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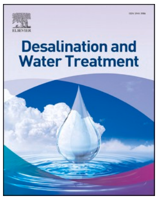

Microplastics toxicity: Classification, sources, exposure routes, and experiments

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ABSTRACT

Microplastics (MPs), including polymers such as polyethylene, polyvinyl chloride (PVC), and polystyrene (PS), are widespread environmental contaminants detected in air, water, soil, and food. These particles originate from the breakdown of larger plastics and from direct industrial and consumer sources, including packaging, textiles, and personal care products. MPs enter the human body primarily through ingestion, inhalation, and dermal contact, with food, water, and air serving as major exposure pathways. Once internalized, MPs have been found in various human tissues and biological fluids, indicating their capacity for bioaccumulation. Toxicological studies in experimental models and occupational settings link MP exposure to oxidative stress, inflammation, cellular dysfunction, and potential organ toxicity, including effects on the gastrointestinal, respiratory, immune, reproductive, and nervous systems. PVC microplastics, in particular, are associated with liver toxicity and increased cancer risk in occupationally exposed populations. MPs can also act as vectors for environmental pollutants and plastic-associated chemicals, further amplifying health risks. This review summarizes the classification, major sources, exposure routes, and toxicological activity of MPs. A comprehensive understanding of MP properties is essential for developing effective strategies to mitigate their persistent harmful effects on public health and the environment.

1. Introduction

Microplastics are posing an increasing risk to healthcare and environmental management due to their prevalence and potential toxic impact. Global plastic production and use have led to what is termed the "plastic world" [1,2]. MPs enter the human body through contaminated food after being consumed by organisms and moving up the food chain. By absorbing and transferring additional pollutants, such as heavy metals, these contaminants can seriously endanger human health and aquatic ecosystems [3–5].

Plastics are petroleum-based resources, and despite the development of recycling technologies, feedstock recycling, and thermal recycling, much of the plastic waste persists in the environment [6]. The artificial polymers not only contaminate the environment but also act as chemical vectors, characterizing them as Anthropocene-markers, typical of the epoch after the mid-20th century Their utilization continues to grow, propelling environmental risk [7,8].

Many researchers have identified MPs of different types, sizes, shapes, polymers and concentrations in different environmental components. Campanale *et al.* [9] reported the presence of MPs in fresh and marine water. Rillig *et al.* [10] reported that it can be found in agricultural ecosystems, whereas other researchers have reported that it can be found in other components, such as drinking water, the atmosphere, organisms, food, and sediments [11–15].

Frias and Nash [12] reported that MPs include materials with different diameters (<5 mm) and morphologies (regular or irregular). According to Alimi *et al.* [16], in 2018, 20 % of global plastic production was recycled. Unfortunately, a considerable portion of plastics are exposed to UV radiation and mechanical damage; however, they are not biodegradable and become plastic waste [17].

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Studies have shown that MPs can accumulate in aquatic organisms and induce health complications, including damage to the intestinal tract and metabolic alterations. Khan et al. [18] and Bhusare et al. [19] mentioned that the persistence of MPs in the environment requires innovative solutions to control them. While attention to Mps has often focused on their ecological impacts, the link between this compunds and climate change points to a broader environmental crisis that requires integrated research and policy action [20].

As MPs degrade in the environment, they release embedded PAEs, making them a persistent and widespread secondary source of pollution. This degradation increases the environmental distribution of PAEs and their associated ecological and health risks. Phthalate esters (PAEs) are found in a wide variety of consumer and industrial products are synthetic substances that are frequently employed as plasticizers to improve the softness, flexibility, and durability of plastics, especially in PVC, and other plastic polymers are responsible for more than 80 % of the world's phthalate usage [21,22]. Both direct (such as sewage treatment plant discharges, urban wastewater, and industrial effluents) and indirect (such as surface water runoff, atmospheric deposition, and landfill leachate) pathways allow PAEs to infiltrate aquatic environments. Through resuspension, these substances may build up in sediments and serve as reservoirs and possible sources of contamination [23,24]. The most popular technique for detecting PAEs was gas chromatography-mass spectrometry (GC-MS), which was employed in 78.8 % of the investigations for precise quantification [25].

