Vantage: Journal of Thematic Analysis
DOI: https://doi.org/10.68903/vjta.2026.v07i02.03
Vol. 7(2), October, 2026, 133-149
ISSN(E): 2582-7391

Review Article

The Promise and Peril of Plastics in Modern Society

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Received: 06/07/2026 | Accepted: 13/10/2026 | Published: 30/10/2026

ABSTRACT

A key global pollutant threatening the environment and human health is micro- and nano-plastics, which are widely produced and often improperly discarded. Micro- and nano-plastics are microscopic particles ranging from 1 μm to 5mm and <1 μm, respectively, that inundate and accumulate across every ecosystem. Secondary microplastics form when plastics break down, while primary microplastics are intentionally added to many products. When microplastics enter ecosystems, they enter the food chain and pose serious health risks to organisms that consume them. The presence of micro- and nano-plastics in various human tissues and organs clearly indicates that they can cross biological barriers. The presence of this unwanted menace inside the vital organs raises concerns about their possible toxic health hazards. Their mere presence might cause molecular alterations at the cellular level due to the toxic chemicals they might leach. Micro- and nano-plastics are likely to play a key role in the development and spread of various malignancies through chronic exposure. This review presents an overview of microplastics' presence in the environment and their known potential health effects, focusing on specific organ-barrier breaches.

Keywords: Environmental threat, Microfibers, Microplastics, Nanoplastics, Toxicity

1. INTRODUCTION

A significant scientific interest has recently been attracted to the ubiquitous presence and potential impacts on the environment and human health of the pertinent pollutant micro- and nano-plastics (MNPs) (Zhang et al., 2025; Aranha, 2026). These pervasive plastic pollutants, with a diameter less than 5 millimeters, are broken products of larger plastic debris dumped in the environment and left to degrade (Bora et al., 2024; Ho, 2026). Despite enhancing the quality of human life through durability, lightness, and cost- effectiveness, MNPs contribute substantially as a pollutant at the end of their life cycles (Li et al., 2024). The extensive distribution and rising global production of plastics, exceeding 450 million metric tons annually, worsen this environmental burden as these materials gradually disintegrate and integrate into the biological system (Dokl et al., 2024; Anih et al., 2025). These micron-sized fragments are composed of polymers such as polyethene (PE), polypropylene (PP), and polystyrene (PS), and associated additives, and pose complex challenges to ecological systems and human health (Bora et al., 2024; Li et al., 2024). Humans are potentially exposed to MPs through ingestion, inhalation, and dermal contact (Bhardwaj et al., 2025; Ririe et al., 2025). The global production of plastics is exceeding the shocking levels annually, with a large portion dedicated to single-use items, ensuring a continuous release of these persistent materials into the environment (Kumar et al., 2025). A recent report forecasts that global use

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of plastics is expected to rise from 450 million metric tons at present to 884 million metric tons in 2050, with accumulated stock doubling (Dokl et al., 2024). Thus, it remains an active area of research to determine the full extent of excessive production, indiscriminate consumption and improper disposal leading to hazardous environmental effects, ultimately affecting the human body, including inflammation, oxidative stress, and changes to histological structures (Li et al., 2024; Bhardwaj et al., 2025; Aranha, 2026).

Several recent investigations have found MPs in human blood, brain, heart, placental tissue, and gastrointestinal samples; systematic reviews consistently demonstrate a correlation between MP exposure and biological markers of inflammation, oxidative stress, and endocrine disruption (La Maestra et al., 2024; Marfella et al., 2024; Nihart et al., 2025; Ririe et al., 2025). These results highlight the urgent need for further investigation into their accumulation, translocation, and toxicological consequences inside human organs to identify possible systemic circulation (Pechcińska et al., 2025; Ririe et al., 2025). These concerns, studied in animal models, are supported by findings on MP's role in oxidative stress, inflammation, immunological disturbance, and endocrine consequences. Also notably, in rodent models, higher correlations were seen in reproductive, gastrointestinal, and neurotoxic indicators (Adamopoulos et al., 2025). MNPs can also operate as carriers of toxic substances like phthalates and heavy metals, which can increase their toxicity through synergistic interactions within biological systems (Pechcińska et al., 2025). However, direct evidence regarding the dose-response relationship and chronic impacts of these interactions in human populations remains limited and requires further rigorous epidemiological studies (Anih et al., 2025). This review aims to synthesize recent advances in understanding the presence of MPs in ecosystems and how they interact with biological systems, clarifying their potential health effects and toxicological mechanisms. This study will also examine the exposure routes and accumulation in human tissues, as well as emerging evidence of their ability to damage cells, causing inflammation and oxidative stress, an underlying root of all diseases.

