REVIEW

Beyond Pollution: Microplastics as an Emerging Health Hazard

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Received: 03 Jul 2025 | Revised: 28 Nov 2025 | Accepted: 08 Dec 2025 |Published Online: 22 Dec 2025

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Abstract

The long-term existence of microplastics in biosphere and the sharp rise in yearly emissions have prompted concerns about the possible health effects on humans. The micro plastics (MPs) refer to plastic fibers, films and particles, which are less than five millimeters in diameter. The human contact with microplastics has become considerably increased due to the increase in the consumption of single-use food packaging and wrapping material. MPs have been identified in the human blood, excrement, and placenta. MPs and its derivatives influence the human health greatly because they cause the inflammation of the gastrointestinal and respiratory system, imbalances the body hormones level resulting in reproductive disorders, and cardiovascular diseases to increase. The overall toxicological investigations related to MPs have continued to increase. This review summarizes the latest toxicological data to relate MPs and human health, and the negative outcomes of MPs with their toxicity mechanism. The study will improve the knowledge in terms of health hazards caused by MPs to be used in comprehensive assessment of toxicity and will establish the fact to define policy actions.

Key words: *Human Health, Microplastics, Plastics Pollution, Public Health*

ISSN 2816-8119

Open Access

Citation
Latif M., Sheikh N., Arif A., Kawish N., Sehar E., Batool A. & Aslam I. (2025). Beyond Pollution: Microplastics as an emerging health hazard. *Albus Scientia*, *2025,* Article ID e251222, 1-7.

DOI
http://doi.org/10.56512/AS.2025.2.e251222

Competing interests
The authors have declared that no competing interests exist.

Introduction

Plastics are essential to the global economic system of the throwaway culture because they are utilized every day in many activities, such as textile, preserving and packing of food, shipping, cosmetic, and medical supplies (de Sá et al., 2018). Increase in plastic wastes owing to the proliferation of plastic materials in everyday life has been one of the utmost environmental issues in the world over the last 50 years. The world has increased plastic production by a record level of 359 million tons in the year 2020 (Priya et al., 2023).

Plastics are categorized as macro plastics (MCPs), meso-plastics (MSPs), micro-plastics (MPs), nano-plastics (NPs) according to their size. MCPs that have a diameter of over 25 millimeters are discharged and deposited constantly in different environmental contexts like in landfills and waste waters. Annually 52.1 metric ton (Mt) of MCPs trash is generated. MSPs, with a diameter of 5 to 25 mm (millimeter) are found in river floodplains, agricultural lands and urban zones. The primary use of these plastics is in irrigation set ups, pesticides and fertilizers (Carrieri et al., 2022; Weber et al., 2022). MPs disintegrate into NPs that have a size ranging between 1 and 1000 nm. The NPs were found in sea ecosystems, coastal sediments, and in day-to-day human objects (Weber et al., 2022).

MPs are plastic polymers with size one to five millimeters, and they have become a ubiquitous source of pollution on the planet today (Hu & Kuan, 2026). The prime source of these pollutants (15-30 %) includes industrial pellets and microbeads contained in cosmetics; personal care items and the secondary source (> 80 %) are weathering of large plastic debris, photodegradation, and mechanical abrasion (C. Chen et al., 2024). MPs can also be categorized by shape as fragments, beads, filaments, pellets, foams, and films (Chouchene et al., 2021). They fall also into the category of thermoplastics (meltable, recyclable plastics), thermosetting plastics (cured plastics), elastomers (Flexible plastics), and biodegradable plastics depending on their chemical structure (Karali et al., 2024).

Occurrence of MPs

MPs are found inside the human body, drinking water, surface water, air , rocks, and soil (X. Chen et al., 2022; Möller et al., 2020; Zhang et al., 2024). More than eighty percent of the MPs are generated on the land because of wastewater, textile washing, industrial processes, and natural erosion, whereas the small percentage generated by marine operations (Figure 1). These particles are hazardous to both humans and animals since they enter the water sources and travel up with different trophic levels. About 81% of tap water samples verified the presence of MPs across the world (Kosuth et al., 2018).

