that a substantial number of vessels continue to illegally dispose of plastic waste into the ocean, resulting in the increase of microplastic pollution in oceans and other waterbodies^{56,57}.

Transport of Microplastics from Terrestrial ecosystems into the Atmosphere

There are various mechanisms by which microplastics move from the land into the Atmosphere. These include the following:

1. **Wind Erosion:** Microplastics (MPs) are transported from land into the atmosphere through various mechanisms, primarily driven by wind erosion. The textile industry is a major contributor to atmospheric MP pollution, with synthetic fibers such as polyester, polyolefin, nylon, polyurethane, polymethyl methacrylate, and vinyl being key sources⁵⁸. Manufacturing processes, including cutting, grinding, and weaving, generate a substantial number of these microscale synthetic fibers, which can be carried into the atmosphere by wind. Wind action also facilitates the movement of synthetic polymer particles and enriches wind-eroded sediments with MPs. Secondary MPs originate from the breakdown of larger plastics due to weathering, UV exposure, and physical, chemical, or biological degradation^{59,60}. Significant sources of secondary MPs include micro-rubbers from tire wear and tear, as well as microfibers released during the wearing, washing, and drying of clothes⁶¹. Despite synthetic rubber containing polymers, the classification of micro-rubbers as natural or synthetic remains debatable due to the presence of both natural and synthetic components in tires.
2. **Industrial Processes:** Microplastics (MPs) are transported from land into the atmosphere through various industrial processes, including the intentional manufacture of micro-sized plastics. For example, polyvinyl chloride (PVC) resin is often produced and supplied as a fine powder due to its enhanced resistance to degradation and oxidation⁶². These powder forms are susceptible to becoming airborne during the processing stages. Additionally, during thermoplastic polymer molding processes, polymers are ground into

powder form (150-500 μm) to achieve higher-quality polymer molds⁶³. This molding process can release polymer powder into the atmosphere, thereby contributing to atmospheric MP pollution.

3. **Transpiration:** Microplastics in fertilizers and on the land surface can sink into the soil. Animals can transport and disperse these microplastics through external attachment or by ingestion and subsequent defecation^{64,65}. Once microplastics enter plant roots, they are transported from the roots to the shoots, with the uptake rate predominantly determined by the plant's transpirational pull; higher transpiration rates lead to greater uptake⁶⁶. This process results in the transportation of microplastics along with water vapor through transpiration (the evaporation of water from plant leaves) into the atmosphere.
4. **Burning of plastics:** Microplastics (MPs) are significantly transported from land into the atmosphere through the open burning of plastic waste, a widespread practice in many regions. This burning process releases MPs directly into the air, accompanied by a variety of other pollutants. In open landfills, substantial quantities of plastics are incinerated daily, causing the volatilization of numerous harmful compounds that integrate into atmospheric aerosols^{67,68}. The release of MPs and toxic chemicals during burning not only contaminates the immediate environment but also allows MPs to travel vast distances through air currents, exacerbating global pollution. This highlights the critical need for improved waste management practices to mitigate the pervasive spread of MPs and protect atmospheric quality.

Transport of Microplastics From Aquatic Ecosystems into Both the Terrestrial Ecosystem and the Atmosphere

Microplastics are transported from the atmosphere to both water bodies and land through various mechanisms. These include the following:

1. **Sea Spray:** The oceans have been investigated as possible sources of atmospheric MPs. Allen et al. (2020) conducted a groundbreaking study that suggested that MPs from the sea could enter the atmosphere through sea spray aerosols produced by wave breaking at the water's surface^{69,70}. This process involves the airborne release of tiny aerosol particles from bursting bubbles during wave breaking, driven by convective updraft. When the voids left by the bursting bubbles are filled by rushing water, secondary ejection takes place, expelling particles at a larger microscale. In situ studies have confirmed that MPs from the sea can become airborne through these mechanisms⁷¹. Since most plastic particles have lower densities than ocean water, sea spray,

and winds can likely cause MPs from rivers and lakes to become airborne in oceanic air. Sea sprays are formed during wave breaking in the coastal surf zone and through white cap formation caused by wind stress.

2. **Meteorological Event:** Atmospheric microplastics (MPs) are considered part of particulate matter (PM) and share several similarities with PM. Both primarily enter the atmosphere through strong wind flow processes, travel horizontally with air mass movement, and undergo deposition influenced by gravity and precipitation⁷¹. Meteorological conditions such as precipitation, air temperature, atmospheric pressure, humidity, wind velocity and direction, and atmospheric stability class can significantly influence the transport of atmospheric MPs. Irregular meteorological events like typhoons and storms can also alter regional airflow, affecting the transport of MPs^{72,73}
3. **Surface impact:** When raindrops hit the surface of lakes or oceans, they create numerous small droplets that are ejected into the atmosphere at high velocities. A recent study estimated that about 4,800 particles per square kilometer per hour can be propelled into the atmosphere through these droplets during a typical rainfall of 10 mm/h⁷⁴.
4. **Food Web:** The small size and slow biodegradation rate of microplastics (MPs) enable their absorption by various organisms, facilitating their transport through food webs and from oceans to land^{45,75}. Marine organisms, from plankton to fish and larger animals, ingest MPs, which can then be carried across different habitats. Migrating fish and birds, for instance, can transfer MPs between oceanic and terrestrial environments. Additionally, when marine animals are caught and processed for human consumption, MPs in their guts and tissues enter terrestrial waste streams. Birds feeding in the ocean and nesting on land deposit MPs through their droppings, and sea turtles can introduce MPs to beaches during nesting. Thus, the persistence and small size of MPs allow them to be transported from oceans to land through diverse biological processes, highlighting the interconnectedness of marine and terrestrial ecosystems and the pervasive nature of plastic pollution.

Transport of Microplastics from the atmosphere into Both Aquatic and Terrestrial Ecosystems

Microplastics in the atmosphere are transported and deposited on water bodies and land through various mechanisms. These include the following:

1. **Precipitation:** Microplastics (MPs) are transported from the atmosphere onto both land and water bodies primarily through atmospheric deposition, which is significantly driven by precipitation events such as rain and snow^{76,77}

Wet deposition, including rainfall and snowfall, plays a crucial role in this process, effectively scouring atmospheric particles and depositing them in urban areas, seas, and even remote Arctic regions^{76,77}. Snow, in particular, is an efficient method for depositing MPs, as it captures and deposits atmospheric particulates over large areas. A study by Bergmann et al. (2019) found that microplastic deposition ranged from 190 to 154,000 particles per liter in melted snow sampled from Europe and from 0 to 14,400 particles per liter in the Arctic. This demonstrates the pervasive nature of MP pollution and its ability to reach even the most remote and pristine environments⁷⁸.

2. **Wet and dry deposition:** Microplastics (MPs) and nanoplastics (NPs) have been shown to act as effective cloud ice nuclei, potentially explaining the correlation between MP deposition and snowfall events^{77,79}. Snow effectively scrounges atmospheric MPs, contributing to the deposition of plastic particles in both urban and remote areas, such as the Arctic, as well as in global marine environments⁸⁰. Suspended MPs are removed from the atmosphere through dry or wet deposition. Dry deposition occurs when gravitational forces on suspended MPs surpass wind flow forces⁸¹. Factors such as aging-induced cracks, void formation, and the adsorption of chemical or biological pollutants on MP surfaces can alter their specific gravity and buoyancy, triggering dry deposition⁸². Thus, the surface state and degree of internal aging significantly influence the dry deposition process. Wet deposition involves MPs being washed out by precipitation, with rain droplets scavenging airborne MPs during rainfall and depositing them on surfaces. Mist and fog droplets can also interact with MPs before surface deposition^{83,84}. For instance, atmospheric deposition of non-fibrous microplastics and fibers in Dongguan, China, ranged from 175 to 313 particles per square meter per day^{85,86}.

The Impacts of the Transport of Microplastics between the various environmental Domains

The potential hazards of microplastics arise from the release of unreacted monomers, oligomers, and chemical additives over time. These monomers and oligomers can migrate from food packaging materials, and as their concentrations increase, the remaining particles can be absorbed by the human body through various pathways. Microplastics can impact the environment in multiple ways, including mechanical harm to organisms, serving as carriers for hydrophobic pollutants, and providing substrates for organisms^{8,88}. Below are some of the ways microplastics pose risks to both environmental and human health.

