The Environmental and Health Implications of Microplastics on Human and Aquatic Life

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ABSTRACT

The pervasive presence of microplastics in the environment has emerged as a significant concern due to their potential health implications for both human and aquatic life. Microplastics are plastic particles smaller than 5 millimeters, originated from various sources, including the degradation of larger plastic debris, industrial processes and consumer products. In aquatic ecosystems, microplastics are ingested by a wide range of organisms, from plankton to fish, leading to physical and chemical impacts. These particles can cause internal injuries, blockages, and alterations in feeding behavior, ultimately affecting growth, reproduction, and survival rates of marine species. The bioaccumulation and biomagnification of microplastics and associated pollutants further aggravates these effects and eventually disrupting entire food webs. However, human exposure to microplastics occurs through multiple pathways including consumption of contaminated seafood, drinking water and inhalation of airborne particles. Studies have shown that microplastics can translocate across the gastrointestinal tract and accumulate in various tissues, raising concerns about their potential toxicity. The health implications for humans include inflammatory responses, cytotoxicity and potential endocrine disruption. Although extensive long-term studies are still needed to fully understand these effects. Microplastics can also act as vectors for harmful chemicals and pathogens, further complicating their impact on health. Additionally, addressing the issue of microplastic pollution requires a multi-faceted approach, encompassing improved waste management practices, reduction in plastic production and use, and enhanced public awareness. Research into alternative materials and innovative technologies for plastic degradation is also essential. By mitigating the sources and impacts of microplastics, we can safeguard the health of both aquatic ecosystems and human populations.

Keywords: Bioaccumulation, Biomagnification, Microbeads, Microplastics, Pollution.

INTRODUCTION

Plastic is the most common type of marine debris in our oceans and Great Lakes. Plastic debris varies in shape and size, but pieces smaller than five millimeters (5mm) in length (approximately the size of a pencil eraser) are referred to as "**microplastics**." Microplastics originate from various sources, including the degradation of larger plastic debris into progressively smaller fragments. Additionally, microbeads—a specific type of microplastic—are tiny manufactured polyethylene particles added to health and beauty products like cleansers and toothpaste as exfoliants. These miniature particles can easily bypass water filtration systems, ultimately ending up in oceans and the Great Lakes, where they pose a potential threat to aquatic life (National Oceanic and Atmospheric Administration, 2024).

Primary microplastics are small plastic particles that are intentionally manufactured (Ghosh *et al*., 2023; Karbalaei *et al*., 2018). They are generally found in facial cleansers and cosmetics or used in air blasting

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technology. In some cases, they have been used in medicine as vectors for drug delivery (Patel *et al*., 2009). Microplastic "scrubbers," employed in exfoliating hand cleansers and facial scrubs, have replaced traditional natural ingredients such as ground almond shells, oatmeal, and pumice. These primary microplastics are also manufactured for use in air-blasting technology, where acrylic, melamine, or polyester microplastic scrubbers are blasted at machinery, engines, and boat hulls to get rid of rust and paint. As these scrubbers are used repeatedly until they diminish in size and lose their cutting power, they often become contaminated with heavy metals like cadmium, chromium and lead (Cole *et al*., 2011). Although many companies have committed to reducing the production of microbeads, bioplastic microbeads with long degradation life cycles, such as those used in cosmetics, are still prevalent.

Secondary plastics are small fragments derived from the breakdown of larger plastic debris, occurring both at sea and on land (Ghosh *et al*., 2023). Over time, a combination of physical, biological, and chemical degradation processes, including photo-oxidation from sunlight exposure, reduces the structural integrity of plastic debris to sizes that eventually become undetectable to the naked eye (Masura *et al*., 2015). This process of breaking down large plastic materials into much smaller pieces is known as fragmentation (Cole *et al*., 2011). It is believed that microplastics may further degrade into even smaller particles, with the smallest microplastic currently detected in the oceans being 1.6 micrometers (6.3×10^{-5} inches) in diameter (Conkle *et al*., 2017). The prevalence of microplastics with irregular shapes suggests that fragmentation is a major source (Grossman, 2015). Observations show that biodegradable polymers may form more microplastics than non-biodegradable polymers in both seawater and freshwater (Wei *et al*., 2021).