2. SOURCES OF MICROPLASTICS

Despite the many conveniences that plastics provide, MPs, a direct by-product with a diameter of less than 5 mm, have been implicated in an ecological disaster that was not anticipated. The surge in plastic manufacturing reflects people's growing reliance on plastic products. Despite being convenient and creative, plastic waste has spread to almost every part of the Earth due to littering, improper disposal, and poor waste management (Dokl et al., 2024; Aranha, 2026). In 2004, MPs were first discovered and reported, and due to their strong structure and chemical makeup, they can live for a century or more in the environment. They can thrive in the environment for hundreds of years due to their strong chemical resilience. Most of them are commonly composed of polyethylene (PE), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET), low-density polyethylene (LDPE), high-density polyethylene (HDPE), and polyvinyl chloride (PVC) (Kongpran et al., 2026). As depicted in Figure 1, MPs mostly come from two sources: primary and secondary sources. Among the primary sources are plastic particles from paints, textile finishing, industrial pellets (nurdles), abrasives used in industrial cleaning, medicinal and research applications, cosmetics, personal care, and beauty products like glitter. Personal care products such as toothpaste, body wash and shower gels, sunscreens, cosmetics, hair styling products, nail polishes, face masks and peels, anti-ageing and skin creams, and abrasive media for cleaning formulations are made using primary MPs, and they are the major

sources of MPs in aquatic bodies (Ho, 2026).

Secondary sources include the physical and chemical disintegration of long-chain polymers of plastics, as well as biodegradation brought on by some microorganisms. Erosion from exposure to heat, water, and air occurs naturally when plastics are dumped in terrestrial environments. As a result, dumping generates landfill leachate (LL), a key driver of the massive buildup of MPs in these landfills. Because LL, a liquid formed when waste decomposes, and precipitation percolate through waste layers, MPs are more likely to enter the adjacent aquatic bodies, groundwater and soil. This leachate may include MPs as well as other toxins that endanger the health of the soil in surrounding ecosystems and contaminate water supplies (Fu & Yang, 2025). Untreated and unregulated municipal solid waste dumps leak leachate, which presents a serious risk of contaminating land, surface water, and groundwater. An alternative important secondary source of MPs is wastewater treatment plants (WWTPs) designed to remove pollutants. Most of the time, WWTPs serve as both conduits and reservoirs for LL, producing effluent with high concentrations of MPs (Aranha, 2024).

Residual solid waste generated from sewage treatment is also a source of secondary MPs in landfill leachate. The most frequent and common forms of MP polymers in landfill leachate are fibres and fragments, with PE, PS, and PP. The most prevalent polymer in LL is PE, which is followed by PP. The most noticeable kinds of secondary MPs in the leachate fibre are shown to be transparent, blue, white, green, and black in LL. MPs recovered from the leachate differ in size from 0.03 to 5 mm (Kabir et al., 2023). Leachate from non-sanitary waste disposal facilities is also a significant source of secondary MPs. Thus, municipal waste disposal sites are both significant sources and accumulation zones of secondary microplastics (Kongpran et al., 2026).

China, India, and the United States are the top three countries in terms of the number of publications on MPs in landfill leachate. The high research output from these countries may be associated with their large populations, substantial municipal solid-waste generation, and growing environmental concerns related to landfill operations. Polyethylene (PE) is the most dominant type of polymer in LL, followed by polypropylene (PP). Fibre is the most prominent shape of MPs in leachate. The increasing number of publications reflects growing scientific interest in the occurrence, characterization, transport, fate, and potential environmental impacts of MPs in landfill leachate. Particular attention has been given to the development of analytical techniques for microplastic detection and to the effectiveness of different leachate-treatment technologies for their removal. Since landfill leachate can serve as a potential pathway for MPs to reach surrounding soil, groundwater, and aquatic ecosystems, understanding their behaviour and developing effective treatment strategies are important for environmental protection. The dominance of China, India, and the United States also demonstrates their significant contribution to advancing research in this emerging field, while highlighting the need for broader international collaboration and increased research in underrepresented regions (Anilbose et al., 2025).

3. ENVIRONMENTAL PRESENCE OF MICROPLASTICS

Modern industry, which primarily depends on petroleum by-products, consumer behaviour, and lifestyles, has been profoundly altered by the growing production and consumption of plastic-based products. This has led to the replacement of glass and metal packaging materials largely by lightweight, inert single-use plastic materials, leading to a huge volume of persistent plastic waste in the environment (Lamichhane et al., 2023; Razaviarani et al., 2024).

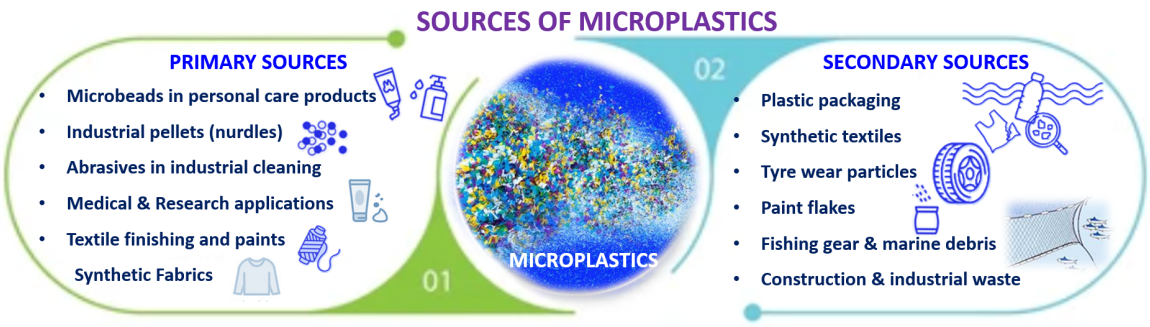


Figure 1: An illustration of the primary and secondary types of microplastics and their sources.