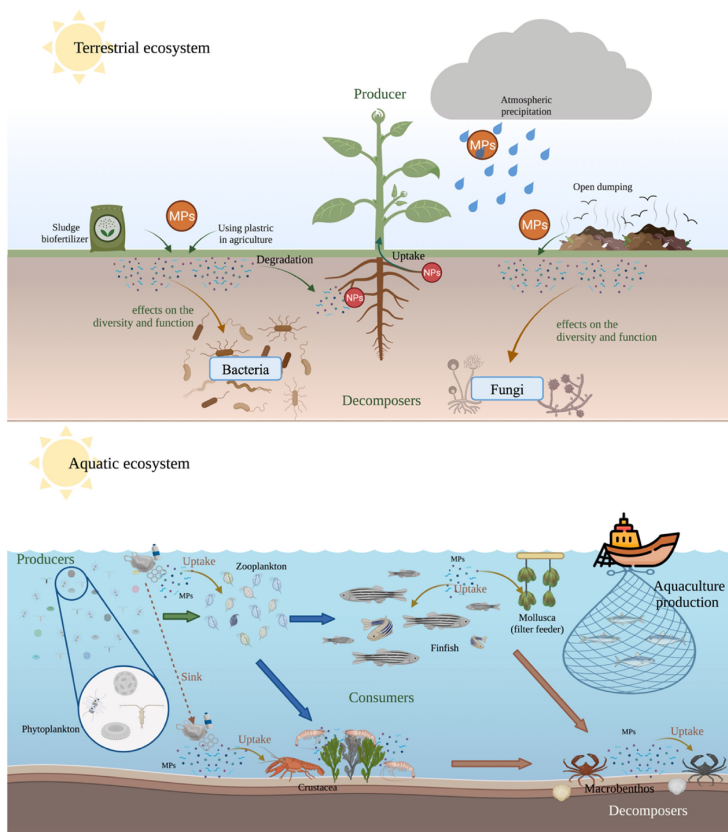


Fig. 2 Illustrate the impacts of microplastics on the various environmental domains⁸⁷. Reprinted with permission from the Author.

1. **Entanglement:** The transport of microplastics from land and atmospheric environments into oceans and aquatic ecosystems poses significant risks to marine life. These particles can entangle organisms, impairing their ability to feed and avoid predators, which may lead to exhaustion, starvation, or drowning (Fig 2)⁸⁹. While larger plastics can directly harm marine creatures through entanglement or ingestion, smaller microplastics can be absorbed through gills or ingested via the digestive system. For instance, in mussels, smaller microplastics are taken up through the gills via endocytosis, while larger particles are consumed. Air-breathing animals that become entangled in plastics may suffer severe injuries or death due to restricted movement and reduced food intake. Microplastics can cause similar physical damage, obstructing feeding and digestion, and injuring sensitive tissues such as gills or the intestinal tract. Even if immediate death does not occur, injuries and reduced foraging ability can critically impact an organism's health and survival^{77,89}.
2. **Smothering:** Microplastics transported from oceans and the atmosphere and deposited on land can profoundly affect ecosystems. In the intertidal zone, such debris can

severely damage delicate salt marsh vegetation by either crushing plants or blocking essential light needed for their growth through its weight and shading, resulting in barren patches in these already sensitive environments^{90,91}. Furthermore, accumulating these materials can abrade or crush plant blades into anoxic sediments, potentially leading to the suffocation of plants, reduced photosynthetic activity, and eventual decay of above-ground biomass⁹². These impacts highlight the potential for long-lasting damage to ecosystem function and biodiversity in these vulnerable habitats.

3. **Vectors for pollutants:** The transport of microplastics across various environmental domains—such as air, water, and soil—plays a critical role in the widespread dispersal of harmful pollutants. These tiny particles, characterized by their hydrophobic nature and large surface area, effectively adsorb and concentrate pollutants like hexachlorinated hexanes, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and polybrominated diphenyl ethers (PBDEs). As microplastics migrate through different environments, they act as vectors, carrying these toxic substances over long distances and into new ecosys-

tems. This movement not only facilitates the spread of chemical contaminants but also increases the risk of environmental pollution and the exposure of organisms to toxic compounds⁹³⁻⁹⁶. Microplastics can interact with pollutants through hydrophobic, Van der Waals, and π - π interactions, further enhancing their ability to bind and transport these substances. The chemical composition of microplastics, along with their additives, determines their potential toxicity which is amplified as they move between ecosystems, releasing both pathogens and chemical contaminants^{97,98}. Consequently, the mobility of microplastics across environmental domains exacerbates their environmental and health impacts by enabling the far-reaching distribution of hazardous pollutants.

4. **Impacts on human health:** The cycle of microplastics in the environment presents significant risks to human health through various pathways, notably ingestion, inhalation, and dermal exposure. When microplastics are released into the environment, they can enter the human body through contaminated food, air, and water. Ingestion is one of the most common pathways, as microplastics are present in seafood, drinking water, and even in food packaging and utensils. Once ingested, these particles can accumulate in the digestive tract and potentially translocate to other organs, leading to localized inflammation and possible genotoxic effects. Inhalation of microplastics is another critical concern, particularly for individuals exposed to airborne microplastics in industrial settings. Studies have documented the presence of fibrous microplastics in human lungs, with some fibers detected as large as 250 μm ^{99,100}. These particles can evade the body's natural clearance mechanisms, persisting in the lungs and leading to reduced lung capacity, coughing, breathlessness, and inflammation¹⁰¹. Furthermore, fine microplastics have the potential to enter the circulatory system¹⁰², posing risks to other organs¹⁰³. Dermal exposure to microplastics can occur through personal care products containing microbeads, such as facial scrubs and body washes, as well as through synthetic clothing and textiles that shed microfibers. In addition to the physical presence of microplastics, the chemical additives and dyes used in plastics, such as plasticizers and heavy metals like lead, can have toxic effects on humans^{104,105}. Long-term exposure to these substances can result in severe health issues, including brain damage, muscle weakness, kidney failure, and even death¹⁰⁶. Moreover, microplastics serve as efficient substrates for the colonization of microorganisms, including pathogenic bacteria, viruses, protozoa, and fungi. These microorganisms can be transported by wind, water, and other environmental factors, further increasing the risk of infections and disease transmission. Overall, the cycle of microplastics in the environment not only con-

tributes to widespread contamination but also poses a multifaceted threat to human health through various exposure routes, leading to both direct and indirect health impacts.

Methods

The literature review was conducted using databases like Google Scholar to ensure broad coverage of relevant studies. The search incorporated keywords such as "microplastics," "environmental impact," "pollutant transport," and "ecotoxicology," along with synonyms and related terms, to ensure a comprehensive exploration. The review focused on studies published between 2010 and 2023 to capture the most recent and relevant research. Only peer-reviewed studies in English that directly addressed the environmental impact of microplastics were included, while those published before 2010 or not directly related to the topic were excluded.

Summary of Literature Review Scope and Distribution: To provide an overview of the literature reviewed, a total of 200 studies were initially identified through database search. After screening for relevance and quality, 80 studies were excluded due to criteria such as lack of peer review, focus on unrelated topics, or publication before 2010. The remaining 120 studies were further categorized based on their focus areas: 40 studies on terrestrial microplastics, 60 on aquatic microplastics, and 20 on atmospheric microplastics. This distribution is summarized in the table below, which shows the number of studies included in each category and their respective percentages of the total literature reviewed.

| Focus Area | Number of Studies | Percentage of Total |
|---------------------------|-------------------|---------------------|
| Terrestrial Microplastic | 40 | 33% |
| Aquatic Microplastics | 60 | 50% |
| Atmospheric Microplastics | 20 | 17% |
| Total | 120 | 100% |

Table 2 Focus Areas of Microplastic Studies

Limitations of the study

This review paper acknowledges several limitations that may affect the validity and generalizability of its findings. The presence of data gaps, particularly in underrepresented environments, hinders a complete understanding of the microplastic cycle. The review's scope may be constrained by the selection of studies, potentially introducing biases such as an overemphasis on specific geographical areas or research methods. Additionally, the variability in methodologies across the included studies can lead to inconsistencies, complicating the ability to draw cohesive conclusions.