The importance of this review lies in synthesizing current evidence on the mechanistic pathways by which environmental MPs contribute to toxicity in humans. Highlights the need for a deeper understanding of the properties of microplastics and their harmful effects. Contribute to the development of effective strategies to mitigate the impact of microplastics. The review will be helpful to researchers, decision-makers and those interested in the environment and public health.

2. Classification of microplastics

2.1. Polymer types

Common polymers involve polypropylene (PP), low-density polyethylene (LDPE), high-density polyethylene (HDPE), polyvinyl chloride (PVC), polyethylene terephthalate (PET), and polystyrene (PS) [26,27]. Other plastics are thermoplastic elastomers (TEPs), polybutylene terephthalate (PBT) and polyoxymethylene (POM) [28]. Monogenic classification is another approach to categorizing plastics, based on origin, size, shape, composition, colour and toxicity [29].

2.2. Forms and sizes

Plastic is a widely used material with different shapes, sizes, and compositions, and can be divided into macroplastics, mesoplastics, microplastics and nanoplastics:

- Macroplastics: Items larger than 20 mm, such as bottles and containers, contribute significantly to environmental pollution [28].
- Mesoplastics: Items with sizes between 5 and 20 mm, including larger particles such as resin particles [30].
- Microplastics: Particles, typically less than 5 mm, forming microplastics [31].
- Nanoplastics are even smaller, 0.2–2 mm in size, and can penetrate biofilms [31].

Additionally, researchers [18,19] have classified microplastics as degradable or undegradable (Table 1) [32,33].

Microplastics are widespread pollutants and their effect is crucial for freshwater ecosystems and health hazards. The predominant sources of MPs can be further categorized as terrestrial and marine point sources, and terrestrial sources alone are responsible for around 80–90 % total pollution (Fig. 1) [34]. The main pathway of MPs is wastewater treatment plants, with millions of microplastics particles disposed of through wastewater treatment plants. These facilities are capable of disposing of more than 90 % of MPs efficiently; however, huge quantities still find their way into natural water sources [35].

Table 1
Categories of microplastics (MPs) (32,33).

Classification	Name	Density (g/cm^3)	Melting point (°C)
Biodegradable MPs	Poly lactide	1.20 –1.30	155–185
	Poly carprolactone	1.146	60
	Poly (butylene succinate co-adipate	1.23	800–1000
	Polybutylene succinate	1.26	114
Non-biodegradable MPs	Polyethylene terephthalate	/	250—255
	polypropylene	0.89 – 0.91	165
	Polyethylene	0.920	130–145
	Polyvinyl Chloride	1.38	N/A
	Polystyrene	1.05	240

Source of Microplastics

Another pathway is the residential activities, such as laundry and personal care products, which create huge amounts of MPs,which made of synthetic materials, especially textile fibres from clothing and microbeads used in cosmetics and personal care formulations [36]. MPs detected urban and coastal locations: More studies show that the highest levels of plastic pollution are found near landfills and urban areas, leading to detection from low laying debris items and fishing gear [37].

Food contains a number of plastic polymers that are used, such as polyethylene, polypropylene, polyethylene terephthalate (PET), and polystyrene. MPs exist primarily in the form of fibres (or filaments) At higher or lower concentrations, fibres are more hazardous by comparison, compared to spherical particles [38]. Moreover, a range of plastic contaminants are present in food also ingested by people; e.g.: Sucrose (044 particles/g), Sodium Chloride (0.11particles/g), Ethanol (33particles/L), Water bottle (95 particles/L), and Honey (0.10 particles/g),as a result, various stakeholders and policymakers have collaborated in seeking and implementing solutions to address this pollution [39–42].

3. The Interact of microplastics

3.1. The Interaction with heavy metals and PFAS

Recent studies show that MPs adsorb heavy metals such as Cd, Ni, and Pb through physical interactions, influenced by factors like pH, contact time, and microplastic type. The adsorption process is often best described by the Langmuir isotherm and pseudo-second-order kinetics, indicating strong and specific binding. Surface characteristics, including pore size and area, play a significant role, and environmental aging (e.g., UV exposure) increases adsorption capacity. These interactions raise concerns about bioaccumulation and biomagnification in aquatic food webs, posing risks to both ecosystems and human health [43,44]. MPs also efficiently adsorb PFAS, with adsorption capacity affected by polymer type, particle size, environmental aging, and the presence of organic/inorganic matter. Mechanisms include hydrophobic interactions, hydrogen bonding, and surface complexation. Environmental factors such as pH, ionic strength, and natural organic matter modulate these interactions. MPs facilitate PFAS transport and increase their environmental persistence and toxicity, especially in aquatic organisms [45].