Beyond simple contamination by individual particles, the interactions between MPs and other environmental pollutants constitute an important field of new research. MPs are efficient adsorbents for a variety of contaminants and chemicals found in both terrestrial and aquatic settings due to their special physicochemical characteristics. Because of their large surface area and hydrophobicity, MPs can also sorb pharmaceuticals like antibodies, polychlorinated phenols (PCPs), heavy metals, pesticides and other persistent organic pollutants, as well as other organic compounds, potentially increasing their bioavailability and environmental persistence. Through ingestion, entanglement, and trophic transfer, MPs' ecotoxicological impacts on biota at all trophic levels frequently cause physiological stress, reproductive toxicity, and mortality in aquatic and terrestrial organisms (Maurya & Kumar, 2026).

MPs in terrestrial environments are considered a severe environmental issue worldwide, as terrestrial systems have become the main sinks of MPs. Terrestrial MP contamination is caused by several human activities and environmental factors, including compost fertilisation, sewage sludge amendment, plastic mulching, wastewater discharge, and atmospheric precipitation, especially in agricultural fields growing food crops. Plastic mulching is one of the most widely used agricultural techniques in modern world agriculture and is a major source of MPs in the terrestrial environment (Surendran et al., 2023). An extremely significant linear relationship between the amount of plastic residue in soils and the amount of mulching film utilised indicates that plastic film mulching is a significant source of MPs in agricultural soils when applied extensively. The average MP content in the soil samples was 83.6 kg/ha, with a range of 0.1 to 324.5 kg/ha (Huang et al., 2020). Studies have revealed that MP pollution impairs plant growth and soil biota in terrestrial environments, threatening our food security by directly decreasing agricultural productivity. A range of modern agricultural techniques used to increase agricultural production in limited space has introduced a lot of MPs into the terrestrial ecosystem. MPs are predominant in sewage sludge, and they enter the terrestrial environment through agroecosystems, especially when these biosolids-also known as wastewater treatment sludge-are applied to the soil as fertilizers (Rolsky et al., 2020). Sewage sludge fertilization adds an estimated 63 to 430 and 44 to 300 thousand tons of MPs to agroecosystems in North America and Europe each year (Nizzetto et al., 2022).

WWTPs, where sewage and other wastewater are treated before being discharged, are the primary sources of MPs in aquatic ecosystems, as they typically fail to remove them. Additionally, the accrual of MPs in the environment is greatly influenced by land-use patterns and human activity, as WWTPs are the primary sources of MPs in aquatic environments. This leads to serious concern that MPs in aquatic habitats

are growing extremely high at a global level. It is proven beyond any doubt that MPs are most hazardous to the environment and have detrimental effects on ecological and human health, particularly when they are found in aquatic ecosystems. Daily plastic use, plastic degradation, industrial activities, and WWTPs directly release MPs into the environment. When MPs are in water, aquatic organisms ingest these pollutants, leading to their incorporation into the food chain through them, further posing serious health risks to other trophic consumers (Nematollahi et al., 2025; Zoccali et al., 2025). The effective removal of MPs in WWTPs can be increased by optimising wastewater treatment plants with a focus on MP removal, which includes advanced filtering techniques (such as membrane filtration and granular activated carbon adsorption), flocculation and coagulation, and subsequent flotation or sedimentation approaches (Nematollahi et al., 2025).

4. MICROPLASTICS IMPACT ON BIOLOGICAL SYSTEMS

MPs adversely affect all aquatic and terrestrial organisms through their mere pervasive presence. Due to their small size, they are readily consumed by a wide range of aquatic organisms, mistaking as food, especially by the filter feeders in aquatic ecosystems. Thus, MPs are present at varying concentrations across different trophic levels, with greater concentrations at higher trophic levels *via* bioaccumulation within the bodies of these organisms. Because of their persistence and small size, MPs can infiltrate biological barriers and endanger living beings. Since they come from a multitude of sources, they end up in soil and seas. The existence of MPs in aquatic ecosystems poses a substantial risk to aquatic life, as most of these aquatic organisms, including fish, birds, and invertebrates, confuse them for food. When ingested, these particles cause physical harm, such as blockages in the digestive tract, causing reduced feeding and leading to starvation. Besides obvious physical damage that MPs cause to the organisms when ingested, they can attract many hazardous chemicals and pathogens and act as carriers of them (Lamichhane et al., 2023; Li et al., 2024; McGoran et al., 2025).

