Fusion of Multidisciplinary Research, An International Journal (FMR) , Vol. **2**, Iss. **2**, 2021
https://doi.org/10.63995/SGQE2230

ARTICLE

The Widespread Environmental and Health Effects of Microplastics Pollution Worldwide

Ishaan Jain, Anjali Reddy, and Nila Rao*

Department of Environmental Studies, North Eastern Hill University, Shillong, Meghalaya 793022, India
*Corresponding author: Nilarao1039@yahoo.co.in

(Received: 09 March 2021; Revised: 12 May 2021; Accepted: 10 June 2021; Published: 24 July 2021)

Abstract
Microplastics pollution, characterized by plastic particles smaller than 5 millimeters, has become a pervasive environmental and health issue worldwide. Originating from various sources, including the breakdown of larger plastic debris, synthetic textiles, and personal care products, microplastics have infiltrated diverse ecosystems, from oceans and freshwater bodies to soil and air. These particles pose significant threats to marine and terrestrial life, as they are ingested by organisms across the food chain, leading to physical harm, reproductive issues, and disruptions in growth and development. The health implications for humans are increasingly concerning, as microplastics have been detected in drinking water, food, and even the air we breathe. Potential health risks include inflammatory responses, oxidative stress, and the introduction of toxic chemicals into the body, which can exacerbate chronic diseases and affect overall well-being. Moreover, the persistence and accumulation of microplastics in the environment exacerbate the pollution problem, complicating cleanup efforts and posing long-term ecological risks. Addressing microplastics pollution requires comprehensive strategies, including improved waste management, reduction of plastic use, and development of biodegradable alternatives. Additionally, enhanced public awareness and policy interventions are crucial to mitigate the spread of microplastics and protect environmental and human health. This abstract underscores the urgency of tackling microplastics pollution to safeguard ecosystems and public health globally.

Keywords: Environmental Impact; Health Risks; Marine Ecosystems; Human Ingestion; Microplastics Pollution; Toxic Chemicals; Waste Management

Abbreviations: ASEAN: Association of Southeast Asian Nations, ITRCL: Interstate Technology and Regulatory Council, MP: Microplastics, PE: Polyethylene, PET: Polyethylene terephthalate, PP: Polypropylene, PS: Polystyrene, PVC: Polyvinyl chloride, SDG: Sustainable Development Goal, UNEA: United Nations Environmental Assembly

1. Introduction

Microplastics, tiny fragments of plastic less than 5 mm in length, have emerged as a pervasive global pollutant, posing significant threats to both environmental and human health. These minuscule particles infiltrate marine ecosystems, food chains, and even the air we breathe, carrying potential risks of inflammation and exposure to hazardous substances like BPA and heavy metals [1]. Originating from various sources such as plastic waste, fishing gear, personal care products, and COVID-19 protective equipment, microplastics have been detected in sediments, water bodies, and biota across the globe. This article delves into the types and classification of microplastics, their environmental presence, human exposure routes, potential health impacts, toxicity mechanisms, and the far-reaching consequences for ecosystems. Additionally, it explores regulatory efforts, future research directions, and the urgent need to address this burgeoning crisis exacerbated by climate change and plastic pollution (Fig. 1) [2, 3, 4, 5, 6].

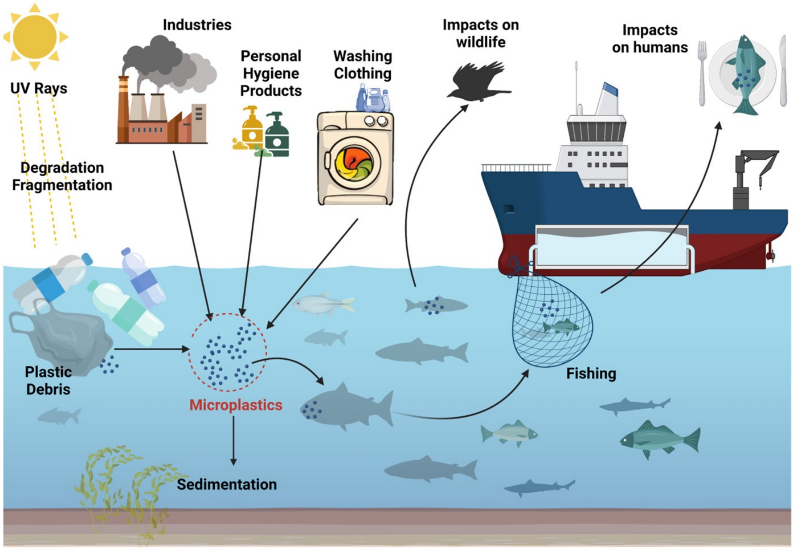

Figure 1. Microplastics in aquatic environment.