3.2. Antibiotic interactions

Microplastics (MPs) and antibiotics are increasingly recognized as co-occurring pollutants in aquatic and terrestrial environments, with their interactions raising significant environmental and public health

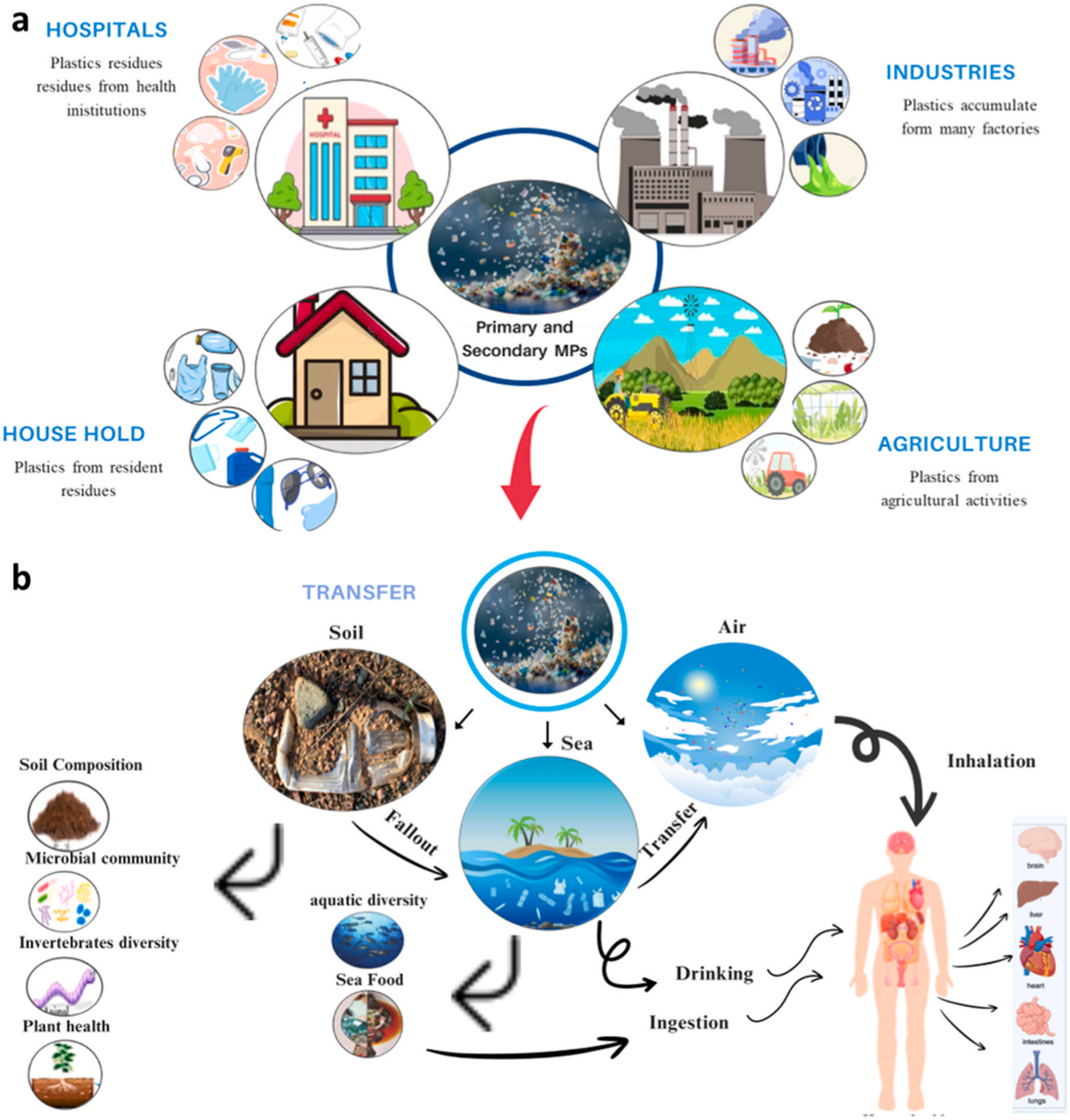

Fig. 1. The source of MPS. The scheme illustrates the different sources of MPs in the environment. a: MPs source from domestic, agriculture, industries, and hospitals. Each source releases plastic debris to the environment, which in turn accumulates and becomes toxic. b: the transfer of MPs to air, water, and soil. MPs can fall from soil into the aquatic system, affecting the aquatic diversity and drinking water, and from water can be transferred to the air, which subsequently enters the human body through inhalation [34]. The figure is adopted by Canva tools.

concerns. Recent research has provided new insights into the mechanisms and consequences of these interactions.