Polystyrene microplastics (PS MPs) are an emerging aquatic pollutant with potential toxicological impacts on fish health and aquaculture sustainability. Studies revealed that PS MNPs of different sizes can alter similar pathways related to energy metabolism (e.g., lipid, carbon, and amino acid metabolism), oxidative stress, immune response, and the nervous system in both fishes and aquatic invertebrates, and that these can be linked to alterations in widely studied lethal/sublethal endpoints (e.g., reproduction, development, growth, mortality, nervous system, and metabolic disorders) at the population level (Eliso et al., 2024). PS MPs affect growth performance, enzymatic activity, haematological parameters, behaviour, nutrient digestibility, and histopathology in common freshwater carps like Rohu and Catla (Latif et al., 2026). A study investigated the toxic mechanisms of environmentally relevant concentrations of 1 mg/L of PS MPs on juvenile *Macrobrachium rosenbergii*, an economically important freshwater prawn, through a 42-d chronic exposure and a 14-d recovery experiment. MPs inhibited growth and reduced body length and weight remarkably. Study revealed the MPs accumulation extensively in the gills, stomachs, intestines, and hemolymph of the prawn. Ultrastructural analysis showed persistent mitochondrial swelling in gill filaments and shedding of intestinal villi, even during the recovery phase. Additionally, oxidative stress biomarkers and upregulated lipid metabolism genes indicate metabolic dysregulation (Zhou et al., 2026).

Farm animals are particularly vulnerable to MP exposure due to continuous ingestion of

contaminated pasture, fodder, and water. MPs have been detected in farm soil, water, and feed, raising concerns about chronic exposure and cumulative reproductive health effects in these animals (Yan et al., 2024; Nahiduzzaman et al., 2025). Animal health is seriously endangered by the pervasiveness of plastic particles in feed, air, and water supplies (Fu & Yang, 2025). These particles can harm vital systems such as the reproductive, cardiovascular, neurological, immunological, excretory and digestive systems. A study done at the Thames estuary, UK, revealed alarming findings about MP pollution. It revealed that all organisms in the estuary are exposed to MP pollution. Fish and shrimp were studied as sample specimens, which revealed the presence of MPs, on average 1.59 ± 2.62 items per individual in fish and 0.39 ± 0.95 items per individual in shrimp (McGoran et al., 2025). According to reports, benthic fish have greater MP concentrations than pelagic fish. Because of their habitat, benthic fish are more likely to inadvertently or purposely consume most MPs; also, a significant number of pollutants build up on the bottom of water basins. Fish frequently consume MPs, which then enter their digestive tracts and, once inside, they spread throughout different tissues and organs after infiltrating the fish's lymphatic and circulatory systems. Fish gills, muscles, liver, heart, swim bladders, ovaries, spinal cords, and even brains have all been reported to contain MPs. Reproductive, neurological, hormonal, and immune system abnormalities are only a few of the serious negative consequences associated with MPs in various organs. MPs are a significant anthropogenic stressor that affects ecosystems on several levels, and their toxicity goes beyond fish since they bioaccumulate and biomagnify in other animals (Ghosh et al., 2025).

5. MICROPLASTIC EXPOSURE PATHWAYS IN HUMANS

MPs may enter the human body through three primary routes: ingestion, inhalation, and skin absorption, as depicted in Figure 2 illustrating these three routes. Human exposure, particularly through food chains, drinking water, and atmospheric inhalation, raises concerns over long-term health effects, including inflammation, oxidative stress, and endocrine disruption. Ingestion is the most common method of exposure to MPs. MPs from contaminated waters are frequently found in seafood, especially fish and shellfish. Table salt contributes over 2,000 MP particles to our meals each year (Villafuerte-Campi et al., 2026), while bottled water, a mainstay for many, has up to 325 particles per litre (Uwaga et al., 2026). These particles enter our systems even through produce that is cultivated on polluted soil. Research has revealed MPs in the liver, colonic tissues, and faeces as they move through the digestive tract following consumption. The majority of the ingested MPs and NPs are made up of plastic particles that range in size from 0.1 to 1 μm. These particles spread throughout the body's various tissues and organs, impacting the nine main systems of the human body, especially the respiratory and digestive systems, which are directly related to the uptake route of these particles. Potential harmful mechanisms such as oxidative stress induction, inflammatory response production, lipid metabolism or energy metabolism modification, or expression of associated functional variables are the main ways that MPs and NPs trigger damage (Zhu et al., 2024).

Synthetic materials dust contaminates indoor air quality and acts as a source of MPs. Outside, the environment is filled with microplastic-containing construction dust, tyre wear and industrial pollution, etc. According to South Korean research, indoor air is 1.5 times more

contaminated with MPs than outdoor air due to household dust and synthetic fabrics (Lee et al., 2023). In addition to fragments, plastic waste can also take the form of tiny, nanoscale polyester fibres that can enter the lungs and cause allergic reactions (Liu et al., 2025). Deeply embedded in lung tissue, these particles cause oxidative stress and inflammation, the two conditions associated with respiratory disorders. Airborne MPs and NPs can harm lungs by entering the system through inhalation. Studies show that prolonged exposure to higher levels of MPs/NPs owing to one's occupational exposure fairly increases the likelihood of acquiring pulmonary disease. MPs may interact with bodily systems and disperse among various tissue systems (Huang et al., 2020). Numerous chemicals, heavy metals, and other toxic substances can also be transported by MPs and eventually end up in the human body through the respiratory system, risking human health directly (Zhu et al., 2024).

