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Review article

# A Comprehensive Review of Plastic Pollution: Public Health and Environmental Impacts, Sources, and Mitigation Strategies

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**ABSTRACT**

Plastic is a basic material widely used in various consumer and industrial sectors, from construction and vehicles to electronics and agriculture. In recent years, plastic pollution has put pressure on the environment and threatens human safety worldwide due to massive global plastic production, which has led to waste generation that exceeds society's ability to manage it efficiently. This review discusses the types of plastic pollution, as plastic chemical composition consists of long polymers that are resistant to degradation by decomposing organisms. Natural processes break down plastic materials into small particles, forming microplastics and nanoplastics that can easily disperse throughout the environment. Consequently, plastic pollution affects terrestrial and marine ecosystems, causing serious effects on the environment, the economy, and the health of organisms. In addition, the article reviews the main sources of plastic waste, including household, industrial, agricultural, and medical waste. It also reveals the major problems caused by plastic waste, especially its environmental and human health impacts, as chemical materials in plastic cause several health issues like reproductive disorders, hormonal disruption, and neurological disease. It also highlights the importance of control measures and coordinated global efforts to reduce single-use plastic, improve recycling systems, and create international partnerships to mitigate the effects of plastic pollution on the planet and public health.

**Keywords:** Environmental impacts, microplastics, plastic pollution, public health.

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## 1. INTRODUCTION

One of the most important and dangerous environmental issues worldwide is plastic pollution. In the last few decades, plastic has become indispensable due to its desirable properties, including insolubility, durability, non-biodegradability, and affordability. At the same time, these properties contribute to its persistence and lead to environmental pollution [1]. Over time, plastic does not degrade; instead, it breaks down into very small particles called microplastics and nanoplastics, which can persist in the environment for hundreds of years. A study estimated that up to 8 million tons of plastic waste are dumped into the ocean annually [2]. This increasing amount of waste threatens marine biodiversity, as these plastic particles are accidentally ingested by many marine organisms, including fish, birds, and turtles, leading to gastrointestinal obstruction, suffocation, or even death. The transfer of these tiny particles through the food chain poses health risks to humans, as these particles have been found in drinking water, seafood, and human tissue [3].

Plastic pollution not only affects the environment and human hea-

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lth but also impacts the economy, negatively affecting the fishing, tourism, and maritime transport sectors and resulting in economic losses estimated at billions of dollars annually. Additionally, the cost of cleaning plastic waste is placing increasing financial pressure on governments, particularly in developing countries that lack the infrastructure for effective waste treatment [4].

There are many factors that contribute to the increase of plastic waste, most notably reliance on single-use plastic, overproduction, and weak waste management systems. Plastic used for packaging accounts for an estimated 40% of total plastic production and is often disposed of after only one use [5]. Even though many developed countries have plastic management systems, only about 9% of plastics are actually recycled globally. The rest is often dumped in landfills, burned, or leaks into natural ecosystems [6]. Furthermore, in developing countries, plastic pollution is even more severe due to the lack of effective waste collection and recycling infrastructure. Rivers in Asia and Africa are major channels for transporting plastic waste to the oceans [7]. It has been estimated that individuals ingest about 11,000 microplastic particles in a year from eating shellfish [8]. The amount of plastic particles entering the human body annually is expected to range from 39,000 to 52,000 particles per person [9]. Additionally, plastic can become widespread in soil, especially in agricultural environments [10]. These plastic molecules may infiltrate the water transport system within plants and then move to other parts of the plant [11]. Once microplastics enter agricultural systems, they can cause food pollution, which may increase the risk of human exposure [12].

Microplastics can enter the body through three routes: ingestion, inhalation, and skin contact. Once inside, these particles are distributed throughout the body via blood and can be absorbed by various organs [9]. It has been shown that plastic particles can reach distant organs such as the kidney, brain, heart, lung, testis, and placenta. As a result, microplastics accumulate in these organs and remain in the body, leading to a range of health issues—from minor respiratory problems to cancer and reproductive disorders [13]. Additionally, microplastics can damage cellular functions, causing inflammation and oxidative stress. The evidence highlights the toxic nature of microplastics, especially when combined with other environmental pollutants, which may work together to worsen health effects [14].

Plastic pollution has become a persistent and serious environmental issue in modern life. Despite economic progress over the past decades, this growth has been linked to a significant increase in pollution levels, causing severe impacts on human health and ecological balance, and disrupting vital natural systems like the climate system [15].