Mineral water contained MPs of size ranging from 5 – 1350 µm. It was reported that the particle counts, reached up to 6292 particles per liter, were the same in water packaged in glass and polyethylene terephthalate (PET) bottles (Oßmann et al., 2018; Schymanski et al., 2018).

The direct or indirect usage of MPs to humans through the intake of seafood that bioaccumulate in the food chain. Research has demonstrated that plastic containers; stored food products, baby feeding bottles, teabags, and plastic kettles leak MPs, during high temperatures (D. Li et al., 2020; Hernandez et al., 2019).

A daily consumption of 0.274 items $kg^{-1}\cdot d^{-1}$ for adults and 0.6 items $kg^{-1}\cdot d^{-1}$ for young ones of MPs has been reported. Approximately an average of 0.1 to 5 g of MPs is consumed by an individual human on weekly basis with higher exposure of children as compared to adults (Senathirajah et al., 2021; Zhang et al., 2021; Zhou et al., 2022).

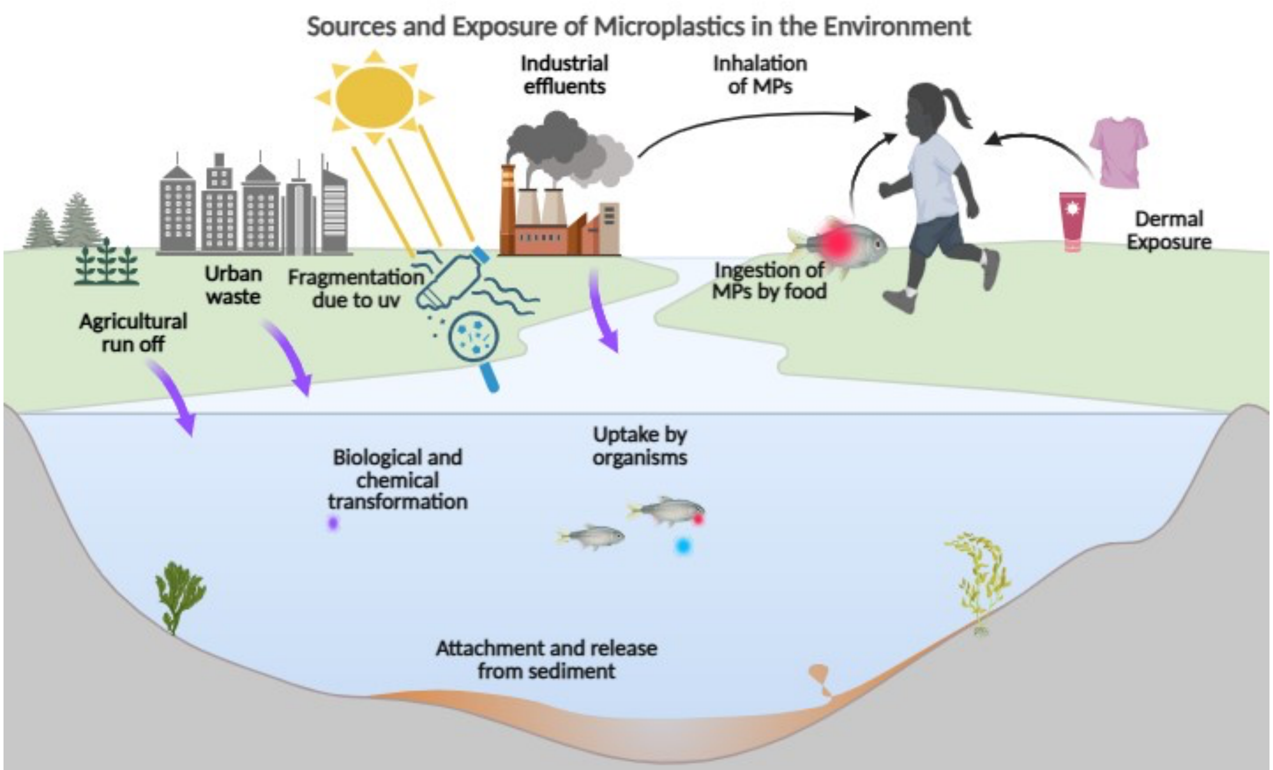

Figure 1: Environmental sources of MPs and route of human exposure (Created in BioRender.com)