Image source: (Abreu & Pedrotti, 2019).

Pathways Of Micro-Plastics Into The Environment

Microplastics enter terrestrial and aquatic ecosystems through various routes of pollution.

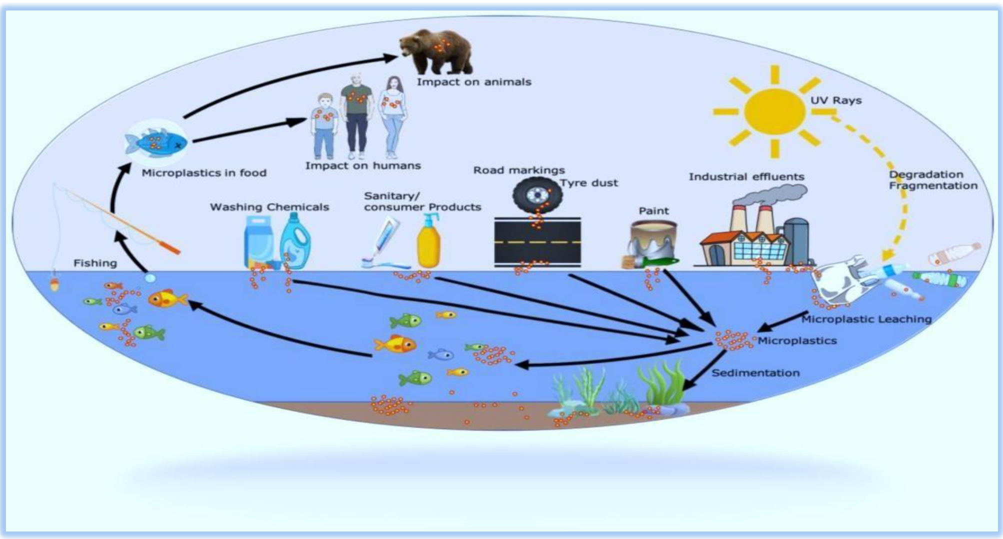

Image Source: (Ghosh *et al*., 2023); retrieved 3rd July, 2024.

Terrestrial Ecosystems:

One of the primary routes through which microplastics spreads to terrestrial surfaces is atmospheric deposition. This process involves microplastics being transported by wind and atmospheric currents before settling onto the ground. Microplastics can settle from the atmosphere onto terrestrial surfaces due to wind transport and atmospheric circulation.

The Mechanism of Atmospheric Deposition

Atmospheric deposition refers to the settling of particles from the atmosphere onto terrestrial surfaces. Microplastics, tiny plastic particles less than 5 millimeters in size (5mm), can become airborne through various processes such as the breakdown of larger plastic debris, industrial emissions and even everyday activities like driving (Allen *et al*., 2020). These particles can travel significant distances before settling on land. Studies have shown that microplastics can be transported over hundreds of kilometers through atmospheric circulation (Allen *et al*., 2022).

The Scale of Atmospheric Microplastic Deposition

The scale of microplastic pollution via atmospheric deposition is disturbing. Recent studies have shown that microplastics can be lifted into the atmosphere through wind action on land and sea surfaces. For example, a study by Brahney *et al*. (2020) revealed that the United States alone deposits more than 1,000 tons of microplastics per annum onto protected areas through atmospheric deposition. This figure is equivalent to over 123 million plastic water bottles. This research further indicated that microplastics in the atmosphere originated predominantly from urban centers, landfills and agricultural activities, which release these particles into the air through various processes, including vehicular emissions, soil tillage, and the disturbance of plastic-covered surfaces.