Microplastics possess a high capacity to adsorb antibiotics due to their large surface area and diverse surface chemistries. This adsorption is driven by hydrophobic, hydrogen-bonding, and electrostatic interactions, and is further influenced by environmental factors such as pH, ionic strength, and the presence of dissolved organic matter. Notably, the weathering or aging of MPs—through processes like photoaging or biotic aging—significantly increases their ability to adsorb antibiotics, as aging introduces more functional groups and surface roughness, enhancing both the quantity and strength of antibiotic binding. The formation of biofilms on MPs further amplifies their environmental impact. Biofilm-coated MPs act as hotspots for antibiotic resistance genes (ARGs), providing a unique microbial community structure that facilitates horizontal gene transfer (HGT) among bacteria. This process accelerates the spread of antibiotic resistance, as biofilms on MPs serve as reservoirs and vectors for ARGs in aquatic systems [46]. For example, aged polystyrene and polypropylene MPs have been shown to adsorb more antibiotics, potentially prolonging the environmental persistence of these contaminants and influencing microbial resistance patterns [47]. The co-existence of MPs and antibiotics in environments such as wastewater treatment plants and agricultural soils has been shown to increase the abundance and mobility of ARGs, posing heightened risks to both ecosystem and human health [48]. Recent studies emphasize that the combined presence of MPs and antibiotics not only alters the fate and transport of these pollutants but also exacerbates the development and dissemination of antibiotic resistance. This underscores the urgent need for integrated pollution control strategies and further research into the long-term ecological and health impacts of MP-antibiotic interactions [49].

3.3. *Engagements with organic contaminants*

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MPs adsorb organic contaminants primarily through hydrophobic interactions, hydrogen bonding, and electrostatic attraction. The efficiency of adsorption is strongly influenced by the type of polymer, surface charge, and the degree of aging. For instance, aged polylactic acid (PLA) MPs show increased adsorption of hydrophilic organic pollutants such as benzoic acid and sulfonamide antibiotics, with surface charge emerging as the dominant factor affecting adsorption performance. The main mechanisms include hydrophobic interaction, hydrogen bonding, and electrostatic attraction, with hydrophobicity being the most significant. Charge-assisted hydrogen bonding and partition effects can further enhance adsorption under specific conditions. Notably, the adsorption capacity of aged PLA for hydrophilic organic pollutants is generally higher than that of virgin PLA, highlighting the importance of environmental weathering in modulating MP behaviour [50].

Aging processes, such as UV exposure and oxidation, significantly increase the adsorption affinity of MPs for organic contaminants. For example, weathered high-density polyethylene (HDPE) and polypropylene (PPE) MPs exhibit much higher adsorption of model contaminants like phenanthrene and methylene blue compared to their pristine counterparts. The increase in adsorption is attributed to changes in surface chemistry, such as the introduction of oxygen-containing functional groups and increased specific surface area. These changes enhance the MPs' ability to act as vectors for contaminants in aquatic food chains, potentially increasing ecological risks [51].

3.4. *Microplastics and Microorganisms*

Microplastics are now recognized as significant environmental pollutants, and their interactions with microorganisms are a rapidly evolving area of research. Recent studies have shown that microplastics provide new surfaces for microbial colonization, leading to the formation of unique biofilms—sometimes called the "plastisphere"—that differ in composition from those found on natural substrates. The characteristics of microplastics, such as polymer type, size, and degradability, as well as environmental factors like temperature and salinity, play crucial roles in shaping these microbial communities. Notably, non-degradable microplastics like polyvinyl chloride and polystyrene tend to support higher microbial biomass and diversity compared to degradable plastics, and smaller microplastics are generally more conducive to colonization. Over time, environmental conditions become increasingly important in determining the diversity and structure of these biofilms [52,53].