The largest organ, the skin, functions like a strong barrier to prevent foreign substances from entering the human body. It is a potentially valuable target for the controlled delivery of diagnostic or therapeutic agents, offering advantages over other routes of administration. However, the penetration of unwanted substances and pollutants through breached skin can be extremely dangerous for human health. Recent research has shown that small particles, especially those in the nanosized range, can not only penetrate the skin but also act as vectors to transport active molecules. Dermal diffusion of MP and NP particles is one of the major health concerns at present. While the primary toxicity of these materials is still debated, their possible role in transporting toxic molecules through the skin, which could lead to secondary toxicity, is surely alarming (McLean et al., 2025; Menichetti et al., 2025). A large number of studies on MNP skin uptake focused on fluorescently tagged polystyrene particles, which limited the applicability of the results to environmentally relevant MNPs. Research revealed that MNPs were retained in the stratum corneum and hair follicles, the outermost layers of the epidermis, with little indication that they penetrated deeper tissues. However, particles smaller than 2 μm may reach deeper layers, according to isolated investigations; nonetheless, methodological discrepancies make it impossible to set clear size-based criteria for regulatory purposes. Particle form, surface charge, skin state, and co-exposure with cosmetic or occupational items are some of the elements that seem to affect uptake but have not been thoroughly investigated. There are still significant gaps, such as the lack of long-term exposure studies, scant information on populations at risk, little study on particles that have weathered in the environment, and a dearth of standardised test procedures unique to MNPs (McLean et al., 2025).

6. MICROPLASTICS AND HUMAN HEALTH

MNPs are composed of carbon- and hydrogen-based polymer chains and often contain additives such as flame retardants, UV filters, plasticisers and many more that have reproductive dysfunction, endocrine disruption and carcinogenic effects (Alijagic et al., 2024; Li et al., 2024). Humans are primarily exposed to MPs through ingestion and inhalation, with dermal contact (Figure 2) also identified as a potential, though less-studied, pathway (Bhardwaj et al., 2025; Ririe et al., 2025). MPs can cause various adverse effects when they reach the human body, such as oxidative stress, inflammation, and histopathological alterations in all organ systems, while investigations are still ongoing to fully understand their impacts and causes (Kannan & Vimalkumar, 2021; Li et al., 2024; Bhardwaj et al., 2025). Several investigations have found MPs in human blood, placental tissue,

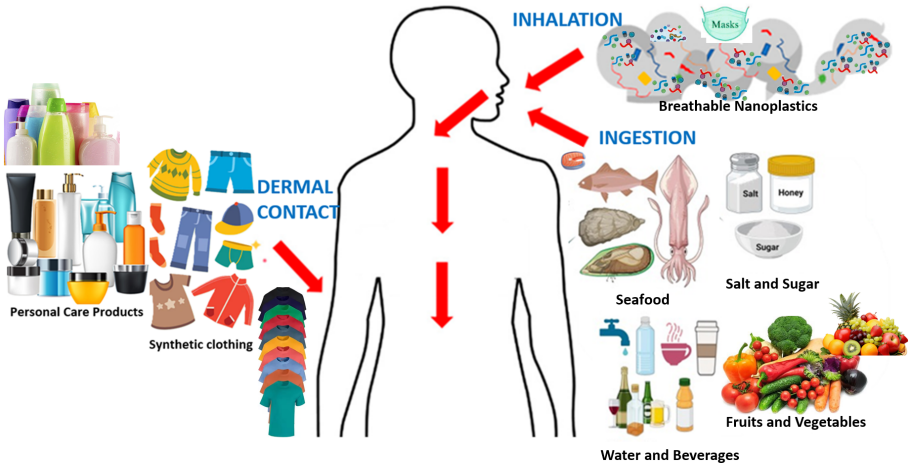


Figure 2: An illustration of how humans are exposed to microplastics through dietary intake, skin contact, and inhalation.

and gastrointestinal samples. Systematic reviews consistently demonstrate a correlation between MP exposure and biological indicators of diseases (Liu et al., 2024; Ririe et al., 2025). These results highlight the critical need for more investigation to be carried out to account for accumulation, translocation, and toxicological effects inside human organs (Pechcińska et al., 2025; Ririe et al., 2025).

In addition to some direct effects, MNPs can carry harmful chemicals, such as phthalates and heavy metals, further increasing toxicity through synergistic interactions within biological systems (Pechcińska et al., 2025). MPs are present in human blood, urine, placenta, and even amniotic fluid, suggesting potential systemic bioavailability and transplacental transfer (Brožová et al., 2025). Furthermore, studies have identified MPs in human stool, lung, and liver tissues, underscoring multiple entry points and their capacity to breach various biological barriers (Anih et al., 2025). Quantitative assessments have revealed varying concentrations of MPs across human organs, with detected levels ranging from 1. 1.6 μg/mL in blood, 0 −7.75 MPS/g in heart tissue, and 0. 69 – 14. 1 MP/g in lungs (Li et al., 2024). Together, these results show that MPs are widely distributed and accumulate in a variety of organs and tissues, thereby raising questions regarding possible health effects (Li et al., 2024; Pechcińska et al., 2025).