Further Directions and Considerations

Research on microplastics (MPs) in the lithosphere is limited, with significant gaps in understanding their effects on soil microbial communities and nutrient cycles. MPs might alter microbial niches, potentially disrupting key soil microbes and nutrient cycles, and could lead to the spread of pathogens. Groundwater contamination by MPs is also poorly understood, with few studies showing the presence of plastic particles in some aquifers. More research is needed on the physical and ecological impacts of MPs in soil, their atmospheric transport, and their effects on snow, ice, and freshwater systems. Future studies should focus on standardizing data collection methods, understanding long-term impacts, and exploring remediation strategies.

Conclusion

Microplastic pollution is a growing environmental challenge with its related negative impacts on marine, freshwater, terrestrial, and atmospheric ecosystems. This review provides the various mechanisms by which microplastics are being transported and deposited into the various ecosystems through complex mechanisms or agents and their impact on the environment and human health. The majority of research has focused only on their abundance in the oceans with few focused on their abundance on the land or terrestrial ecosystem. Current research and analysis have shown the existence of microplastics in the atmosphere which suggest there are mechanisms responsible for this unusual deposition into the atmosphere. This shows that if microplastics existed in the atmosphere, then there are mechanisms that transport these microplastics into the atmosphere. This imperfect cycle is what this review pinpoints and the various ways by which these microplastics enter each ecosystem with their long-term effects. These problems clearly show the need to derive strategies to remove these microplastics from various environmental compartments and ways to effectively reduce their continuous abundance. To address this multifaceted issue, comprehensive strategies for the prevention, reduction, and removal of microplastics are crucial. This includes improving plastic waste management, advancing research on microplastic toxicity and environmental impacts, deriving effective ways to control their abundance in the environment, and promoting public awareness and policy initiatives to mitigate microplastic pollution. This review clearly shows much research is needed to determine the ways to measure the abundance of microplastics in the environment and understand both their present and their long-term impact.

Statements and Declarations

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Consent to Publish: Not Applicable

Code Availability: Not Applicable

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References

- 1 S. Ghosh, J. K. Sinha, S. Ghosh, K. Vashisth, S. Han and R. Bhaskar, *Microplastics as an Emerging Threat to the Global Environment and Human Health*.
- 2 H. Ritchie and M. Roser, *Plastic pollution*, <https://ourworldindata.org/plastic-pollution>.
- 3 D. MacArthur, D. Waughray and M. Stuchtey, *The new plastics economy, rethinking the future of plastics*.
- 4 K. Zhang, H. Shi, J. Peng, Y. Wang, X. Xiong, C. Wu and P. Lam, *Microplastic pollution in China's inland water systems: a review of findings, methods, characteristics, effects, and management*, <https://doi.org/10.1016/j.scitotenv.2018.02.300>.
- 5 F. Galgani, G. Hanke, S. Werner and L. Vries, *Marine litter within the European marine strategy framework directive*, <https://doi.org/10.1093/icesjms/fst122>.
- 6 L. Lei, S. Wu, S. Lu, M. Liu, Y. Song, Z. Fu, H. Shi, K. Raley-Susman and D. He, *Microplastic particles cause intestinal damage and other adverse effects in zebrafish *Danio rerio* and nematode *Caenorhabditis elegans**.
- 7 P. Zuccarello, M. Ferrante, A. Cristaldi, C. Copat, A. Grasso and D. Sanguerogio, *Exposure to microplastics ($j10\text{ m}$) associated with plastic bottles mineral water consumption: The first quantitative study*.
- 8 R. Thompson, Y. Olsen, R. Mitchell, A. Davis, S. Rowland, A. John, D. McGonigle and A. Russell, *Lost at sea: where is all the plastic?*, <https://doi.org/10.1126/science.1094559>.
- 9 K. Zhang, H. Shi, J. Peng, Y. Wang, X. Xiong, C. Wu and P. Lam, *Microplastic pollution in China's inland water systems: a review of findings, methods, characteristics, effects, and management*, <https://doi.org/10.1016/j.scitotenv.2018.02.300>.

- 10 M. Cole, P. Lindeque, E. Fileman, C. Halsband, R. Goodhead, J. Moger and T. Galloway, *Microplastic Ingestion by Zooplankton*, hdl:10871/19651. PMID 23692270.
- 11 V. Hidalgo-Ruz, L. Gutow, R. Thompson and M. Thiel, *Microplastics in the marine environment: a review of the methods used for identification and quantification*.
- 12 B. Peng, Y. Zheng and L. Y. Coupling ecosystem services and regional ecological security pattern.
- 13 J. Katta, H. Griffiths, C. Waluda, S. Thorpe, I. Loaiza Alamo, B. Moreno, C. Pacherras and K. Hughes, *Microplastics in the Antarctic marine system: An emerging area of research*.
- 14 H. Liu, J. Li and J. Paul Chen, *Microplastics in freshwater systems: a review on occurrence, environmental effects, and methods for microplastics detection*.
- 15 L. J., D. J. A. and C. J. J., *Speech and language therapy interventions for children with primary speech and/or language disorders*.
- 16 K. Grace, A. Lerner, J. Mikal and G. Sangli, *A qualitative investigation of childbearing and seasonal hunger in peri-urban Ouagadougou, Burkina Faso*.
- 17 A. Lusher, G. Hernandez-Milian, S. Berrow, E. Rogan and I. O'Connor, *Microplastic and macroplastic ingestion by a deep diving, oceanic cetacean: The True's beaked whale Mesoplodon mirus*, <https://doi.org/10.1016/j.envpol.2015.01.023>.
- 18 H. Hirai, H. Takada, Y. Ogata, R. Yamashita, K. Mizukawa, M. Saha, C. Kwan, C. Moore, H. Gray and D. Laursen, *Organic micropollutants in marine plastics debris from the open ocean and remote and urban beaches*.
- 19 Y. Song, C. Cao and R. Qiu, *Uptake and adverse effects of polyethylene terephthalate microplastic fibers on terrestrial snails (Achatina fulica) after soil exposure*.
- 20 E. Lwanga, H. Gertsen and H. Gooren, *Microplastics in the terrestrial ecosystem: Implications for Lumbricus terrestris (Oligochaeta, Lumbricidae)*.
- 21 J. Berger, S. Berger, T. Hall, G. Lieschke and P. Currie, *Dystrophin-deficient zebrafish feature aspects of the Duchenne muscular dystrophy pathology*.
- 22 J. Davison, R. Newcombe, S. Lovegrove and I. S. DTAM, *Dense tracking and mapping in real-time*.
- 23 M. Browne, A. Dissanayake, T. Galloway, D. Lowe and R. Thompson, *Ingested microscopic plastic translocates to the circulatory system of the mussel, Mytilus edulis (L)*.
- 24 A. Andrady, *Microplastics in the marine environment*, <https://doi.org/10.1016/j.marpo>.
- 25 J. Sun, X. Dai, Q. Wang, M. Loosdrech and B.-J. Ni, *Microplastics in wastewater treatment plants: detection, occurrence, and removal*, <https://doi.org/10.1016/j.watres.2018.12.050>.
- 26 J. Meeker, S. Sathyanarayana and S. Swan, *Phthalates and other additives in plastics: human exposure and associated health outcomes*.
- 27 K. Law, S. Morét-Ferguson and D. Goodwin, *Distribution of surface plastic debris in the eastern Pacific Ocean from an 11-year data set*.
- 28 R. Habib, J. Aldhanhani and A. Ali, *Trends of microplastic abundance in personal care products in the United Arab Emirates for 3 years (2018–2020)*.
- 29 D. Green, M. Jefferson, B. Boots and L. Stone, *All that glitters is litter? Ecological impacts of conventional versus biodegradable glitter in a freshwater habitat*, Archived from the original on 5 May 2024. Retrieved 17 October 2023.
- 30 J. Boucher and D. Friot, *Primary microplastics in the oceans: A global evaluation of sources*.
- 31 B. Resnick, *More than ever, our clothes are made of plastic. Just washing them can pollute the oceans*, Retrieved 4 October 2021.
- 32 C. Crawford, B. Quinn, C. Crawford and B. Quinn, *Microplastic identification techniques*, <https://doi.org/10.1016/b978-0-12-809406-8.00010-4>.
- 33 A. Abu-Hilal and T. Al-Najjar, *Plastic pellets on the beaches of the northern Gulf of Aqaba, Red Sea*, <https://doi.org/10.1080/14634980903361200>.
- 34 A. Mamun, T. Prasetya, I. Dewi and M. Ahmad, *Microplastics in human food chains: Food becoming a threat to health safety*.
- 35 J.-Q. Jiang, *Occurrence of microplastics and environmental pollution: a review*, <https://doi.org/10.1016/j.spc.2017.11.003>.
- 36 M. Eriksen, L. Lebreton, H. Carson, M. Thiel, C. Moore, J. Borrorro, F. Galgani, P. Ryan and J. Reisser, *Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea*.
- 37 R. Thompson, C. Moore, F. Vom Saal and S. Swan, *Plastics, the environment and human health: current consensus and future trends*, <https://doi.org/10.1098/rstb.2009.0053>.
- 38 M. Browne, P. Crump and S. Niven, *Accumulation of microplastic on shorelines worldwide: Sources and sinks*.
- 39 M. Long, I. Paul-Pont and H. Hegaret, *Interactions between microplastics and phytoplankton aggregates: Impact on their respective fates*.
- 40 F. Murphy, C. Ewins, F. Carbonnier and B. Quinn, *Wastewater treatment works (WwTW) as a source of microplastics in the aquatic environment*, <https://doi.org/10.1021/acs.est.5b05416>.
- 41 L. Jin, G. Zhang and H. Tian, *Current state of sewage treatment in China*, <https://doi.org/10.1016/j.watres.2014.08.014>.
- 42 Y. Song, S. Hong, M. Jang, G. Han, S. Jung and W. Shim, *Combined effects of UV exposure duration and mechanical abrasion on microplastic fragmentation by polymer type*. *Environ Sci Technol* 51(8):4368–4376, <https://doi.org/10.1021/acs.est.6b06155>.
- 43 J. Gasperi, S. Wright, R. Dris, F. Collard, C. Mandin, M. Guerrouache, V. Langlois, F. Kelly and B. Tassin, *Microplastics in air: are we breathing it in?*, <https://doi.org/10.1016/j.coesh.2017.10.002>.
- 44 S. Ghosh, J. K. Sinha, S. Ghosh, K. Vashisth, S. Han and R. Bhaskar, <https://doi.org/10.3390/su151410821>, as an Emerging Threat to the Global Environment and Human Health.
- 45 A. Horton, C. Svendsen, R. Williams, D. Spurgeon and E. Lahive, *Large microplastic particles in sediments of tributaries of the River Thames, UK—Abundance, sources and methods for effective quantification*.
- 46 L. Nizzetto, M. Futter and S. Langaas, *Are agricultural soils dumps for microplastics of urban origin?*, <https://doi.org/10.1021/acs.est.6b04140>.