In Europe, a 2017 study conducted in Paris found that microplastics were deposited at a rate of 29 to 280 particles per square meter per day. This transforms to an annual deposition of approximately 3 to 10 kilograms of microplastics per hectare. Given that Paris is a major urban center, these figures underscore the impact of human activities on microplastic pollution through atmospheric pathways (Zhang *et al*., 2020).

Globally, the implications of atmospheric microplastic deposition are shocking. A 2019 study estimated that around 80% of airborne microplastics originate from urban sources (Zhao *et al*., 2023), with the remaining 20% coming from industrial sources. This distribution indicates that both everyday human activities and industrial processes contribute significantly to the presence of microplastics in the atmosphere.

Furthermore, a research conducted in China, one of the world's most populous and industrialized nations, shown that atmospheric deposition contributed to significant microplastic accumulation in agricultural fields (Yu *et al*., 2021). The study found out that approximately 120,000 microplastic particles per square meter were deposited annually in farmland areas. This level of contamination has serious implications for soil health and agricultural productivity, as microplastics can affect soil structure, water retention, and nutrient availability.

i. **Land Application**

Another primary route through which microplastics penetrates into terrestrial ecosystems is land application in agricultural practices. This involves the use of plastic mulches, composts containing plastic residues, and sewage sludge as fertilizer. These practices inadvertently introduce microplastics into the soil, leading to widespread contamination and raising concerns about long-term environmental impacts.

ii. Use of Plastic Mulches

Plastic mulches are widely used in agriculture to increase crop yield by conserving soil moisture, controlling weeds and regulating soil temperature. However, the degradation of these mulches over time results in the fragmentation of plastic into microplastic particles. According to a study published in "Environmental Pollution," approximately 3.3 million tons of plastic mulch was used globally in 2019. In China alone, the usage was estimated at 1.5 million tons. Also, it is estimated that between 30% -40% of those mulches degrade into microplastics annually, leading to accumulation of significant amounts of microplastics in agricultural soils.

iii. Compost Containing Plastic Residues

Compost derived from organic waste is widely used to improve soil fertility, yet improper waste sorting can lead to plastic residues being incorporated into compost. A study by the European Environment Agency (EEA) in 2020 revealed that up to 150,000 tons of microplastics enter European soils annually through contaminated compost application. This issue is not confined to Europe; research in the United States also indicated that around 30% of compost samples contain detectable levels of microplastics. Such widespread contamination poses significant threats to soil health, which can in turn affects agricultural productivity by impairing soil structure, nutrient cycling and the growth of beneficial soil organisms.

iv. Sewage Sludge as Fertilizer

Sewage sludge, a nutrient-rich byproduct of wastewater treatment, is mostly used as fertilizer in agriculture. However, it also serves as a significant source of microplastic pollution, as it contains microplastics from household and industrial wastewater. According to a report by the International Union for Conservation of Nature (IUCN) in 2021, approximately 80% of microplastics in sewage sludge originate from synthetic textiles and personal care products. In Europe alone, about 500,000 tons of sewage sludge is applied to agricultural lands each year, introducing between 1,500 to 2,000 tons of microplastics into the soil annually. This inflow of microplastics can disrupt soil ecosystems, hindering plant growth and potentially entering the food chain, raising concerns about long-term environmental and human health impacts.

Aquatic Ecosystems

i. **Surface Runoff**:

Urban areas are significant sources of microplastic pollution due to high population densities and the wide-range use of plastic products. Rainwater runoff from these areas can carry substantial amounts of microplastics into nearby water bodies. According to a study by the National Oceanic and Atmospheric Administration (NOAA) (2019), urban runoff can transport up to 100,000 particles of microplastics per cubic meter of water. The same study estimated that over 1.5 million tons of microplastics enter the oceans per annum through urban runoff alone.