The presence of microplastics in both aquatic and terrestrial environments has been shown to alter microbial community structure and function. In aquatic systems, microplastics act as vectors for microorganisms, including potential pathogens and antibiotic resistance genes, raising concerns about ecosystem and human health. The microbial communities that develop on microplastics are often distinct from those in the surrounding environment, with certain taxa being selectively enriched. For example, microplastic biofilms in freshwater and marine environments have been found to harbor opportunistic pathogens and exhibit unique resistomes, which may facilitate the spread of antibiotic resistance [54].

Microorganisms also play a role in the fate of microplastics through biodegradation. Both bacteria and fungi have demonstrated the ability to degrade various types of microplastics, although the efficiency of this process depends on the microbial species involved, the type of plastic, and environmental conditions. Biofilm formation on microplastics can enhance degradation by increasing the surface area for microbial activity and facilitating the breakdown of plastic polymers. However, the overall rate of microbial degradation in natural environments is generally slow, and more research is needed to identify effective microbial strains and enzymes for bioremediation purposes [55].

4. Toxic effects of MPs and various additives on human Health

4.1. *Impacts on hormones*

Diverse chemicals utilized in plastic manufacture have been documented to have varied harmful effects on humans. Many substances, including synthetic ones like BPs, biphenyls, phthalates, parabens, phenols, organochlorines, alkylphenols, pesticides, and polychlorinated compounds, as well as natural ones like phytoestrogens and estrogens, function as Endocrine-Disrupting Chemicals (EDCs) [56,57].

Table 2 illustrates many sorts of additives utilized in plastic manufacture, their impacts, and the corresponding types of polymers [58].

4.2. *Cellular and systemic effects*

Emerging evidence shows MPs bioaccumulate in critical organs such as the brain, blood, and cardiovascular tissues, potentially contributing to neurodegenerative diseases, cardiovascular inflammation, and multisystemic toxicity, although causal links require further study. The "triple exposure nexus" concept integrates the physical particles, plastic-associated chemicals, and adsorbed environmental pollutants, emphasizing their combined genotoxic, inflammatory, and endocrine-disrupting effects, which remain poorly understood [59].

Novel research directions include developing standardized terminology and methodologies, advancing interdisciplinary risk assessments incorporating probabilistic models, and exploring innovative remediation and mitigation strategies such as biodegradable plastics and improved waste management [60,61]. Additionally, there is a critical call for enhanced governance, public engagement, and behavioral change to reduce plastic use and exposure, alongside filling knowledge gaps on long-term health impacts and environmentally relevant exposure levels [62].

Numerous *in vitro* and *in vivo* investigations have demonstrated that micro- and nano plastics can induce significant adverse effects on the body of a person, involving destruction and physical stress, inflammatory processes, apoptosis, immunological activities, oxidative damage, and necrosis (Table 3).

4.3. *The correlation with intestinal disorders*

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Table 2
Various additives utilized in plastic manufacturing, their impacts, and the classifications of plastics [58].

Additives	Applications	Impacts on the General Public	Types of plastics
Polycyclic aromatic hydrocarbons	Pesticide	Developmental, reproductive toxicity	All
Nonylphenol	Surfactant	Esterogen mimic	Polychlorides
Bisphenol A	Plastics	Ovarian dysfunction	Polychloride, Polycarbonate
Styrene monomers	Decomposition	Carcinogen	Polystyrenes
Phthalates	Plasticizers	Testosterone Interference	Polychloride, Polycarbonate
PCBs	Electrical Equipment	Thyroid disruption	All
Persistent organic pollutants	Pesticide, flame retardant	Neurological and Reproductive	All
Dioxins	PVC combustion	Carcinogenic	All

Table 3
Toxicological effect of MPs on Human health.

Effect	Plastic Type	Size	Observed Toxicity	Ref.
Inflammation	Polystyrene	202–535 nm	Upregulation of IL-8 Lung inflammation	[63]
	Polyethylene	0.2–10 μm	TNFa, 1L-1,RANKL, production, Bone resorption	[64]
	Polystyrene	5–20 μm	Hepatic inflammation	[65]
Oxidative Stress and Apoptosis	polystyrene	20–100 nm	Cell death	[66]
	PVC, PMMA	120–140 nm	ATP depletion, ROS accumulation	[29]
Energy homeostasis	polystyrene	0.5–5 μm	Metabolic imbalance, Gut microbiota dysbiosis	[67, 68]
	polystyrene	50–200 nm	Iron acquisition	[69]

Table 4
The impact of microplastics on intestinal disease.