- 47 R. Hurley, J. Woodward and J. Rothwell, *Microplastic contamination of river bed 889 was significantly reduced by catchment-wide flooding*.
- 48 H. Golwala, X. Zhang, S. Iskander and A. Smith, *Solid waste: An overlooked source of microplastics to the environment*.
- 49 P. Iyare, S. Ouki and T. Bond, *Microplastics removal in wastewater treatment plants: A critical review*.
- 50 S. Zahra, M. Iqbal and S. Ashraf, *Comparison of ambient air quality among industrial and residential areas of a typical South Asian city*.
- 51 F. Jabeen, M. Adrees and M. Ibrahim, *Trash to energy: A measure for the energy potential of combustible content of domestic solid waste generated from an industrialized city of Pakistan*.
- 52 P. Cheung and L. Fok, *Characterization of plastic microbeads in facial scrubs and their estimated emissions in Mainland China*.
- 53 J. Derraik, *The pollution of the marine environment by plastic debris: a review*.
- 54 S. Lambert, C. Sinclair and A. Boxall, *Occurrence, degradation and effect of polymer-based materials in the environment*.
- 55 J. Hammer, M. Kraak and J. Parsons, *Plastics in the marine environment: the dark side of a modern gift*.
- 56 C. Bannick, K. Brand, M. Jekel, F. König, D. Miklos and B. Rechenberg, *Kunststoffe in der Umwelt. Ein Beitrag zur aktuellen Mikroplastikdiskussion*.
- 57 S. Sheavly, *Marine debris—an overview of a critical issue for our oceans*, http://www.un.org/Depts/los/consultative_process/documents/6_sheavly.pdf, open-ended informal consultative processes on oceans and the law of the sea.
- 58 R. Akhbarizadeh, S. Dobaradaran and M. Amouei Torkmahalleh, *Suspended fine particulate matter (PM_{2.5}), microplastics (MPs), and polycyclic aromatic hydrocarbons (PAHs) in the air: Their possible relationships and health implications*.
- 59 M. Gregory, *Environmental implications of plastic debris in marine settings—Entanglement, ingestion, smothering, hangers-on, hitch-hiking, and alien invasions*.
- 60 S. O'Brien, E. Okoffo and J. O'Brien, *Airborne emissions of microplastic fibers from domestic laundry dryers*.
- 61 J. Sun, S. Ho and X. Niu, *Explorations of tire and road wear microplastics in road dust PM_{2.5} at eight megacities in China*.
- 62 *Plastics Europe. Polyvinyl chloride (PVC)*, <https://plasticseurope.org/plastics-explained/a-large-family/polyvinyl-chloride-pvc-2/>, Published 2022. Accessed September 3, 2024.
- 63 L. Francis, *Powder processes*.
- 64 C. D., *Effects of polystyrene microplastics on the fitness of earthworms in agricultural soil*.
- 65 M. Rillig, R. Ingraffia and A. Souza Machado, *Microplastic incorporation into soil in agroecosystems*.
- 66 J. Li, H. Liu and J. Chen, *Microplastics in freshwater systems: A review on occurrence, environmental effects, and methods for pollution control*.
- 67 D. Wu, Q. Li and X. Shang, *Commodity plastic burning as a source of inhaled toxic aerosols*.
- 68 C. Velis and E. Cook, *Mismanagement of plastic waste through open burning with emphasis on the global south: a systematic review of risks to occupational and public health*.
- 69 S. Allen, D. Allen, K. Moss, G. Le Roux, V. Phoenix and J. Sonke, *Examination of the ocean as a source for atmospheric microplastics*, <https://doi.org/10.1371/journal.pone.0232746>.
- 70 M. Trainic, J. Flores, I. Pinkas, M. Pedrotti, F. Lombard, G. Bourdin, G. Gorsky, E. Boss, Y. Rudich, A. Vardi and I. Koren, *Airborne microplastic particles detected in the remote marine atmosphere*, <https://doi.org/10.1038/s43247-020-00061-y>.
- 71 J. Prata, *Airborne microplastics: Consequences to human health?*
- 72 S. Abbasi, *Microplastics wash out from the atmosphere during a monsoon rain event*.
- 73 L. Chen, J. Li and Y. Tang, *Typhoon-induced turbulence redistributed microplastics in coastal areas and reformed the plastisphere community*.
- 74 M. Lehmann, L. Oehlschlägel, F. Häusel, A. Held and S. Gekle, *Ejection of marine microplastics by raindrops: A computational and experimental study*.
- 75 M. Rillig, *Microplastic in terrestrial ecosystems and the soil?*
- 76 R. Dris, J. Gasperi, M. Saad, C. Miranda and B. Tassin, *Synthetic fibers in atmospheric fallout: A source of microplastics in the environment?*
- 77 S. Allen, D. Allen and V. Phoenix, *Atmospheric transport and deposition of microplastics in a remote mountain catchment*.
- 78 M. Bergmann, S. Mützel and S. Primpke, *White and wonderful? Microplastics prevail in snow from the Alps to the Arctic*.
- 79 M. Ganguly and P. Ariya, *Ice nucleation of model nano-micro plastics: A novel synthetic protocol and the influence of particle capping at diverse atmospheric environments*.
- 80 Q. Zhang, Y. Zhao and F. Du, *Microplastic fallout in different indoor environments*.
- 81 P. Samson, *Air Pollution, the Automobile, and Public Health*.
- 82 Q. Zhou, C. Tian and Y. Luo, *Various forms and deposition fluxes of microplastics are identified in the coastal urban atmosphere*.
- 83 A. Tai, L. Chen and X. Wang, *Atmospheric deposition of particles at a sensitive alpine lake: Size-segregated daily and annual fluxes from passive sampling techniques*.
- 84 B. Viner, *Coming and Going: Transport and Tracking*. In: *Conceptual Boundary Layer Meteorology: The Air Near Here*.
- 85 L. Cai, J. Wang and J. Peng, *Characteristic of microplastics in the atmospheric fallout from Dongguan city, China: Preliminary research and first evidence*.
- 86 R. Dris, J. Gasperi and C. Miranda, *A first overview of textile fibers, including microplastics, in indoor and outdoor environments*.
- 87 P. N. T. R, P. S and S. S., *Influencing factors of microplastic generation and microplastic contamination in urban freshwater*, Reprinted from Heliyon, Fig.3, pp.4, Copyright 2024, with permission from Elsevier.
- 88 O. Piringer and A. Baner, *Plastic Packaging Materials for Food: Barrier Function, Mass Transport, Quality Assurance, and Legislation*.