# 2. TYPES OF PLASTIC POLLUTION

## 2.1. Macroplastic

These plastic particles are larger than 5 mm and accounted for 88% of the entire plastic discharge into the environment in 2019, equivalent to approximately 20 million metric tons, causing widespread pollution over various ecosystems. A significant portion of this pollution is attributed to disposable plastic items, like bottles, cigarette butts, bags, food-grade plastic, cups, and straws [4].

**Primary microplastics**: These are tiny plastic particles mainly produced for industrial and commercial uses. They are found in many products such as skin exfoliants, cleaning agents, plastic care products, and synthetic fabrics. Some of these particles, such as microbeads less than 5 mm in size made of polyethylene and polypropylene, are used in cosmetics [17]. These microbeads have specific properties such as viscosity, stability, and shape, and sometimes act as abrasives. Another type is produced from textiles like synthetic fabrics and cigarette filters, known as microfibers, which can enter the environment during various stages of a textile's lifecycle from production to disposal [18]. Although these plastics are made for specific purposes, they can be unintentionally released into the environment. These primary microplastics can adsorb and carry other toxic substances, increasing their environmental impact [1].

**Table 1.** Types and sources of microplastics

**Secondary microplastic**: When plastic enters ecosystems, it undergoes various processes, including mechanical movement, physical changes, and biological activity. Under the influence of ultraviolet radiation, low temperatures, and constant friction from waves and sand, plastic gradually breaks down, and its chemical bonds disintegrate, producing smaller particles over time. These small fragments are known as secondary microplastics because they result from the disintegration of larger plastics. The common forms of secondary microplastics include fragments and fibers [19]. These particles are a major source of microplastic spread in aquatic environments [3]. Table (1).

## 2.2. Nanoplastics:

Ultra-fine particles (less than 100 nanometers) that spread in water and air and pose a threat to the food chain. The spread of nanoparticles in the environment occurs through advanced fragmentation of plastic particles and through direct emission from the breakdown of plastic materials such as plastic films, foams, plastic manufacturing factories, and other sources. These tiny plastic particles create risk, because they can enter the cells easily and even penetrate the subcellular components, leading to harmful effects at the molecular level of organisms [20]. It has been revealed that nanoplastics can penetrate biological barriers and accumulate in body tissues and organs, resulting in adverse health effects. In addition, many other environmental toxins, such as toxic hydrocarbons and heavy metals, can be adsorbed onto nanoplastics, resulting in greater chemical toxicity [21]. For this reason, studies in this field are still ongoing, because many of the environmental and health impacts of these particles are not yet fully understood [20].

# 3. PLASTIC POLLUTION SOURCES

Plastic pollution is a critical environmental problem worldwide, as it poses increasing risks to all ecosystems. That results from weak plastic waste management and recycling systems coupled with widespread use of plastics [17]. The main categories of plastic pollution can be classified into the following:

## 3.1. Household and Municipal Waste

Household waste is one of the primary sources of plastic pollution worldwide, particularly single-use plastic items. These wastes are very difficult to manage as they can spread into the natural environments easily and the rate of their recycling is low. The wastes include plastic bottles, cups, food packaging plastic, cutlery, straws and bags [22].

## 3.2. Industrial Activities and Packaging

The manufacturing of plastics and the spoilage of end products produce large amounts of waste that can easily pollute the environment. Commercial food industries play a key role in increasing the use of plastic containers in packaging and transportation, leading to the accumulation of plastic waste across all ecosystems. Dris et al. revealed that most of the world's total plastic demand is in the packaging sector [23].

| Types of microplastic | Type of microplastic | Source of microplastic | Reference |
|---|---|---|---|
| **Primary microplastics** | Microbread | skin care and cosmetic products like exfoliating scrubs and | **[17]** |
| | Microfiber | Textiles like synthetic fabrics, carpets, and furniture. Personal products, like cigarette filters, tissue, and face masks. | **[18]** |
| **Secondary microplastics** | Fragments | Generated from larger plastic. | **[19]** |
| | **Fiber** | **Textiles, like clothes, bonds, and nets.** | **[19]** |

### 3.3. Fishing and Marine Transport

Water bodies, especially marine ecosystems, are primary sources of plastic pollution. Abandoned or lost fishing nets cause significant harm to marine habitats. Similarly, waste from boats and ships, such as plastic ropes, life jackets, and floats, remain on the water surface for a long time. It is estimated that the maritime transport sector and fishing industry account for a large proportion of total marine plastic waste [24].