The size and physicochemical characteristics of MPs are intimately related to the mechanisms that allow them to pass through biological barriers, including the placenta, blood-brain barrier, and gastrointestinal epithelium (Li et al., 2024; Nihart et al., 2025; Singh et al., 2026). Specifically, smaller MPs and NPs are more readily absorbed and translocated throughout the body due to their increased surface-area-to-volume ratio and their ability to interact with cellular components (Suman et al., 2025). Beyond direct translocation, the inherent characteristics of these particles, such as their polymer type, shape, and surface charge, significantly influence their cellular uptake, biodistribution, and subsequent toxicological impact within human physiological systems (Li et al., 2024). The cardiovascular, brain, digestive, endocrine, integumentary, lymphatic, pulmonary, reproductive, and urinary systems are among the human organ systems where MPs have been found, suggesting a wide systemic dispersion (Roslan et al., 2024; Nihart et al., 2025). A major public health concern is highlighted by the ubiquitous presence of MPs in human organs like the liver, heart, blood, placenta, breast milk, sputum, semen, testes, and urine, especially with

regard to their toxicological effects on numerous physiological processes (Roman et al., 2024). The human body's extensive systemic dispersion of MPs highlights the critical necessity for in-depth investigation. It is necessary to comprehend the unique toxicokinetics and long-term health consequences of MP accumulation within these diverse biological compartments (Raffaele et al., 2024; Zurub et al., 2023; Lu et al., 2025; Nihart et al., 2025). Notably, MPs smaller than 150 μm can cross the gastrointestinal epithelium, and particles under 10 μm have been observed infiltrating different human tissues and organs, including the heart, brain, placenta, and lungs, with some studies suggesting a connection to cardiovascular events (Brander et al., 2024; Jansen et al., 2024; Raffaele et al., 2024).

The pile-up of MP particles, especially in the lungs, heart, and liver, is a significant finding, since the digestive tract is a main site for MP accumulation and potential toxicity (Roman et al., 2024; Pechcińska et al., 2025). MP particles smaller than 1. 09 μm can pass through the intestinal epithelium and enter the circulatory system, while those around 2 to 2.5 μm can enter the systemic circulation *via* endocytosis (Silva et al., 2022; Tursi et al., 2022). This underscores the importance of particle size in influencing translocation efficiency and subsequent bioaccumulation in different tissues (Jahanpeyma & Baranya, 2024). Furthermore, it has been demonstrated that particles between 0.1 and 10 μm can pass through the placenta and the blood-brain barrier, suggesting a broad dispersion and possible negative effects on foetal development and neurological health (Kannan & Vimalkumar, 2021). This transplacental transfer is particularly alarming, with studies identifying MPs in human placentas, breast milk, and even fetal meconium, raising serious concerns about early- life exposure and future developmental implications (Caba-Flores et al., 2023; Sly et al., 2024; Aranha, 2026).

MPs are known to enter the human body through various routes, resulting in their presence in various organs and posing possible dangers from related persistent chemicals they leach (Pechcińska et al., 2025). Once in the body, MPs can reach different tissues, infiltrate the lymphatic system, build up in organs, or affect the immune system. Inhaled MPs can reach the lower respiratory tract and subsequently enter the circulatory system *via* paracellular diffusion or cellular uptake, ultimately accumulating in organs like the lungs, heart, liver, kidneys, brain, and spleen (Caba-Flores et al., 2023). Disturbingly, built-up MPs cannot be easily removed by the immune system, leading to chronic inflammation and a potential increase in the risk of neoplasia (Caba-Flores et al., 2023). This persistent retention and subsequent cellular interaction can cause chronic oxidative stress, further worsen cellular damage, and contribute to pathogenic processes (Ali et al., 2024). Additionally, research on humans and animals shows that MPs can compromise the integrity of the intestinal barrier, allowing them to enter the bloodstream and build up in critical organs, including the kidneys, liver, and brain (La Maestra et al., 2024; Maurya et al., 2024; Beyzaei et al., 2025).

Experimental research done on mice reveals that PS NPs between 20 and 100 nm can pass through the intestinal lining and enter the bloodstream by endocytosis or paracellular transport, and then disperse to organs like the liver, kidneys, and brain (La Maestra et al., 2024; Bhattacharyya et al., 2025). The ability of MPs to breach the intestinal barrier and accumulate in various organs highlights their potential to cause systemic toxicity, including oxidative stress, inflammation, and cellular damage, which can lead to diverse health problems (Chman et al., 2025). Additionally, the long-term accumulation of these particles in tissues can cause several chronic illnesses and metabolic disorders (Anih et

al., 2025; Picone et al., 2025). The disruptions in metabolic pathways and biochemical processes, including changes in the Warburg effect and glutamate metabolism, greatly impair organ function and worsen existing health issues (Roman et al., 2024). Specifically, the liver, a key metabolic organ, is especially vulnerable to MNP buildup and related toxic effects, leading to redox imbalance and metabolic dysfunction (Beyzaei et al., 2025). Preliminary evidence suggests that long-term, chronic exposure to MNPs can create more significant effects, including accumulation in vital organs and altering gut microbiomes (Schmidt et al., 2023; Anih et al., 2025).