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- 89 D. Laist, *Impacts of Marine Debris: Entanglement of Marine Life in Marine Debris Including a Comprehensive List of Species with Entanglement and Ingestion Records*.
- 90 A. Uhrin and J. Schellinger, *Marine debris impacts to a tidal fringing-marsh in North Carolina*.
- 91 H. Viehman, J. Vander Pluym and J. Schellinger, *Characterization of marine debris in North Carolina salt marshes*.
- 92 A. Uhrin, E. Townsend and G. Thayer, *The density and size of derelict fishing gear affect colonization by marine organisms in North Carolina estuaries*.
- 93 L. Bradney, H. Wijesekara and K. Palansooriya, *Particulate plastics as a vector for toxic trace-element uptake by aquatic and terrestrial organisms and human health risk*.
- 94 S. Fournier, J. D'Errico and D. Adler, *Nanopolystyrene translocation and fetal deposition after acute lung exposure during late-stage pregnancy*.
- 95 P. Stapleton, *Microplastic and nanoplastic transfer, accumulation, and toxicity in humans*.
- 96 Z. Wang, J. Gao and Y. Zhao, *Plastisphere enriches antibiotic resistance genes and potential pathogenic bacteria in sewage with pharmaceuticals*.
- 97 C. Campanale, G. Dierkes and C. Massarelli, *A relevant screening of organic contaminants present in freshwater and pre-production microplastics*.
- 98 P. Kumar, R. Sridharan and V. Krishnaswamy, *Analysis and microbial degradation of low-density polyethylene (LDPE) in Winogradsky column*.
- 99 V. Hidalgo-Ruz, L. Gutow, R. Thompson and M. Thiel, *Microplastics in the marine environment: A review of the methods used for identification and quantification*.
- 100 T. Rocha-Santos and A. Duarte, *A critical overview of the analytical approaches to the occurrence, the fate and the behavior of microplastics in the environment*. *Trac* 65:47–53.
- 101 E. Foekema, C. Gruijter and M. Mergia, *Plastic in North Sea fish*.
- 102 C. L., C. M., V. MB and J. CR, *Microplastics are taken up by mussels (*Mytilus edulis*) and lugworms (*Arenicola marina*) living in natural habitats*.
- 103 K. Kim, S. Jahan, E. Kabir and R. Brown, *A review of airborne polycyclic aromatic hydrocarbons (PAHs) and their human health effects*.
- 104 C. Zarfl and M. Matthies, *Are marine plastic particles transport vectors for organic pollutants to the Arctic?*
- 105 C. L., V. A., M. J and J. CR, *Microplastic pollution in deep-sea sediments*.
- 106 A. Jan, M. Azam and K. Siddiqui, *Heavy metals and human health: Mechanistic insight into toxicity and counter defense system of antioxidants*.

| STUDY | AUTHOR | PUBLICATION YEAR | METHODS USED | STRENGTHS | WEAKNESS | MAIN FINDINGS |
|---|---|------------------|--|--|--|---|
| Plastic Pollution | Ritchie H, Roser M | 2018 | Review of global data and literature | Comprehensive global overview | Relies on existing data, no primary research | Provides a global perspective on plastic pollution, highlighting trends, sources, and impacts of plastic waste. |
| The New Plastics Economy | MacArthur DE, Waughray D, Stuchtey M | 2016 | Report based on expert interviews and workshops | Innovative recommendations for future plastics economy | Focuses on economic perspective, less emphasis on ecological impacts | Proposes a circular economy for plastics, emphasizing the need to rethink the production and lifecycle of plastic products. |
| Microplastic Pollution in China's Inland Water System | Zhang K, Shi H, Peng J, Wang Y, Xiong X, Wu C, Lam PK | 2018 | Review of studies in China, analysis of water samples | Regional focus with detailed analysis | Limited to inland water systems, may not be generalizable | Reviews the extent of microplastic pollution in China's inland waters, detailing methods, characteristics, and management strategies. |
| Microplastic Pollution in Deep-Sea Sediments | Van Cauwenberghe L, Vanreusel A, Mees J, Janssen CR | 2013 | Analysis of sediment samples from deep-sea environments | Focuses on under-researched deep-sea areas | Limited geographical scope | Identifies microplastics in deep-sea sediments, suggesting widespread contamination even in remote oceanic areas. |
| Organic Micropollutants in Marine Plastics Debris | Hirai H, Takada H, Ogata Y, et al. | 2011 | Chemical analysis of plastics collected from oceans and beaches | Combines chemical analysis with field sampling | Focus on organic pollutants, may overlook other harmful components | Finds that marine plastic debris carries organic micropollutants, posing additional risks to marine ecosystems. |
| Plastic Pollution in Swiss Surface Waters | Faure F, Demars C, Wieser O, Kunz M, De Alencastro LF | 2015 | Field sampling and analysis of pollutants interacting with plastics in Swiss waters | Detailed case study of a specific region | Focus on Swiss waters, may not apply globally | Highlights the interaction between plastic debris and other pollutants in Swiss surface waters. |
| Distribution of Surface Plastic Debris in the Eastern Pacific | Law KL, Moré-Ferguson SE, Goodwin DS, et al. | 2014 | Analysis of plastic debris data collected over 11 years from the Eastern Pacific Ocean | Long-term data set, comprehensive spatial coverage | Focuses on surface debris, may not account for deeper or smaller particles | Maps the distribution of plastic debris in the Eastern Pacific, showing high concentrations in specific areas. |
| Microplastics in the Marine Environment | Andrady AL | 2011 | Literature review on microplastic pollution in marine environments | Broad overview of microplastics in marine ecosystems | Relies on secondary data, no new experimental research | Microplastics are widespread and persistent in marine environments. |
| Microplastics in wastewater treatment plants | Sun J et al. | 2019 | Sampling and removal efficiency analysis | Focus on wastewater treatment | Only considers wastewater treatment plants | Microplastics are present in wastewater, with varying removal efficiencies. |
| Marine litter within the European marine strategy framework directive | Galgani F et al. | 2013 | Policy analysis and review | Integrates policy with marine litter data | Focused on European context | Reviews European policies on marine litter management. |
| Microplastic particles cause intestinal damage and other adverse effects in zebrafish and nematodes | Lei L et al. | 2018 | Experimental study with zebrafish and nematodes | Provides direct evidence of microplastic toxicity | Focused on specific organisms | Microplastics cause intestinal damage and other adverse effects. |
| Exposure to microplastics associated with plastic bottles mineral water consumption | Zuccarello P et al. | 2019 | Quantitative analysis | First quantitative study on microplastics in bottled water | Limited to specific types of water | High microplastic exposure from bottled water consumption. |