### 3.4. Medical Waste

Healthcare tools are among the items that consume a significant amount of single-use plastic, including gloves, tubes, and syringes. These items are essential for preventing infection, but improper disposal can lead to the accumulation of hazardous plastic materials in the environment. Additionally, their incineration and uncontrolled sterilization can release toxic substances like dioxins [25].

### 3.5. Agricultural Waste

Many plastic products, such as plastic drip irrigation systems and greenhouse covers, have been widely used in modern agriculture recently. Over time, these materials break down through sunlight and other processes into very small particles known as microplastics, which negatively impact soil and water quality used in agriculture [26].

### 3.6. Waste from tourism activities

Tourism and recreational activities are indirect sources of plastic pollution, as visitors contribute to the accumulation of plastic waste on beaches and natural areas. This causes the deterioration of coastal environments and harms wildlife and marine life [27].

## 4. FATE OF PLASTICS IN ECOSYSTEMS

Plastic waste breaks down in the environment due to physical and biological factors into fine particles [28]. These particles build up in organisms and move through the food chain, increasing in concentration at higher levels and negatively impacting human health. They have been found in plankton, fish, and seabirds, making them a global environmental issue [29].

## 5. EFFECTS OF MICROPLASTIC POLLUTION ON ECOSYSTEMS

Human activities cause a profound effect on ecosystems, with microplastics contaminating nearly all environmental matrices, even in remote territories like the Arctic and the Tibetan Plateau [30; 31]. Their proliferation is attributed to urbanization and industrial activities, raising serious environmental concerns, particularly because unmonitored microplastics can disrupt ecosystems [32]. Due to increasing microplastic pollution, these particles are entering the bodies of animals and humans. They can be acquired directly or indirectly through the food chain [33]. They tend to accumulate in filter-feeding organisms such as mollusks and plankton, with blue mussels containing 36 ± 7 particles/100 g, Pacific clams 47 ± 16 particles, and fish around 35 particles in their digestive tracts [34]. Microplastics have also been found in terrestrial animals like chickens (up to 105 particles/g of feces) and sheep (1000 particles/g) [35]. Humans are exposed through food, water, and air, as microplastics have been detected in sugar, honey, salt, beverages, water, and inhaled air [9]. Studies have documented the presence of microplastic particles in human feces, averaging 20 particles per 10 grams, ranging from 50 to 500 micrometers, primarily polypropylene and polyethylene terephthalate [11].

## 6. POTENTIAL IMPACTS ON HUMAN HEALTH

The hazardous effects of microplastics on human health depend on the type and duration of exposure and the organs affected. When ingested, these particles could cause gastrointestinal disturbances. As shown in Figure 1, a study revealed that polystyrene particles were detected in the colons of mice exposed to them and caused multiple disorders, including epithelial barrier dysfunction, decreased intestinal mucus production, damage to tight junction proteins, and alterations in the intestinal microbiota. These particles have also been found in other organs like the kidney and liver, and were shown to have many negative effects like oxidative stress, inflammation, disturbance in lipid and energy metabolism [36].

Another effect of microplastics is cardiac disruption and decreased heart function, mediated by mitochondrial damage and oxidative stress-induced cardiomyocyte death [36]. Similarly, muscle cell growth and division are suppressed, ultimately impairing skeletal muscle regeneration [37]. Additionally, these microplastics alter gene expression in bone marrow cells and inhibit leukocyte differentiation, disrupting hematopoiesis [38]. Other effects observed in mice include behavioral disorders and cognitive impairments [39], as well as reproductive issues and offspring malformations. When microplastics reach the testes of male mice, they damage the epithelial cells of the seminiferous tubules, reduce testosterone levels, induce spermatogenic cell death, and lead to decreased sperm count and motility [40]. They also infiltrate the ovaries in females, leading to granulosa cell fibrosis and death [41].

Regarding human impacts, microplastics have been detected in various human samples, including urine, blood, feces, and even the placenta, which may lead to potential health effects. So far, the evidence indicates that the toxicity mechanisms of microplastics at the cellular level are driven by oxidative stress [42].