Disease	Biological Effect	Mechanism	References
Gut dysbiosis	Reduced microbiota diversity	Biofilm formation on MPs	[70]
Gut barrier dysfunction	Microbial imbalance	Mucus reduction, increase permeability	[71]
Gut inflammation	Increase cytokines level (Il-6, TNF-α, IL-1β, NF-κB	Structural damage to intestinal tissue	[72]

5. Harmful effects of MPs on living microorganisms

5.1. Community structure and diversity

Freshwater ecosystems animportant for nutrient, biogeochemical cycling, and energy flow. Microorganisms play an important part in this ecological cycles, included potential waterborne pathogens, and *Pseudomonas* is a common bacteria found in a variety of surface waters [73]. MPs consistently alter the composition and diversity of microbial communities. In soils, both conventional (e.g., polyethylene, PE) and biodegradable (e.g., polylactic acid, PLA). MPs shift bacterial community structures, often reducing diversity and favoring certain taxa such as *Proteobacteria, Actinobacteria*, and *Chloroflexia.* In aquatic environments, MPs serve as unique substrates for biofilm formation, supporting distinct microbial assemblages compared to natural surfaces [74]. Also, Functional Changes, MPs influence key microbial functions, including nutrient cycling (carbon, nitrogen, phosphorus) and enzyme activities. For example, MPs can stimulate soil carbon dioxide emissions, alter nitrogen cycling (e.g., promoting or inhibiting nitrification/denitrification depending on polymer type), and affect phosphorus cycling genes [75].

MPs act as new microbial niches biofilm formation and plastisphere, called "plastisphere", fostering biofilms with unique community structures and metabolic profiles, which may include plastic-degrading or pathogenic microbes [73]. The impact of MPs depends on their concentration, polymer type, shape, and size. Higher concentrations and certain polymers (e.g., PE, PVC) generally have stronger effects on microbial community assembly and ecosystem functions [73].

5.2. Effect on algae

Through a variety of harmful processes, MPs have a substantial effect on microorganisms, especially microalgae. Polystyrene and polyvinyl chloride are particularly harmful MPs,. Those chemicals cause oxidative stress and stunt the growth of the organisms studied. According to Xie et al. [76], microalgal frequency is lowered at higher PS concentrations because inhibition of growth occurs as a result of an increase in contact area. According to Zhao et al. [77], exposure to PVC inhibits algal development in a dose-dependent manner. In the case of Chlorella vulgaris, doses as high as 1000 mg/L reduce growth by up to 29.34 %. Li et al. [74] found that growth and photosynthesis effectiveness in Karenia mikimotoi drastically decrease with increasing concentrations of PVC, suggesting that the physical barrier induced by PVC particles triggers cytotoxicity.

Toxic effects, not just shadow consequences, result from MPs' interaction with microalgae throughout adsorption and aggregation [74]. Influence of charge: Cyanobacteria become more susceptible to oxidative stress and destruction of membranes when exposed to positively charged MPs [78]. Research predominantly suggests MPs negatively impact microorganisms; some studies suggest that under certain conditions, MPs may stimulate microbial growth, indicating a complex relationship that warrants further investigation [79].

6. Pathways of human exposure

The microplastics (MPs) and nanoplastics (NPs) pose significant health risks by entering the human body through three primary pathways (Fig. 2) [80,81].

1. Inhalation
2. Ingestion
3. Skin contact

It was demonstrated that anthropogenic sources led these particles to be distributed in the ambient atmosphere, taking them away from the human body. Another investigation by Schneider, M. [82] and Carbery, M [83], revealed that the human body receives different plastic fragments from food, in fact, through oral feeding or from water supplies.

Plastic pollution permeates different ecosystems, leading to health issues for living organisms, including humans, through skin contact and eventual absorption into the body. Researchers have shown that microplastics in freshwater lead to food contamination and a higher prevalence of fish diseases, which may be transmitted down the food chain, ultimately impacting people [84,85].