| STUDY | AUTHOR | PUBLICATION YEAR | METHODS USED | STRENGTHS | WEAKNESS | MAIN FINDINGS |
|---|----------------------|------------------|--|--|--|---|
| Phthalates and other additives in plastics: human exposure and associated health outcomes | Meeker JD et al. | 2009 | Literature review | Comprehensive overview of plastic additives and health effects | Focuses primarily on phthalates | Phthalates and other additives are linked to various health issues. |
| Microplastic in terrestrial ecosystems and the soil? | Rillig MC | 2012 | Commentary and review | Highlights an underexplored area of research | Limited empirical data | Suggests the presence and potential effects of microplastics in terrestrial ecosystems. |
| Lost at sea: where is all the plastic? | Thompson RC et al. | 2004 | Literature review and synthesis | Seminal paper in microplastic research | Lacks empirical data | Highlights the uncertainty of plastic's final fate in the environment. |
| Microplastic Ingestion by Zooplankton | Cole M et al. | 2013 | Laboratory experiments with zooplankton | Provides direct evidence of microplastic ingestion | Focused on a specific marine organism | Zooplankton ingest microplastics, potentially affecting the food chain. |
| Microplastics in the marine environment: a review of the methods used for identification and quantification | Hidalgo-Ruz V et al. | 2012 | Review of methodologies | Comprehensive review of methods for microplastic analysis | Limited discussion on standardization | Discusses various techniques for identifying and quantifying microplastics. |
| Coupling ecosystem services and regional ecological security pattern | Peng BF et al. | 2018 | Regional ecological analysis | Integrates ecosystem services with ecological security | Focused on a specific region | Proposes a framework for coupling ecosystem services with ecological security. |
| Microplastics in the Antarctic marine system: An emerging area of research | Katta J et al. | 2017 | Review of Antarctic microplastics research | Focuses on a unique and underexplored region | Limited data availability | Highlights the presence of microplastics in the Antarctic ecosystem. |
| Microplastics in freshwater systems: a review on occurrence, environmental effects, and methods for microplastics detection | Liu H et al. | 2018 | Literature review | Comprehensive review of freshwater microplastics | Lacks primary data | Discusses the occurrence, effects, and detection methods for microplastics in freshwater systems. |
| Speech and language therapy interventions for children with primary speech and/or language disorders | Law J et al. | 2017 | Systematic review | Focused on therapeutic interventions | Limited to speech and language disorders | Evaluates the effectiveness of speech and language therapy interventions. |
| A qualitative investigation of childbearing and seasonal hunger in peri-urban Ouagadougou, Burkina Faso | Grace K et al. | 2017 | Qualitative study | Provides context-specific insights | Limited generalizability | Examines the relationship between childbearing and seasonal hunger in a specific region. |
| Microplastic and macroplastic ingestion by a deep diving, oceanic cetacean | Lusher et al. | 2015 | Field study on cetaceans; analysis of stomach contents | Provides insight into the impact of plastics on deep-sea species | Limited sample size; may not be representative of all cetacean species | True's beaked whales ingest both microplastics and macroplastics, impacting their health. |

| STUDY | AUTHOR | PUBLICATION YEAR | METHODS USED | STRENGTHS | WEAKNESS | MAIN FINDINGS |
|---|-----------------|------------------|--|--|---|---|
| Dystrophin-deficient zebrafish feature aspects of Duchenne muscular dystrophy pathology | Berger et al. | 2010 | Use of dystrophin-deficient zebrafish to study muscle pathology | Zebrafish model closely mimics human muscular dystrophy | Genetic modifications may affect generalizability | Dystrophin-deficient zebrafish show similar pathology to Duchenne muscular dystrophy in humans. |
| DTAM: Dense Tracking and Mapping in Real-time | Davison et al. | 2011 | Real-time dense tracking and mapping algorithm | Real-time processing; applicable to various scenarios | Limited by computational resources and hardware constraints | Developed a method for real-time dense tracking and mapping in computer vision applications. |
| Ingested microscopic plastic translocates to the circulatory system of the mussel, <i>Mytilus edulis</i> (L.) | Browne et al. | 2008 | Laboratory study on mussels; analysis of microplastic ingestion and translocation | Demonstrates how microplastics can enter and circulate in marine organisms | Laboratory conditions may not fully replicate natural environments | Microscopic plastics can enter the circulatory system of mussels, potentially affecting their health. |
| Uptake and adverse effects of polyethylene terephthalate microplastic fibers on terrestrial snails | Song et al. | 2019 | Soil exposure experiment with terrestrial snails | Focuses on terrestrial impacts of microplastics | Specific to polyethylene terephthalate; results may not apply to other types of microplastics | Polyethylene terephthalate microplastic fibers negatively impact terrestrial snails. |
| Microplastics in the terrestrial ecosystem: Implications for <i>Lumbricus terrestris</i> | Lwanga et al. | 2016 | Soil study on earthworms; analysis of microplastic ingestion and effects | Examines effects on terrestrial ecosystems | Focuses on a single species of earthworm; results may not generalize | Microplastics impact the health and behavior of earthworms in terrestrial ecosystems. |
| Trends of microplastic abundance in personal care products in the United Arab Emirates | Habib et al. | 2022 | Analysis of personal care products over three years | Provides trends over a significant period | Limited to UAE; may not reflect global trends | Increasing trend in microplastic content in personal care products in the UAE. |
| Ecological impacts of conventional versus biodegradable glitter in a freshwater habitat | Green et al. | 2021 | Experimental comparison of conventional and biodegradable glitter in freshwater habitats | Compares environmental impacts of different types of glitter | Limited to a specific habitat; may not cover all potential effects | Biodegradable glitter may have less environmental impact compared to conventional glitter. |
| Primary microplastics in the oceans: A global evaluation of sources | Boucher & Friot | 2017 | Review of global sources of primary microplastics | Comprehensive global overview | Review may miss some recent data or emerging sources | Identifies and evaluates global sources of primary microplastics in oceans. |
| Heavy Metals and Human Health: Mechanistic Insight into Toxicity and Counter Defense System of Antioxidants | Jan et al. | 2015 | Review of heavy metal toxicity and antioxidant defense mechanisms | Thorough review of mechanisms and defenses | Focuses on mechanisms rather than specific studies or data | Provides insight into how heavy metals affect human health and how antioxidants can counteract these effects. |
| More than ever, our clothes are made of plastic. Just washing them can pollute the oceans | Resnick | 2018 | News article | Highlights practical implications of plastic pollution from clothing | Non-scientific; more of a summary than a detailed study | Clothing made of plastic contributes significantly to ocean pollution through washing. |

| STUDY | AUTHOR | PUBLICATION YEAR | METHODS USED | STRENGTHS | WEAKNESS | MAIN FINDINGS |
|--|-----------------------|------------------|---|---|---|---|
| Microplastic identification techniques | Crawford & Quinn | 2017 | Review of techniques for identifying microplastics | Comprehensive review of methods | May not cover all new or emerging techniques | Summarizes various techniques for identifying microplastics. |
| Plastic pellets on the beaches of the northern Gulf of Aqaba, Red Sea | Abu-Hilal & Al-Najjar | 2009 | Field study on plastic pellet pollution in beach sediments | Focus on a specific geographic area | Limited to a single location; may not reflect global conditions | Plastic pellets are present on beaches in the northern Gulf of Aqaba, Red Sea. |
| Microplastics in human food chains: Food becoming a threat to health safety | Mamun et al. | 2023 | Review of microplastic contamination in human food chains | Addresses health implications of microplastics in food | Focuses on a broad topic without detailed primary research | Microplastics in food chains pose a significant health risk to humans. |
| Occurrence of microplastics and environmental pollution: a review | Jiang | 2018 | Review of microplastic pollution and its environmental impact | Broad overview of environmental pollution | May not include the latest research or regional variations | Reviews the occurrence and impact of microplastics on the environment. |
| Plastic pollution in the world's oceans: more than 5 trillion plastic pieces | Eriksen et al. | 2014 | Global assessment of plastic pollution in oceans | Extensive global data and estimates | May not account for recent changes or improvements | Over 5 trillion plastic pieces are afloat in the world's oceans, highlighting massive pollution. |
| Plastics, the environment and human health: current consensus and future trends | Thompson et al. | 2009 | Review of plastics' impacts on the environment and human health | Comprehensive review of current understanding | Review may be outdated due to rapid developments in research | Provides current consensus and future trends on the impact of plastics on the environment and health. |
| Accumulation of microplastic on shorelines worldwide: sources and sinks | Browne et al. | 2011 | Global survey of microplastic accumulation | Global perspective on microplastic sources | Focused mainly on shorelines | Identified sources and accumulation patterns of microplastics on shorelines. |
| Interactions between microplastics and phytoplankton aggregates: Impact on their respective fates | Long et al. | 2019 | Study of microplastic interactions with phytoplankton | Investigates interactions and fate in marine environments | Specific to phytoplankton and microplastics | Studied how microplastics affect and interact with phytoplankton aggregates. |
| Wastewater treatment works (WwTW) as a source of microplastics in the aquatic environment | Murphy et al. | 2016 | Analysis of microplastics from wastewater treatment | Addresses a major source of microplastics | Focused on wastewater treatment; may not cover all sources | Found wastewater treatment works as a significant source of microplastics. |
| Current state of sewage treatment in China | Jin et al. | 2014 | Review of sewage treatment practices | Provides insights into sewage treatment in China | Focused on China; may not be applicable globally | Reviewed the state of sewage treatment and its effectiveness in China. |
| Combined effects of UV exposure duration and mechanical abrasion on microplastic fragmentation by polymer type | Song et al. | 2017 | Experimental study on microplastic fragmentation | Examines effects of UV and mechanical abrasion | Specific to fragmentation; does not address biological impacts | Studied how UV exposure and mechanical abrasion affect microplastic fragmentation. |
| Microplastics in air: are we breathing it in? | Gasperi et al. | 2018 | Investigation of airborne microplastics | Addresses less-studied areas of air pollution | Focused on air microplastics; may not cover all aspects | Found that microplastics are present in the air and potentially inhaled. |