Present studies show that MPs can infiltrate several human organs and pose serious health dangers. Because of their presence in arterial plaques, research has linked higher amounts in brain tissues, particularly in dementia patients, to a 4.5-fold increased risk of heart attacks and strokes (Nihart et al., 2025). Furthermore, hormonal abnormalities, decreased fertility, and diseases like polycystic ovarian syndrome (PCOS) are linked to endocrine-disrupting chemicals like BPA and phthalates present in plastics. MPs have also been discovered in the liver, where they may contribute to non-alcoholic fatty liver disease, and the gut, where they may disturb the microbial balance and aggravate inflammation linked to diabetes. Reactive oxygen species produced by MPs can harm proteins and DNA, which are mechanisms linked to the development of cancer (Nihart et al., 2025; Aranha, 2026). MNP exposure causes biological, metabolic, and molecular alterations in cells that could lead to severe consequences. There is growing suspicion that MNPs play a role in the development and spread of human cancers due to the long-term, chronic exposure to increasing doses of these particles. This theory is supported by clinical and experimental research; however, there is currently insufficient proof of a direct cause (Cirillo et al., 2026). Figure 3 provides a summary of MP pollution's impacts on human organ systems and potential hazards.

7. DETECTION OF MICROPLASTICS

MNPs have been found in every species studied and at all trophic levels, demonstrating their widespread bioaccumulation. Furthermore, recent studies have discovered MNPs in a range of human tissues and physiological fluids, suggesting that MNPs may be ingested, circulated, and excreted. Although a number of spectroscopic and microscopic methods, including Raman, μ-FTIR, and LD-IR, have improved the detection and characterisation of MNPs. Their use in environmental exposomic studies is restricted due to polymer-specific limitations, false-positive risks, and decreased sensitivity in complex biological matrices, especially for submicron particles. Formerly, pyrolysis GC-MS was widely acknowledged as a crucial method for identifying and measuring MNPs; however, it has drawn criticism for being susceptible to interference, particularly in biological materials. To detect MNPs in placental blood while reducing false positive detections from matrix interferences, Bissonnette et al., (2025) created a unique pyrolysis-gas chromatography x ion mobility mass spectrometry approach as a solution. Ion mobility is an analytical procedure that aids in the more precise separation of plastics from other biological materials. This enhanced procedure can simultaneously detect compounds linked to plastic, reducing measurement errors, and differentiate between true and false plastic signals.

Kim et al., (2026) developed and validated a cascaded microfiltration followed by pyrolysis-gas chromatography mass spectrometry (Py-GC/MS) approach in a study to quantify MNPs (PS, PC, PMMA, PET, PVC, PP) in diverse biospecimens, facilitating exposure assessment. The method validation focused on reducing background contamination and false-positive sig-

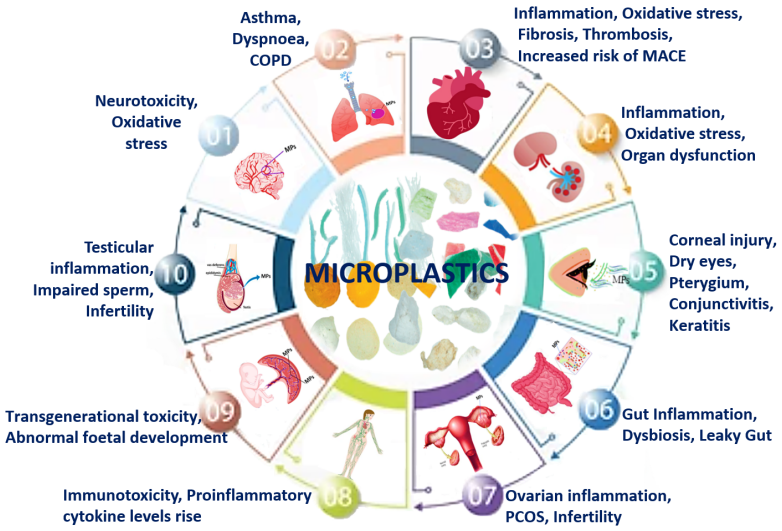


Figure 3: Diagrammatic representation showing the health risks linked to microplastic accumulation in various human organs.

nals via matrix-matched calibration and rigorous quality control. Applied to real samples, they quantified total MNPs at 0.80 μg/mL median in human blood (PET 100% detection, PS/PVC dominant) and at 2.74 μg/mL in shark blood (PVC predominant, >3x humans). From size-range comparisons, they observed MNPs (transitional size range of 0.7- 1.2 μm) prevail in all matrices, showing 74-99% in different types of bodily fluids, suggesting possible partitioning of smaller MNPs into cellular fractions in blood (Kim et al., 2026). This work establishes a validated, cross-species-applicable method for sensitive, contamination-controlled quantification of MNPs in both fluid and solid biological matrices.