Further research by Dris *et al*. (2018) found that 90% of microplastics in urban runoff originate from road wear, tire dust and atmospheric deposition. The presence of microplastics in urban storm water systems was quantified in a study conducted in San Francisco, which revealed that storm water outfalls contributed an estimated 7 trillion microplastic particles annually to the San Francisco Bay.

Agricultural runoff is another significant pathway through which microplastics enter aquatic ecosystems. The use of plastic mulches, fertilizers, and pesticides containing plastic residues contributes to the presence of microplastics in agricultural fields. Rainwater runoff from these fields can transport microplastics into rivers and lakes. A study published in the journal Environmental Science & Technology (2020), reported that agricultural runoff could introduce up to 200,000 microplastic particles per hectare per year into freshwater systems.

In Europe, the application of sewage sludge as fertilizer on agricultural land is a notable source of microplastics. According to the European Commission, it was observed that an estimated 500,000 tons of microplastics are applied to agricultural land annually through sewage sludge. When rainwater washes over these fields, it transports microplastics into adjacent water bodies. This process was highlighted in a study by the Helmholtz Centre for Environmental Research (2019), which found that microplastics were present in 92% of all water samples taken from agricultural runoff in Germany.

ii. **Wastewater Effluents**

Another significant pathway through which microplastics enter water bodies is by wastewater effluents. These effluents come from domestic, industrial and agricultural sources and pass through sewage systems and treatment plants. Domestic wastewater is a significant source of microplastics due to the widespread use of plastic products in households. Microplastics enter the sewage system through everyday activities such as washing clothes, using personal care products and cleaning. Synthetic fibers from clothing, microbeads from personal care products, and fragments from household items are common sources of microplastics in domestic wastewater. A study by the International Union for Conservation of Nature (IUCN) (2017), estimated that synthetic textiles contribute approximately 35% of the primary microplastics released into the environment, with washing machines in the United States releasing an estimated 0.8 to 1.5 million microplastic fibers per load.

However, wastewater treatment plants (WWTPs) play a crucial role in managing domestic wastewater. However, despite their efforts, they are not entirely effective in removing all microplastics. According to a report by the European Commission (2018), WWTPs in Europe can remove up to 90% of microplastics, but the remaining 10% still results in significant quantities being discharged into water bodies. Considering that Europe produces approximately 450 million cubic meters of treated wastewater annually, this equates to around 450,000 cubic meters of microplastic-contaminated water entering rivers, lakes and oceans per year.

Industrial activities also contribute to microplastic pollution through wastewater effluents. Industries like textiles, plastics manufacturing and cosmetics produce significant amounts of microplastics. A study published in Environmental Science & Technology (2016), found that microplastics are prevalent in industrial effluents, particularly from plastic processing facilities. These facilities can release between 3,000 -50,000 microplastic particles per cubic meter of wastewater.

Moreover, the industrial sector's contribution is not limited to direct microplastic emissions. Secondary microplastics, resulting from the degradation of larger plastic items, also find their way into wastewater. For example, abrasion from synthetic rubber products used in industrial machinery can release microplastic particles. A 2018 study by the Norwegian Institute for Water Research estimated that industrial processes in Norway release approximately 650 tons of microplastics into the environment annually, a significant portion of which is transported into water bodies through wastewater.

EFFECT OF MICROPLASTICS ON AQUATIC LIFE

These particles can have both physical and chemical impacts on aquatic organisms, affecting their health, behavior, and overall ecosystem dynamics.

Physical Impacts

1. **Ingestion and Physical Blockage**

One of the primary physical impacts of microplastics on aquatic organisms is ingestion. Many aquatic animals, including fish, invertebrates and even plankton, mistake microplastics for food. This ingestion can lead to physical blockages in the digestive systems, reducing the intake of actual nutrients and causing malnutrition, growth reduction, and eventually death. A study by Baalkhuyur *et al*. (2018), investigated the presence of microplastic litter in the gastrointestinal tracts of 26 commercial and non-commercial fish species from four different habitats along the Saudi Arabian coast of the Red Sea. The researchers examined a total of 178 fish and discovered 26 microplastic fragments in total. Of these fragments, 16 were films (61.5%) and 10 were fishing threads (38.5%). The higher abundance of microplastic particles is likely linked to the fish habitats and the concentration of microplastic debris near the seabed.