7. Adverse effects of microplastics

7.1. Metabolic disorder

Microplastics, particularly polystyrene (PS), have been shown to adversely affect the liver and intestines in various animal studies. Research indicates that exposure to PS. Microplastics alter enzyme activities, disrupt lipid digestion, and impact metabolic processes. In zebrafish, exposure to PS nanoplastics results in structural changes in the intestines, including inflammation and oxidative stress, which disrupt the intestinal microbiota and alter glycolipid metabolism [86]. According to a study conducted by Del Piano et al. [87], mice that were exposed to PS microplastics showed alterations in the variety of gut microbiota and a decrease in the expression of genes related to tight junctions, suggesting that the intestinal integrity was damaged. The presence of PS microplastics in gilthead seabream lipid metabolism was found to enhance the expression of genes associated with inflammation and synthesis of lipids, implying a potential risk for nonalcoholic fatty liver syndrome [88]. MPs interfered with the liver's metabolic processes for energy and changed metabolite levels, according to zebrafish research [89].

7.2. Immunological reaction

It has been demonstrated that microplastics, especially polystyrene (PS), have a major effect on immunological responses in a variety of organisms, resulting in inflammation and changes to gut function.

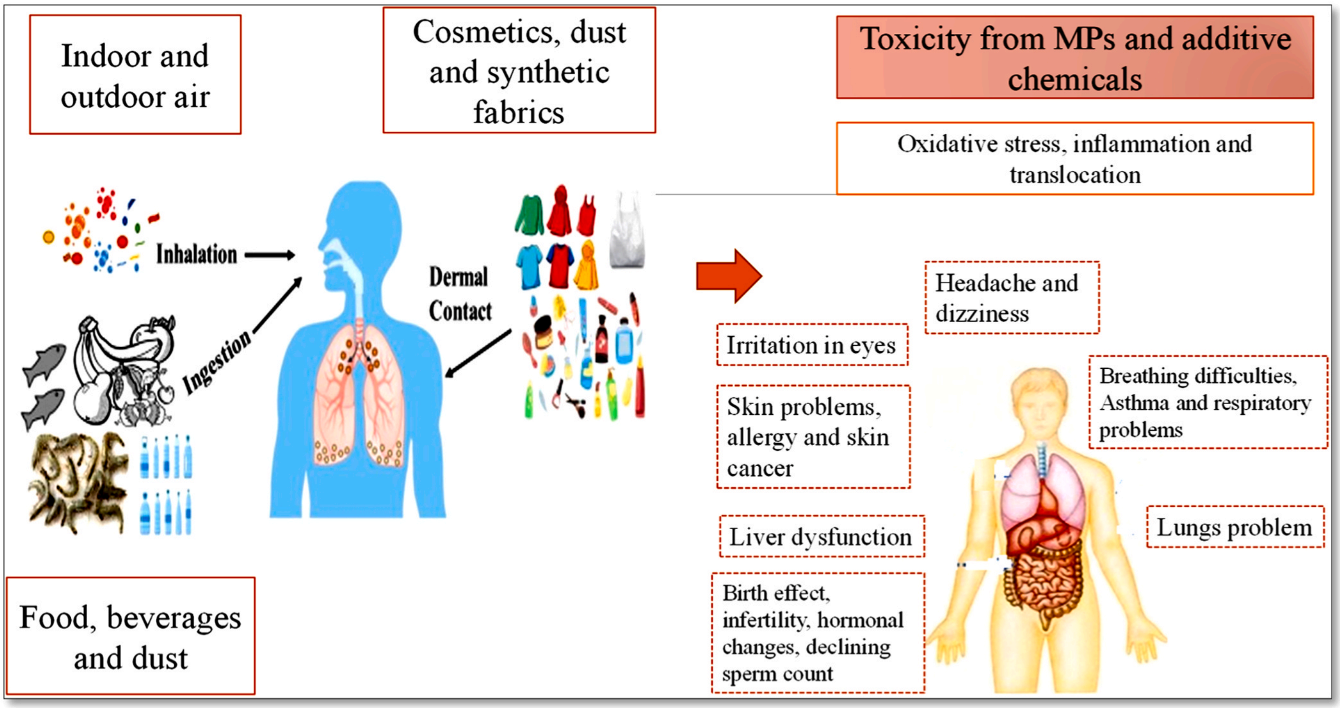

Fig. 2. Human exposure to MPs via various routes and associated human health risks. Modified from. The left panel represents the MPs' exposure route. Humans can be exposed to MPs via inhalation (indoor and outdoor), ingestion (food and beverages), and dermal contact (cosmetics, water bottles, clothes, etc.). The right panel refers to the adverse impact of MPs on human health. The figure is adopted by [80,81].