Health Hazards of MPs to Biological Systems

The presence of MPs in human feces and placentas increased the possibility that long-term exposure to MPs is detrimental to human health (Ragusa et al., 2021; Schwabl et al., 2019). MPs are distributed through the bloodstream after ingestion of food, inhalation of air, or by touching the skin. They significantly affect different tissues and organ systems. They cause various health issues through physical obstacles, chemical toxicity, bioaccumulation and biomagnification (Figure 2).

MPs are also known to have adverse outcomes on the digestive, nervous, cardiovascular, respiratory, excretory, and reproductive systems. Impacts on protein aggregations, stress responses and cellular damages are caused by MPs. GIT (gastrointestinal tract) is the primary point of entrance of MPs in humans' body (Kutralam-Muniasamy et al., 2020). Intake of MPs is primarily linked with the tainted honey, sweeteners, contaminated seafood and minerals, dairy products, canned items and plastic water bottles (Kwon et al., 2020).

Long term exposure of MPs facilitate microbial dysbiosis and gastrointestinal inflammation and malfunction (Fournier et al., 2023), reduces the activity of T17 (T helper 17), Treg (regulatory T) cells, $CD4^{+}$ (clusters of differentiate) cells, affects the gut microflora of Lachnospiraceae family, and Parabacteroides, Bacteroides genera, and increases the number of Staphylococcus genus (Kadac-Czapska et al., 2025; Park et al., 2025). Due to MPs exposure gut microbiota changes due to transfer of major antibiotic resistance genes (ARG), especially those related to resistance to aminoglycosides and glycopeptides. Enterococcus, Clostridioides and Streptococcus genera as well as firmicutes were found to be major ARG hosts. These changes were linked to metabolic processes and bacterial signals related to cell wall remodeling and vancomycin resistance, indicating possible targets for intervention (B. Li et al., 2020).

MPs have directly been linked with the severity of the inflammatory bowel disease (IBD) due to the high levels of MPs