2. Buoyancy and Mobility Issues

Microplastics also affect the buoyancy and mobility of aquatic organisms. For instance, small particles can get embedded in the tissues or shells of organisms, affecting their ability to swim and escape predators. Research conducted by the University of Plymouth (2014), demonstrated that microplastics caused physical harm to marine worms, which showed reduced burrowing ability and overall fitness (Hodgson, 2018).

3. Entanglement

Lastly on physical effect, microplastics can cause entanglement. Aquatic organisms, particularly smaller species, can become entangled in microplastic fibers, leading to physical injuries, restricted movement, and increased vulnerability to predators (Harding, 2016). A study by the Marine Pollution Bulletin (2017), reported instances of entanglement in various marine species, including crabs and juvenile fish, which often led to impaired mobility and higher mortality rates.

Chemical Impacts

1. Toxic Chemical Additives

Microplastics often contain toxic chemical additives used during their production, such as plasticizers which enhance the flexibility and durability of plastics like phthalates, phosphates and lot more, flame retardants used to reduce flammability of plastics includes polybrominated diphenyl ethers (PBDEs), Dimethyl methylphosphonate (DMMP) and colorants. These chemicals can leach out of the microplastics and into the tissues of organisms upon ingestion. Over 50% of microplastics collected from the ocean contained harmful additives, including bisphenol A (BPA) and phthalates (Alkan & Alkan, 2020), which are known as endocrine disruptors.

2. Adsorption of Environmental Pollutants

Microplastics have a high surface area-to-volume ratio, allowing them to adsorb various environmental pollutants, including heavy metals, pesticides and persistent organic pollutants (POPs). When aquatic organisms ingest microplastics, they are also exposed to these adsorbed toxins. A research published by Environmental Pollution (2019), found that microplastics collected from coastal waters had adsorbed significant amounts of pollutants such as polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs).

3. Bioaccumulation and Biomagnification

The ingestion of microplastics and their associated toxins can lead to bioaccumulation and biomagnification within the food web. As smaller organisms consume microplastics, they accumulate toxins in their tissues. Predators that eat these organisms then ingest higher concentrations of these toxins, leading to biomagnification. An investigation was conducted to explore microplastic contamination in various species sampled from different trophic levels in a deep-sea food web in Monterey Bay, CA, USA. The species studied included tuna crab (*Pleuroncodes planipes*), market squid (*Doryteuthis opalescens*), northern lampfish (*Stenobrachius leucopsarus*), chub mackerel (*Scomber japonicus*), California halibut (*Paralichthys californicus*) and Chinook salmon (*Oncorhynchus tshawytscha*). The researchers examined microplastics in the gastrointestinal (GI) tracts and other tissues (abdomen and tail in crustaceans, mantle in cephalopods and fillets in fishes). After chemical digestion, microplastics in the GI tracts were quantified and identified by material type using μ-Raman spectroscopy, while those in other tissues were analyzed using pyrolysis-GC/MS. The concentrations of microplastics in the GI tracts varied significantly among species, with contamination predominantly consisting of microfibers. Additionally, concentrations of microplastics (mainly polyethylene and polyvinyl chloride) in other tissues also varied among species. However, the study did not observe evidence for biomagnification of microplastics in the gastrointestinal tracts (Hermabessiere *et al.*, 2023).

Microplastics And Toxic Chemicals: Interaction, Transport And Health Risks

Microplastics not only act as carriers for these pollutants but also release harmful substances into ecosystems and human bodies. Thus there are interactions between microplastics and environmental pollutants, in which, microplastics transports and releases toxic chemicals that leads to health risks.