8. ENVIRONMENTAL REMEDIATION OF MICROPLASTICS

MPs have a negative impact on the environment because they persist for decades before breaking down. Therefore, reducing MPs in ecosystems is imperative. Reducing the use of plastics, such as bags, covers, and bottles, and increasing the use of degradable and cloth bags, refillable bottles, etc., are effective ways to reduce the emission of MPs. Additionally, a variety of methods should be used to address the significant quantity of residual MPs. Microbial degradation, thermal treatment, and physical techniques such as adsorption and filtration are examples of MP remediation strategies (Chellasamy et al., 2022). Microbial strategies are at the forefront of remedial interventions, leveraging the detoxification capabilities of microbial metabolisms and enzymatic functions to ameliorate MPs' deleterious effects. Microbial consortia and enzymatic pathways for the oxidative degradation of MPs offer insights into enhanced biodegradation processes facilitated by innovative pretreatment methodologies (Song et al., 2024). Bacterial strains, such as *Pseudomonas* and *Bacillus*, can produce lipases and proteases, which break down molecules of various plastics, such as PE, PS, and PP, and produce less-polluting alternatives.

Nanoparticles enable bioremediation, helping remove MPs and other environmental contaminants. Environmental science specialists in bioremediation have closely examined the remarkable properties of nanomaterials, including their distinct structure, chemical strength, and the availability of accurate production methods. Nanomaterials are suitable for bioremediation because of their size, shape, surface plasmon resonance, and quantum effects that lower

activation energies. These properties make them effective for treating, eliminating, and cleaning up MPs (Hammami et al., 2026; Jiang et al., 2026). Bionanomaterials derived from biological sources or engineered to resemble biological systems at the nanoscale have become a viable technique for the green remediation of MPs. They can be generated from many different sources, such as plants, algae, animals, and microorganisms. Their biocompatibility, biodegradability, non-toxicity, and minimal environmental impact make them feasible. Plant-based bionanomaterials, called photogenic nanostructures, have demonstrated high selectivity and efficiency for MPs. Silver nanoparticles produced through biosynthesis are also used to filter out MPs from water because they aggregate into tiny particles that are simple to remove through filtration. To remove MPs from soil, sediments, and water, bionanomaterials such as chitosan-coated magnetic nanoparticles, 2D graphene oxide, carbon nanotubes, silk, and lignin are employed. MPs mitigated using green bionanomaterials can be used as an alternative fuel feedstock, such as through hydrothermal liquefaction, to turn PET MPs into bio-oil (Koul et al., 2025). Advances in nanotechnology now enable large-scale efforts to degrade MPs intelligently.

Electrochemical advanced oxidation (EAOPs) is also used to remove microplastic pollution in water (Rim et al., 2025). Recent advances in bio-based flocculation, nanotechnology, and electrochemical techniques have shown significant potential to improve MP removal efficiency. However, further research is needed to address concerns about scalability, cost-effectiveness, and possible secondary effects of these new methods. The complexity of MP contamination emphasises the need for integrated strategies that combine cutting-edge technology with biological remedies, legislative changes, and effective waste management techniques.

9. CONCLUSION

MP pollution is a global environmental emergency, with its toxic effects on every living organism generating serious concern. Meanwhile, the growing importance of microplastic contamination in the environment has led to an upsurge in research on MPs and NPs in recent years. Numerous studies are concentrating on the potential impacts of MPs/NPs on human health because MPs can accumulate in various human tissues and organs. However, concrete evidence on dose-response relationships and the long-term effects of microplastic exposure in humans remains limited, underscoring the need for more robust epidemiological research globally. Despite current legislative attempts to limit plastic manufacturing and establish safe disposal, an exponential increase in MNP exposure is anticipated in the coming years. Today, the true role of MNPs in the pathophysiology of various diseases is likely underestimated. However, the consistent rise in the prevalence of diseases and syndromes that were previously poorly explained may point to underappreciated environmental factors, such as MNPs, as promising contributors.

Since MP pollution peaks in Southeast Asian nations, eliminating the buildup of terrestrial and aquatic plastic waste can significantly reduce MP uptake by primary consumers. To mitigate MP exposure and associated health risks, governments in both developed and developing countries across Asia, Europe, Africa, and the Americas should promote the removal of free plastic debris from aquatic and terrestrial environments through efficient water treatment and effective waste management. Furthermore, we must ensure that all necessary plastics are made from non-toxic materials and that frivolous single-use plastics are avoided to prevent further accumulation of microplastics in the environment. It will be possible to effectively confront the microplastic pollution crisis and

protect the environment and public health for future generations through collaborative efforts spanning scientific, technological, regulatory, and societal domains.

Conflict of interest

The author declares no competing interests.

Funding

Not Applicable

Declaration of AI-assisted technologies

During the writing process, the author used Grammarly to improve grammar, spelling, and punctuation. After using this tool/service, the author reviewed and edited the content on their own and takes full responsibility for the published article.

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HOW TO CITE?

Ivan Arhana. (2026). The Promise and Peril of Plastics in Modern Society. *Vantage: Journal of Thematic Analysis*, 07(02), 133-149. https://doi.org/10.68903/vjta.2026.v07i02.03