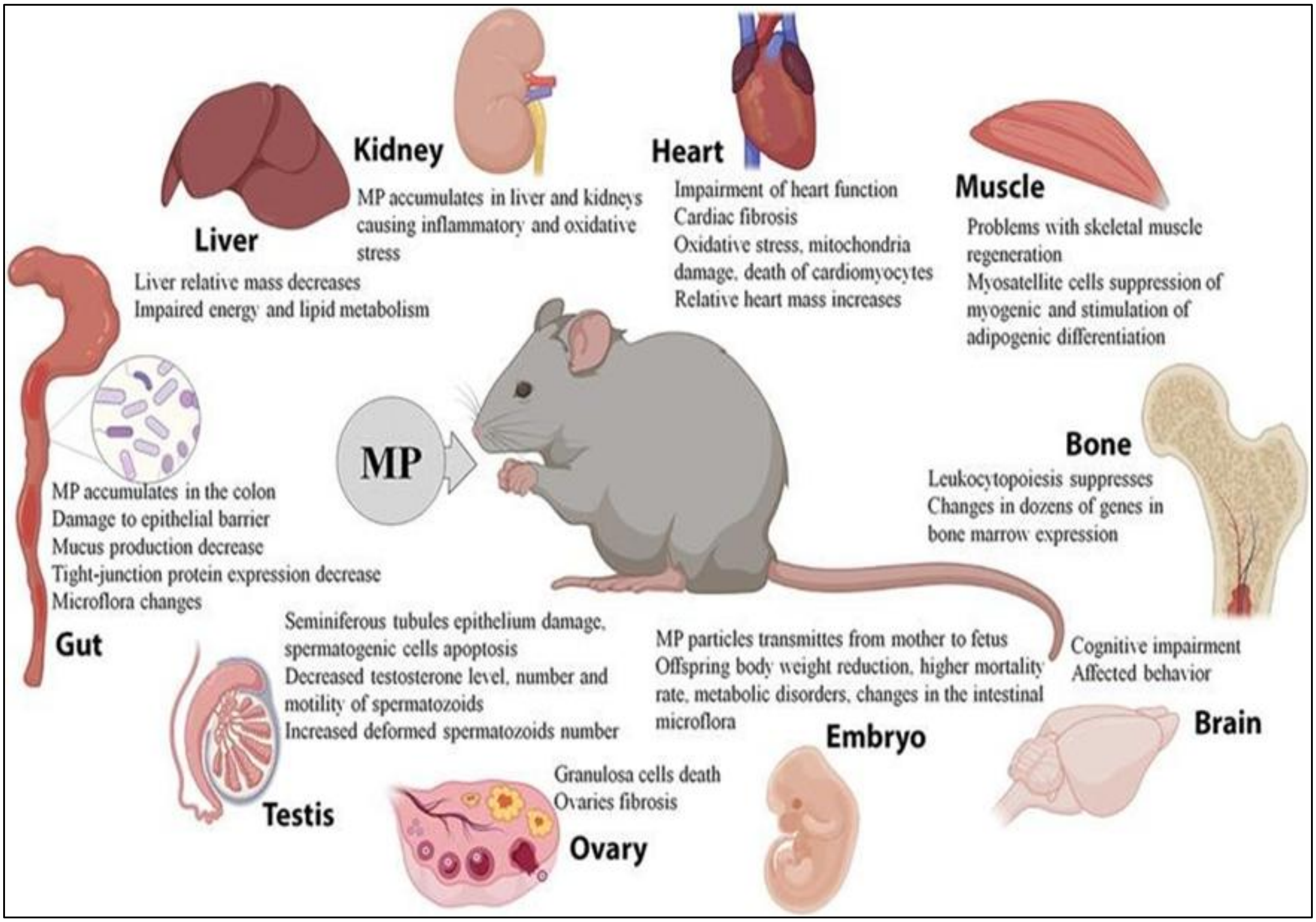


Fig. 1. Systemic effects of microplastic (MP) exposure on mammalian organs and tissues. Microplastics accumulate in multiple organs, including the liver, kidneys, gut, heart, muscle, bone, brain, and reproductive systems, leading to inflammation, oxidative stress, metabolic disturbances, tissue damage, and impaired physiological functions. Adverse outcomes include disruption of intestinal barrier integrity, reduced reproductive capacity, altered gene expression, and potential transgenerational effects through maternal transfer to the embryo [42].