Interaction of Microplastics with Environmental Pollutants

Microplastics have a high surface-area-to-volume ratio, which makes them excellent substrates for the adsorption of various environmental pollutants, including persistent organic pollutants (POPs), heavy metals and hydrophobic organic compounds (HOCs). These interactions occur primarily through physical adsorption and chemical binding. Studies have shown that microplastics can adsorb toxic chemicals from water, air and soil, thereby acting as vectors for their transport.

For instance, Rios *et al*. (2010) demonstrated an experiment by collecting plastic debris in the North Pacific Gyre, extracted and analyzed for 36 individual polychlorinated biphenyls (PCB) congeners, 17 organochlorine pesticides, and 16 EPA priority polycyclic aromatic hydrocarbons (PAHs). Over 50% contained polychlorinated biphenyls (PCBs), 40% contained pesticides, and nearly 80% contained PAHs. The PAHs included 2, 3 and 4 ring congeners. The PCBs were primarily CB-11, 28, 44, 52, 66, and 101. The pesticides detected were primarily p,p-DDTs and its metabolite, o,p-DDD, as well as BHC. The concentrations of pollutants found ranged from a few ppb to thousands of ppb. The types of PCBs and PAHs found were similar to those found in marine sediments. However, these plastic particles were mostly polyethylene which is resistant to degradation and although functioning similarly to sediments in accumulating pollutants. Particles collected included intact plastic items as well as many pieces less than 5 mm in size.

Role of Microplastics in Transporting and Releasing Toxic Chemicals

Once microplastics adsorb toxic chemicals, they can transport these pollutants across different environmental compartments. This transport mechanism is particularly concerning in aquatic environments, where microplastics can travel long distances with ocean currents, spreading contaminants far from their original source. For example, Zhang *et al*. (2019) reported that microplastics in the Yangtze River carried high levels of adsorbed heavy metals, which were then transported into the East China Sea.

Moreover, microplastics can release adsorbed chemicals under certain environmental conditions, such as changes in temperature, pH and salinity. This desorption process can reintroduce pollutants into the environment, making them bioavailable to aquatic organisms. Bakir *et al*. (2014) conducted laboratory experiments showing that microplastics can release adsorbed PAHs when exposed to varying salinities, highlighting the dynamic nature of pollutant-microplastic interactions.

Health Risks of Combined Exposure to Microplastics and Toxic Chemicals

The combined exposure to microplastics and toxic chemicals poses significant health risks to both wildlife and humans. Ingested microplastics can cause physical harm, such as gastrointestinal blockages and tissue damage. When these microplastics also carry toxic chemicals, the risks are compounded. For instance, studies have shown that microplastics can transfer adsorbed pollutants to marine organisms, leading to bioaccumulation and biomagnification within the food chain (Brennecke *et al*., 2016).

Human health is also at risk, particularly through the consumption of contaminated seafood. Rochman *et al*. (2013) revealed that fish and shellfish can ingest microplastics along with their adsorbed pollutants, which are then passed on to humans upon consumption. This exposure can lead to various health issues, including endocrine disruption, reproductive toxicity and carcinogenic effects.

Additionally, microplastics themselves may leach toxic additives, such as bisphenol A (BPA) and phthalates, which are commonly used in plastic manufacturing. These additives are known to have harmful health effects, including hormone disruption and developmental problems (Teuten *et al*., 2009).

FUTURE DIRECTIONS AND RESEARCH NEEDS

Gaps in Current Research on Micro-Plastics and Their Health Implications

i. **Toxicological Impact**: While there is growing evidence that micro-plastics can carry harmful chemicals, the specific toxicological impacts on human health remain poorly understood. More research is needed to determine the long-term effects of micro-plastic ingestion and inhalation (Wright & Kelly, 2017).
ii. **Dose-Response Relationship**: Current studies often focus on the presence of micro-plastics rather than quantifying exposure levels. Establishing dose-response relationships is crucial to assess the risk associated with different levels of exposure (Wright & Kelly, 2017).
iii. **Combined Effects**: Micro-plastics often carry a variety of pollutants, such as heavy metals and persistent organic pollutants (POPs). Research is needed to understand combined effects of micro-plastics and the co-contaminants on human health (Wright & Kelly, 2017).