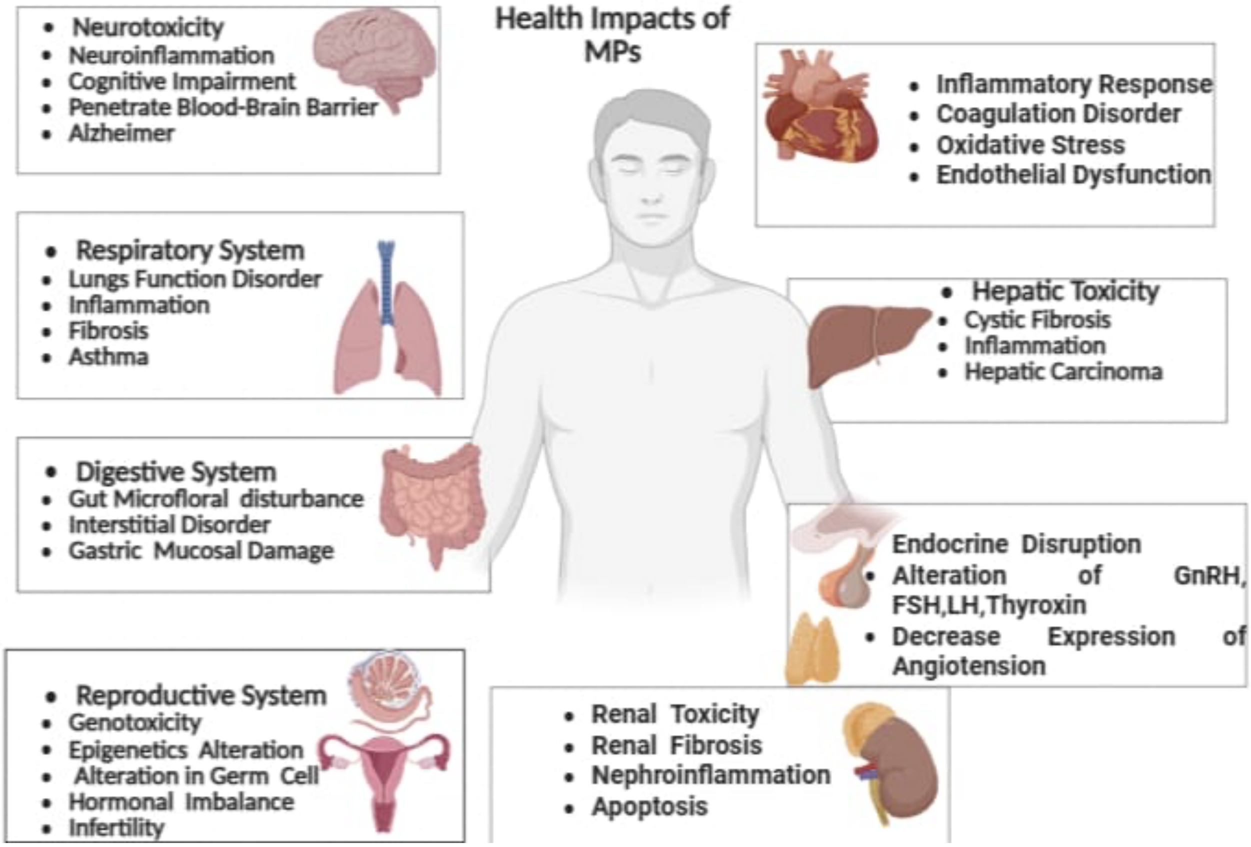

Figure 2: MPs effects on human biological systems (Created in BioRender.com)

in the feces of such patients as compared to normal healthy persons, and this association (Yan et al., 2022). Gut bacterial biochemical changes, gastrointestinal permeability disruption, liver and bile salt dysfunction, intestinal mucosa stimulation and decreased mucus discharges are caused by increased MPs (Chen et al., 2022; Okamura et al., 2023; Park et al., 2025).

Oral administration of MPs caused a significant change in metabolism with fat rich diet as shown by the increase activity levels in blood sugar, serum fatty acid ratios, and nonalcoholic fatty liver (NAFLD) disease. Oxidative stress, inflammation, genotoxicity, DNA and cell membrane disruption, death of intestinal lining cells, breakdown of the functional barrier of GIT have been reported due to oral administration of MPs in mice (Busch et al., 2021; Stock et al., 2022; Wu et al., 2020).

In human body, liver is responsible for protein production, toxin detoxification, glucose deoxidation and storage (Yin et al., 2022). Serum level of liver markers like reactive oxygen species (ROS), catalase, anti-oxidant enzyme, glutathione S-transferase (GST), alkaline phosphatase (ALP) gradually rise with the exposure of MPs which affects the biotransformation that leads to oxidative stress, cellular damage and increase in lipid deposition (Cheng et al., 2022; da Silva Brito et al., 2022; Iheanacho & Odo, 2020; Yang et al., 2023). Another study has reported reduction in the cholesterol and liver triglyceride (TG) levels due to an oral administration of MPs, but hepatic pyruvic acid (PYR) had risen. The transcriptional changes in TG formation and lipogenesis controlling genes in hepatocytes were well used to explain these changes. MPs in liver, induces insulin resistance through the stimulation of inflammation, inhibition of hepatic insulin signaling pathway, and dysbacteriosis (Huang et al., 2022). Liver steatosis, cystic fibrosis and tumors risk increased due to MPs exposure. MPs also affect the histological architecture of liver causing lesion, hemorrhage, necrosis, altered cell organization, decrease in the number of hepatocytes, and inflammatory cell infiltration (Hu et al., 2022; Park et al., 2025).