Immune responses, oxidative stress, and heightened susceptibility to infections have all been linked to PS microplastic exposure, according to research. Increased cytokine production and changed gene expression in intestinal cell lines are signs that PS microplastics cause immune cells to respond proinflammatoryly. After being exposed to PS microplastics, macrophage' metabolic changes to glycolysis, which raises the production of inflammatory markers and could lead to immunological dysfunction [90].

7.3. Function of the intestines

Animal models have shown that microplastics upset the balance of bacteria and shape in the gut, which leads to changes in overall gut health. When microplastics are exposed, they create reactive oxygen species that can hurt cells and mess up immune signaling pathways, which makes inflammation even worse. Masud and Cable found that fish that were exposed to MPs had higher levels of pathogens and higher death rates, which showed that they were less resistant to disease. According to Yang et al., [74], Su et al. [86], Chen et al. [71], PS microplastics destruction the intestines of mice and lead to more bacterial illnesses. This is linked to higher levels of inflammatory markers like TNF-α and IL-1β.

7.4. Immunotoxicity mechanisms

- **Pathogen Carriage:** MPs can build up in environmental pathogens, which can make people more likely to get sick by weakening their immune systems. When MPs interact with bacteria, they can make them more dangerous, which puts more stress on the immune system [19]
- **Production of reactive oxygen species (ROS):** MPs cause ROS to be made, which can cause immune cells like macrophages to die, which weakens immune reactions. According to Frank et al. [91] and Lin et al. [92], this oxidative stress can damage intracellular signaling pathways and make tissue damage and inflammation worse.
- **Changes in cytokines:** MPs change the production of cytokines, which throws off the immune system's balance and T-cell reactions. This can cause long-lasting inflammation. According to Siwach et al. [93], these changes can lead to a higher inflammatory state, which makes people more likely to get sick.

- **Damage to immune organs:** MPs build up in important immune organs like the kidneys and liver, resulting harm to the structure and lipids buildup. The actual existence of MPs may inhibit immune reactions, making fish less resistant to disease [94].
- **Interfering with Intracellular Signaling:** MPs mess up intracellular signaling pathways, lowering important immunity factors like interleukin-1 beta (il1b), that was needed for the immune system to work [79]. According to Wang et al. (20), this disruption changes the amounts of cytokines and gene expression, which in turn weakens immune homeostasis.

8. Conclusions

Microplastics (MPs), including particles derived from polyethylene, polyvinyl chloride, polystyrene, and other polymers, have become ubiquitous environmental contaminants due to the extensive use and improper disposal of plastics. MPs are generated through the degradation of larger plastic items and are found in air, water, soil, and a wide range of food products, leading to human exposure primarily via ingestion, inhalation, and dermal contact. Once internalized, MPs have been detected in various human tissues and biological fluids, raising concerns about their bioaccumulation and potential health risks. Toxicological studies indicate that MPs can induce oxidative stress, inflammation, cellular dysfunction, and may contribute to the development of gastrointestinal, reproductive, cardiovascular, and neurodegenerative disorders. The toxicity of MPs is influenced by their size, shape, polymer type, and surface properties, with smaller particles generally exhibiting higher bioactivity. Despite growing evidence of adverse effects, significant knowledge gaps remain regarding environmentally relevant exposure levels, long-term health impacts, and the combined effects of MPs with other environmental contaminants. Current research emphasizes the urgent need for standardized methodologies, comprehensive risk assessments, and the development of effective mitigation strategies to address the global challenge posed by microplastic pollution and its implications for human health and the environment to reduce their toxic effects, which threaten human health in the future.

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CRediT authorship contribution statement

Hassan fikrat M.: Writing – review & editing, Supervision, Resources, Methodology, Data curation, Conceptualization. **Sabbah Majeed:** Supervision. **Warqaa Y. Salih:** Writing – review & editing, Writing – original draft, Software, Conceptualization.

Declaration of Competing Interest

The authors declare that there are no conflicts of interest.

Data availability

No data was used for the research described in the article.

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