Emerging Technologies for Monitoring and Removing Micro-Plastics from the Environment

i. **Advanced Filtration Systems**: Innovations in filtration technology, such as Nano-filtration and membrane bioreactors, can effectively capture micro-plastics from wastewater and drinking water sources (Rochman *et al*., 2013).
ii. **Bioremediation**: Research into microbial and enzymatic degradation of plastics is advancing, with some bacteria and fungi showing potential in breaking down micro-plastics into less harmful substances (Rochman *et al*., 2013).
iii. **Electrochemical Methods**: Electrocoagulation and other electrochemical techniques are being explored for their ability to aggregate and remove micro-plastics from water bodies.
iv. **Nanotechnology**: The development of nanomaterial that can selectively bind to micro-plastics offers a potential method for detecting and extracting micro-plastics from various environmental media (Galloway & Lewis, 2016).
v. **Remote Sensing and AI**: Emerging technologies in remote sensing combined with artificial intelligence (AI) are being developed to detect and map the distribution of micro-plastics in oceans and other large bodies of water (Galloway & Lewis, 2016)..

Policy Recommendations for Addressing Micro-Plastic Pollution

i. **Regulation of Micro-Plastic Sources**: Implementing stringent regulations on the primary sources of micro-plastics, such as microbeads in personal care products, microfibers from textiles and plastic pellets from manufacturing is crucial (Koelmans *et al*., 2017).
ii. **Extended Producer Responsibility (EPR)**: Encouraging manufacturers to take responsibility for the entire lifecycle of their plastic products can incentivize the development of sustainable alternatives and improve recycling efforts.
iii. **Public Awareness Campaigns**: Educating the public about the sources and impacts of micro-plastics can lead to behavioural changes that reduce micro-plastic pollution, such as choosing products with less plastic packaging and properly disposing of plastic waste.
iv. **Research Funding**: Governments and international organizations should increase funding for research focused on the health impacts of micro-plastics, as well as the development of new technologies for monitoring and remediation.
v. **International Collaboration**: Micro-plastic pollution is a global issue that requires coordinated international efforts. Policies should promote collaboration between countries to share research, technology and best practices for addressing micro-plastic pollution.

CONCLUSION

The article highlights the significant health implications of micro-plastics for both humans and aquatic life. Key points include the various ways in which micro-plastics can carry harmful chemicals, the specific toxicological impacts on human health, including biological pathways and dose-response relationships, are still poorly understood. For aquatic life, micro-plastics are ingested by organisms, leading to physical harm and exposure to toxic substances. These micro-plastics accumulate in tissues and can biomagnify up the food chain, ultimately affecting larger predators, including humans. Moreover, micro-plastics persist in the environment due to their origin from various sources, being detected in diverse ecosystems from oceans to freshwater bodies.

Addressing the issue of micro-plastic pollution requires ongoing research and proactive measures. Enhanced research, particularly comprehensive toxicological and epidemiological studies, is necessary to understand the health impacts on humans and aquatic life. Developing advanced technologies for detecting, monitoring and removing micro-plastics can help mitigate their presence in the environment. Additionally, implementing regulations to reduce micro-plastic production and release, promoting extended producer responsibility and educating the public can significantly reduce micro-plastic pollution. Coordinated global efforts are essential for effectively addressing micro-plastic pollution, including sharing research, technology, and best practices. In conclusion, the pervasive issue of micro-plastic pollution poses significant risks to human health and aquatic life. Continued research is vital to fill knowledge gaps, and proactive measures are crucial to mitigate these impacts, ensuring a healthier environment for all

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