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| Microplastics as an Emerging Threat to the Global Environment and Human Health | Ghosh et al. | 2023 | Review of microplastics' impact on the environment and health | Comprehensive overview of emerging threats | Recent reviews; may lack long-term data | Reviewed the threats of microplastics to the environment and human health. |
| Large microplastic particles in sediments of tributaries of the River Thames, UK—Abundance, sources and methods for effective quantification | Horton et al. | 2017 | Analysis of microplastic particles in sediments | Detailed quantification methods | Limited to a specific region; may not be universally applicable | Found large microplastic particles in sediments of the River Thames tributaries. |
| Are agricultural soils dumps for microplastics of urban origin? | Nizzetto et al. | 2016 | Study of microplastic contamination in soils | Explores the impact of urban microplastics on soils | Focused on specific contamination sources | Examined the role of agricultural soils in microplastic pollution from urban areas. |
| Microplastic contamination of river bed was significantly reduced by catchment-wide flooding | Hurley et al. | 2018 | Study of flood impact on microplastic levels | Shows the impact of natural events on microplastic distribution | Specific to flooding events; may not generalize to all conditions | Found that flooding events significantly reduced microplastic contamination in river beds. |
| Solid waste: An overlooked source of microplastics to the environment | Golwala et al. | 2021 | Review of solid waste as a microplastic source | Highlights a significant but often overlooked source | Review format; may lack new experimental data | Identified solid waste as a major, overlooked source of microplastics. |
| Microplastics removal in wastewater treatment plants: a critical review | Iyare et al. | 2020 | Critical review of microplastic removal methods | Comprehensive review of existing technologies | Focused on wastewater treatment; may not cover all removal methods | Reviewed various methods for removing microplastics from wastewater. |
| Comparison of ambient air quality among industrial and residential areas of typical South Asian city | Zahra et al. | 2022 | Air quality comparison in different areas | Provides data on air quality in diverse settings | Limited to one city; may not be representative of all South Asian cities | Compared air quality and found differences between industrial and residential areas. |
| Trash to energy: A measure for the energy potential of combustible content of domestic solid waste generated from an industrialized city of Pakistan | Jabeen et al. | 2022 | Assessment of waste-to-energy potential | Explores energy potential of solid waste | Specific to one city; may not generalize globally | Evaluated the energy potential of combustible solid waste in Pakistan. |
| Characterization of plastic microbeads in facial scrubs and their estimated emissions in Mainland China Characterized microbeads and estimated emissions from facial scrubs. | Cheung | Fok | 2017 | Analysis of microbeads in facial scrubs | Focuses on a specific product type | Limited to facial scrubs; may not cover all sources of microplastics |

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| The pollution of the marine environment by plastic debris: a review | Derraik | 2002 | Review of marine plastic pollution | Comprehensive review of marine pollution | Older review; may not include recent data | Reviewed various aspects of marine plastic pollution. |
| Occurrence, degradation and effect of polymer-based materials in the environment | Lambert et al. | 2014 | Review of polymer-based materials | Provides detailed information on polymer materials | Review format; may lack new experimental data | Reviewed the occurrence, degradation, and effects of polymers in the environment. |
| Plastics in the marine environment: the dark side of a modern gift | Hammer et al. | 2012 | Review of marine plastic pollution | Addresses various aspects of plastic pollution | Older review; may not include recent data | Reviewed the negative impacts of plastics in the marine environment. |
| Plastics in the environment. A contribution to the current microplastics discussion | Bannick et al. | 2015 | Discussion of microplastics in the environment | Provides insights into current microplastic discussions | Specific to German context; may not generalize globally | Discussed microplastics issues and current discussions in Germany. |
| Marine debris—an overview of a critical issue for our oceans | Sheavly | 2005 | Overview of marine debris | Provides a broad overview of marine debris issues | Older source; may lack recent data | Reviewed the critical issue of marine debris in oceans. |
| Suspended fine particulate matter (PM2.5), microplastics (MPs), and polycyclic aromatic hydrocarbons (PAHs) in the air: their possible relationships and health implications | Akhbarizadeh et al. | 2021 | Study of air pollutants and microplastics | Explores relationships between different pollutants | Specific to air pollutants; may not cover all health impacts | Investigated the relationships between PM2.5, microplastics, and PAHs in the air. |
| Environmental implications of plastic debris in marine settings—entanglement, ingestion, smothering, hangers-on, hitch-hiking, and alien invasions | Gregory | 2009 | Review of environmental impacts of plastic debris | Comprehensive review of various impacts | Older review; may not include recent data | Reviewed various environmental impacts of plastic debris in marine settings. |
| Airborne emissions of microplastic fibers from domestic laundry dryers | O'Brien et al. | 2020 | Study of microplastic emissions from laundry dryers | Investigates a specific source of airborne microplastics | Limited to one type of emission source | Found significant airborne emissions of microplastic fibers from laundry dryers. |
| Explorations of tire and road wear microplastics in road dust PM2.5 at eight megacities in China | Sun et al. | 2022 | Analysis of road dust for microplastics | Focuses on tire and road wear sources | Limited to road dust; may not cover all sources | Examined tire and road wear microplastics in road dust across megacities in China. |
| Polyvinyl chloride (PVC) | Plastics Europe | 2022 | Information on PVC | Provides detailed information on PVC | Industry-specific source; may not cover broader issues | Provided an overview of polyvinyl chloride (PVC) and its uses. |
| Powder Processes | Francis | 2016 | Overview of powder processing | Comprehensive overview of powder processing | Specific to processing methods; may not cover other aspects | Discussed various powder processing techniques in materials processing. |

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|---|-----------------|------------------|---|---|---|--|
| Effects of polystyrene microplastics on the fitness of earthworms in agricultural soil | Cao et al. | 2017 | Experimental study on earthworms | Provides insights into the effects of polystyrene on soil organisms | Limited to one type of plastic and one species | Investigated the effects of polystyrene microplastics on earthworms in soil. |
| Microplastic incorporation into soil in agroecosystems | Rillig et al. | 2017 | Study of microplastic incorporation into soil | Examines microplastic effects in agricultural contexts | Specific to agricultural soils; may not generalize | Studied how microplastics are incorporated into soil and their effects. |
| Microplastics in freshwater systems: A review on occurrence, environmental effects, and methods for pollution control | Li et al. | 2020 | Review of microplastics in freshwater systems | Comprehensive review of occurrence and effects | Review format; may lack new experimental data | Reviewed microplastics' occurrence, effects, and control methods in freshwater systems. |
| Commodity plastic burning as a source of inhaled toxic aerosols | Wu et al. | 2021 | Study of plastic burning and aerosol emissions | Addresses a specific source of toxic aerosols | Focused on plastic burning; may not cover other sources | Found that burning commodity plastics generates toxic aerosols. |
| Mismanagement of plastic waste through open burning with emphasis on the global south: a systematic review of risks to occupational and public health | Velis & Cook | 2021 | Systematic review of open burning of plastics | Comprehensive review of health risks | Specific to open burning; may not cover all plastic waste management issues | Reviewed health risks associated with open burning of plastic waste, especially in the global south. |
| Examination of the ocean as a source for atmospheric microplastics | Allen et al. | 2020 | Study of oceanic sources of atmospheric microplastics | Investigates an important source of atmospheric microplastics | Limited to oceanic sources; may not cover other sources | Found that the ocean is a significant source of atmospheric microplastics. |
| Airborne microplastic particles detected in the remote marine atmosphere | Trainic et al. | 2020 | Detection of airborne microplastics in remote areas | Provides data from remote marine environments | Limited to remote marine areas; may not cover all regions | Detected airborne microplastics in the remote marine atmosphere. |
| Constraining Microplastic Particle Emission Flux from the Ocean | Yang et al. | 2022 | Study of microplastic emission flux from oceans | Focuses on emission flux measurements | Limited to oceanic emissions; may not cover other sources | Constrained the emission flux of microplastic particles from the ocean. |
| Airborne microplastics: Consequences to human health? | Prata | 2018 | Review of airborne microplastics and health effects | Provides a detailed review of health consequences | Review format; may lack new experimental data | Reviewed potential health consequences of airborne microplastics. |
| Microplastics wash out from the atmosphere during a monsoon rain event | Abbasi, S. | 2021 | Field study, Atmospheric sampling | Captures real-world data during monsoon | Limited to a single event | Significant microplastic washout observed during monsoon rains. |
| Typhoon-induced turbulence redistributed microplastics in coastal areas and reformed the plastisphere community | Chen, L. et al. | 2021 | Field study, Water sampling, Microbial analysis | Investigates both redistribution and microbial communities | Focused on a specific geographical area | Typhoon-induced turbulence significantly alters the microplastic distribution and microbial communities. |