Pathophysiology of MPs influences cardiovascular system (CVS) in several complex mechanisms. ROS generated by MPs and NPs cause the cell damage, oxidative stress and increase the risk of cardiovascular diseases (Park et al., 2025; Song et al., 2024). MPs cause myocardial fibrosis via the Wingless β-catenin signaling channel, and redox stress affects the cardiac tissues and programmed cell death i.e. apoptosis. It causes cardiac toxicities such as defect in cardiac functioning, irregular heart rate, endothelial dysfunction, pericardial edema, and disrupts the angiogenesis. MPs-NPs lead to break down of blood cells, thrombosis, blood clotting and inner lining damage of the vascular system (Chowdhury et al., 2024; Sun et al., 2021). MPs add adhesion molecules to the aortic tissue and lead to aortic inflammation (Vlacil et al., 2021) that impacts cardiovascular functioning through the induction of adiposity (Wang et al., 2023; Zhao et al., 2022). Coagulation malfunction and vascular damages have been associated with NPs, because of the enabling of the Janus kinase/signal transducer and activator of transcription factor signaling cascade (Wang et al., 2023).

MPs lead to thrombus development when it interacts with blood platelets causing adherence, platelet stimulation, and clumping (Mangin et al., 2021). PS (Polystyrene)-NPs lead to atherosclerosis through free radical, fat drop deposition as well as lysosomal degradation, in phagocytes (Florance et al., 2022).

MPs have been reported in the gonads indicating that they can cross the gonad blood barriers and inflict the damage (Mangin et al., 2021; Zhao et al., 2023). The effects of MPs administration on the male reproductive system were numerous and negatively affect the health of the system, such as the reduce amount of sperm, the suppression of sperm motility, poor quality, enhance malformation of sperms, testis and seminiferous tissue structural damage, and the disruption of normal testosterone levels. Prolonge exposure to MPs cause DNA damage (B. Hou et al., 2021; Jin et al., 2021; Wen et al., 2023; Xie et al., 2020). MPs lead to the generation of ROS in testes and activate Nrf2 and PGC-1 (autophagy and cell death) signaling pathways (Li et al., 2022). Such pathways enable the MPs and NPs to infiltrate the seminiferous tubules and degenerate and disrupt spermatogonia. Moreover, these MPs prevent the generation of acrosomes in sperms, reducing the quality of sperm and causing autophagy (Zhou et al., 2022). MPs alter testicular morphology, decrease male reproductive hormones, reduced fertility of sperm and increase anomalies. When MPs gain access to the Leydig cells, the AC/cAMP/PKA network gets inhibited, that leads to reduced testosterone by down regulation of steroidogenic enzymes and steroidogenic acute regulatory protein expression (Jin et al., 2022).

In female reproductive system, MPs block oocyte maturation, reduce follicular cell formation and block follicular development, embryo implantation dysfunction, atresia, lethal birth defects, and impaired placental perfusion. Oxidative damage triggered by the MPs affect calcium homeostatic imbalance and inflammation resulting in apoptosis and necroptosis of ovarian granulosa cell (J. Hou et al., 2021; Huang et al., 2023; Liu et al., 2022; Q. Chen et al., 2024; Wu et al., 2023; Yang et al., 2024) .MPs induced biochemical changes led to physiological abnormalities in the subsequent generation of mice. The autoimmune adjustments induced by the endometrial NK (natural killer) cells, $CD4^+$ T cells, and phagocytes were found to reduce the size and number of uterine blood vessels (Luo et al., 2019).

MPs exposure initiates the endoplasmic reticulum (ER) stress and placental cell death, causing a decrease in placental barrier function, increased inflammation, and placental dysfunction via the glucose regulated protein 78, inositol-requiring enzyme-1alpha, and c-jun N-terminal kinase pathway (Ageel et al., 2024). The treatment of MPs decreases the ratio of estradiol in female blood and disrupts the ovarian endocrine mechanism (Barboza et al., 2019), which indicates the involvement of MPs in inducing endocrine disruption associated with the bioaccumulation and histological lesions (Amereh et al., 2020).

Conclusion

Conclusively, the literature establishes that the exposure of MPs damages the human organ systems and their normal functioning leading to health issues. Therefore, it is the need of time that policy makers immediately address the disposal of MPs trash in the ecosystem to minimize MPs associated health hazards.

Authors Contribution

ML, ES, AB, IA, did literature review, ML, AA, NK prepared visual illustrations and prepared the initial and revised drafts. NS conceptualized, designed, supervised, and validated the work.

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