Another study has shown that microplastics are linked to many health issues, including oxidative stress, nervous system inflammation, and protein aggregation, all of which are essential processes in the development of neurodegenerative diseases such as Parkinson's and Alzheimer's [44]. Furthermore, plastic can serve as a medium for transporting and storing human pathogens, potentially enhancing the spread of infectious diseases in the environment. Continuous exposure to microplastics may increase a person's body burden, or the amount of plastic accumulated in their tissues. Various factors influence the risks and severity of health effects from plastic pollution, including lifetime exposure, developmental changes, and individual behavior [45].

# 7. METHODS FOR CONTROLLING PLASTIC POLLUTION

## 7.1. Raising public awareness

Governments need to promote and implement awareness campaigns and programs to inform consumers about the environmental and health impacts of microplastics, especially their negative effects on humans and other living beings, using approaches such as multimedia campaigns, educational programs, and workshops in institutions [13]. These initiatives should also teach people to adopt sustainable behaviors, such as using reusable alternatives or eco-friendly materials, and to promote daily practices that reduce single-use plastic use. Through these efforts, individuals can better understand their responsibilities toward the environment and strengthen the fight against plastic pollution [46].46].

## 7.2. Political-level solutions

Governments have several policy tools at their disposal to reduce single-use plastics and promote recycling, including legislative bans on specific items like shopping bags, microplastics, and food packaging. Economic measures such as taxes and fees can also be employed to decrease usage and fund environmental initiatives like recycling programs and educational efforts. Another fundamental approach is extended product responsibility (EPR), which mandates companies to manage plastic waste and collaborate with local authorities to minimize environmental impacts [47]. As the plastic crisis worsens, in 2022, the United Nations Environment Programme (UNEA) adopted a landmark, legally binding global agreement on plastics to cut production and manage waste, finalized in 2024 and subsequently moving into its implementation phase [48]. Simultaneously, the agreement encourages innovations such as producing plastics that can be broken down by natural processes, developing improved recycling technologies, and utilizing enzymes capable of degrading plastic materials [49].

## 7.3. Recycling

Enhancing recycling includes reinforcing infrastructure by developing waste-sorting centers and facilitating the collection of recyclables. Plastic products can also be manufactured to be more easily recycled, avoiding multi-layered plastics that make the process difficult. In addition, policies that encourage the circular economy can be used to support the use of recycled plastic waste to manufacture new products such as clothing and furniture [50]. Although many studies suggest that recycling processes are primary waste management strategies, their performance is limited because of pollution, economic inefficiencies, low rates, and the production of lower-quality items. Besides, textile manufactured from recycled plastics release microplastics raising concerns and questions about their use [51].

## 7.4. Use of eco-friendly alternatives

Governments need to offer sustainable and effective alternatives accessible to everyone, as the loss of essential products like plastic could disproportionately impact the poorest communities [52]. Eco-friendly options should match or surpass the quality of the items they replace, considering their environmental impact during manufacturing, especially in the production process. For example, paper bags are a common alternative, and although their quick decomposition is beneficial, they consume more energy to produce, are more costly, and require more space for collection and disposal [47].

In developing countries, these alternatives are hindered by infrastructure limitations. Additionally, the waste sorting at home and institutions is not done properly, resulting in recycled plastic contamination and lower value recycled plastics. Furthermore, there is weak management in landfills and a lack of essential systems to contain emissions and leachate [50].

# 8. CONCLUSION

The widespread use of plastic has led to one of the most significant environmental problems due to its impact on both ecosystems and human health. The plastic materials, especially microplastics and nanoplastics, have properties that make them resistant to natural degradation processes, allowing them to persist in the environment for many years. This results in their accumulation in air, water, soil, and the food chain. Despite government efforts to reduce plastic use, production and consumption continue to increase. To control this pollution, many strategies must be integrated, including raising public awareness, improving recycling processes, using alternative or recyclable materials, and reducing plastic usage. Therefore, addressing plastic pollution is not only an environmental priority but also a necessity for global health and the sustainability of the planet.

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### Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could be perceived as influencing the work reported in this paper.

### Ethical Approval

Not applicable

### CRediT authorship contribution statement

**Hassan M.K.:** Conceptualization, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing.

**Abdul-Kareem S.: Data curation, Resources, Writing – review & editing.**

All authors have read and agreed to the published version.

### Availability of data and materials

Data sharing is not applicable to this article as no new datasets were created or analyzed during the current study. All information used is available in the cited literature.

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