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| Ejection of marine microplastics by raindrops: a computational and experimental study | Lehmann, M. et al. | 2021 | Computational modeling, Experimental study | Combines computational and experimental approaches | Limited to specific conditions | Raindrops can eject marine microplastics, contributing to atmospheric transport. |
| A review of airborne polycyclic aromatic hydrocarbons (PAHs) and their human health effects | Kim, K.H. et al. | 2013 | Literature review | Comprehensive overview of PAH sources and effects | Does not include newer studies | Airborne PAHs pose significant health risks, especially in urban areas. |
| Synthetic fibers in atmospheric fallout: a source of microplastics in the environment? | Dris, R. et al. | 2016 | Field study, Microscopy | Early evidence of atmospheric microplastic fallout | Limited sample size | Synthetic fibers are prevalent in atmospheric fallout, contributing to environmental microplastics. |
| Atmospheric transport and deposition of microplastics in a remote mountain catchment | Allen, S. et al. | 2019 | Field study, Atmospheric deposition analysis | Investigates remote areas, long-range transport | Geographically limited study | Microplastics can be transported and deposited in remote mountain regions. |
| Ice nucleation of model nano-micro plastics: a novel synthetic protocol and the influence of particle capping at diverse atmospheric environments | Ganguly, M., Ariya, P.A. | 2019 | Laboratory experiments, Synthetic protocol | Novel approach to studying microplastics in ice nucleation | Limited to model particles | Microplastics can influence ice nucleation, with implications for cloud formation. |
| Microplastic Fallout in Different Indoor Environments | Zhang, Q. et al. | 2020 | Indoor sampling, Microplastic analysis | Broad study across different environments | Focused only on indoor environments | Microplastics are prevalent in various indoor environments, posing potential health risks. |
| Air Pollution, the Automobile, and Public Health | Samson, P. J. | 1988 | Literature review, Policy analysis | Historical perspective on air pollution and health | Outdated, lacking recent developments | Automobiles significantly contribute to air pollution, impacting public health. |
| Various forms and deposition fluxes of microplastics are identified in the coastal urban atmosphere | Zhou, Q., et al. | 2017 | Field study in urban coastal areas | Relevant to urban coastal environments | Limited geographical focus | Identified various forms of microplastics and their deposition fluxes in urban coastal areas. |
| Atmospheric deposition of particles at a sensitive alpine lake | Tai, A.Y.C., et al. | 2017 | Passive sampling techniques | High relevance to sensitive environments | Limited to one location | Showed the size-segregated daily and annual fluxes of atmospheric particles in an alpine lake. |
| Coming and going: Transport and tracking | Viner, B. | 2023 | Literature review in boundary layer meteorology | Focused on transport and tracking within boundary layer meteorology | More theoretical, less field data | Reviewed the dynamics of air transport and tracking within the boundary layer. |
| Characteristic of microplastics in the atmospheric fallout from Dongguan city, China | Cai, L., et al. | 2017 | Field study in urban environment | First evidence of microplastics in atmospheric fallout in Dongguan | Limited to a single city | Characterized microplastics in atmospheric fallout, highlighting urban environmental impact. |

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| A first overview of textile fibers, including microplastics, in indoor and outdoor environment | Dris, R., et al. | 2017 | Field sampling in various environments | Broad environmental coverage | Limited to fiber-type microplastics | Provided an overview of the presence of textile fibers and microplastics in both indoor and outdoor environments |
| Plastic packaging materials for food: barrier function, mass transport, quality assurance, and legislation | Piringer OG, Baner AL | 2008 | Literature review and analysis | Detailed coverage of food packaging | Focused more on legislation than environmental impact | Discussed plastic packaging materials, their barriers, and related legislation |
| Impacts of marine debris: entanglement of marine life in marine debris including a comprehensive list of species with entanglement and ingestion records | Laist, D. W. | 1997 | Literature review and species records | Comprehensive species impact review | Dated data | Provided a comprehensive list of species affected by marine debris through entanglement and ingestion |
| Marine debris impacts to a tidal fringing-marsh in North Carolina Characterized the impact of marine debris on a tidal marsh in North Carolina | Uhrin, A. V., | Schellinger, J. | 2011 | Field study in a specific location | Focused on tidal marshes | Limited to one geographic area |
| Characterization of marine debris in North Carolina salt marshes | Viehman, H. A., et al. | 2011 | Field study in salt marshes | Detailed environmental focus | Limited to salt marshes | Characterized marine debris in North Carolina salt marshes, providing insight into local environmental impact |
| Density and size of derelict fishing gear affect colonization by marine organisms in North Carolina estuaries | Uhrin, A. V., et al. | 2005 | Field study of derelict fishing gear | Focused on estuarine environments | Limited scope (only fishing gear) | Demonstrated how derelict fishing gear affects colonization by marine organisms in North Carolina estuaries |
| A relevant screening of organic contaminants present in freshwater and pre-production microplastics | Campanale, C., et al. | 2020 | Screening study | Focused on organic contaminants | Limited to pre-production microplastics | Screened for organic contaminants in freshwater and pre-production microplastics |
| Analysis and microbial degradation of Low-Density Polyethylene (LDPE) in Winogradsky column | Kumar, P.S; Sridharan R.; Krishnaswamy, V.G | 2021 | Experimental study | Novel microbial degradation approach | Laboratory-based, may not apply to all environments | Analyzed the microbial degradation of LDPE using a Winogradsky column |
| Particulate plastics as a vector for toxic trace-element uptake by aquatic and terrestrial organisms and human health risk | Bradney, L., et al. | 2019 | Literature review and risk analysis | Focus on human health risk | Limited to existing data | Examined how particulate plastics can act as vectors for toxic trace elements, posing risks to human health |

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| Nano polystyrene translocation and fetal deposition after acute lung exposure during late-stage pregnancy | Fournier, S.B., et al. | 2020 | Experimental study on animals | Critical human health implications | Ethical concerns with animal studies | Demonstrated the translocation and fetal deposition of nano polystyrene following lung exposure during pregnancy |
| Microplastic and nano plastic transfer, accumulation, and toxicity in humans | Stapleton, P.A. | 2021 | Literature review | Comprehensive coverage of human impact | Limited to existing studies | Reviewed the transfer, accumulation, and toxicity of microplastics and nano plastics in humans |
| Plastisphere enriches antibiotic resistance genes and potential pathogenic bacteria in sewage with pharmaceuticals | Wang, Z., et al. | 2021 | Field and laboratory study | Combined field and lab approaches | Limited to sewage environments | Found that the plastisphere can enrich antibiotic resistance genes and potential pathogens in sewage |
| A first overview of textile fibers, including microplastics, in indoor and outdoor environment | Dris, R., et al. | 2017 | Field sampling in various environments | Broad environmental coverage | Limited to fiber-type microplastics | Provided an overview of the presence of textile fibers and microplastics in both indoor and outdoor environments |
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| Microplastics in the marine environment: A review of the methods used for identification and quantification | Hidalgo-Ruz, V., et al. | 2012 | Literature review | Comprehensive review of methods | No new experimental data | Reviewed the various methods used to identify and quantify microplastics in marine environments |
| A critical overview of the analytical approaches to the occurrence, the fate, and the behavior of microplastics in the environment | Rocha-Santos T, Duarte AC | 2015 | Literature review | Detailed analysis of analytical approaches | Limited to existing methods | Provided a critical overview of analytical approaches to studying microplastics in the environment |