1.1 Types and Classification

Microplastics (MPs) can be broadly classified into two categories based on their origin:

1. **Primary Microplastics:** These are intentionally manufactured small plastic particles used in various products and applications, such as:
   - Microbeads in personal care products (e.g., facial cleansers, toothpaste)
   - Pre-production plastic pellets or nurdles used as raw materials
   - Abrasives in air-blasting and cleaning agents
   - Synthetic fibers from clothing and textiles
2. **Secondary Microplastics:** These are formed through the fragmentation and degradation of larger plastic items due to physical, chemical, and biological processes. Common sources include:
   - Breakdown of plastic litter and waste
   - Weathering and erosion of plastic products
   - Abrasion from synthetic rubber tires
   - Degradation of fishing nets and gear

In terms of shape and composition, microplastics can take various forms, including:

- **Shapes:** Fragments, fibers, pellets, films, and foams
- **Polymers:** Polyethylene (PE), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET), polyvinyl chloride (PVC), and nylon

Studies have found that fibers and fragments are the most prevalent shapes of microplastics in the environment, with fibers being particularly abundant due to their release from synthetic textiles during washing and wear [7]. It's important to note that while primary microplastics are intentionally manufactured, both primary and secondary microplastics contribute significantly to plastic pollution and can have detrimental impacts on ecosystems and human health [8].

2. Environmental Presence

Microplastics have been detected in various environmental matrices, demonstrating their ubiquitous presence and widespread distribution across the globe (Fig. 2). Here are some key findings:

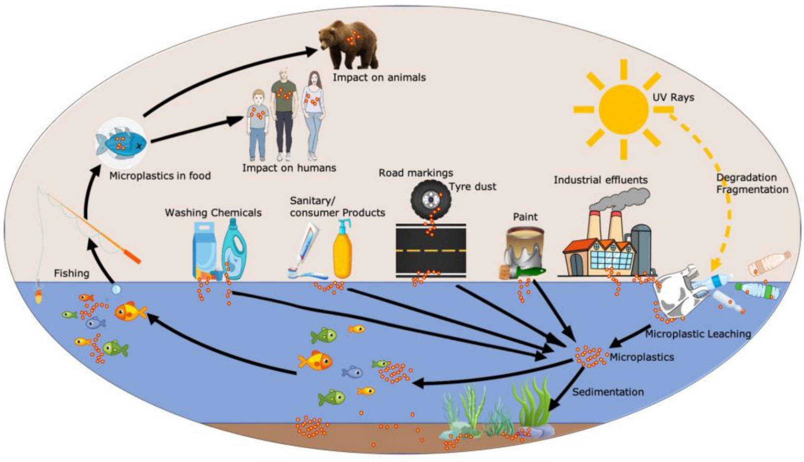

Figure 2. Microplastics generation.

- **Air:** Concentrations ranging from 0.45 to 6.64 pieces/m^3 have been reported in South Korea, with higher levels observed indoors compared to outdoors.
- **Water:**
  - Freshwater: Mean concentration of 0.05 pieces/L in water treatment plants in South Korea.
  - Seawater: Concentrations ranging from 0.57 to 15,560 pieces/m^3 have been found, with paint particles, Styrofoam, and fibers being the most abundant types.
- **Marine Products:** Concentrations ranging from 0.07 to 2.22 pieces/g have been detected, with fragments of 20 to 200μm composed mainly of polypropylene (PP), polyethylene (PE), and polystyrene (PS).
- **Soil:** Mean concentration of 700 pieces/kg has been reported in South Korea, with higher levels found in upland soil compared to urban soil.

Microplastics have been found in remote and pristine locations, including the Arctic, Antarctic, and deep ocean trenches, highlighting their widespread distribution. They originate from various sources, such as plastic waste, fishing gear, personal care products, textiles, and COVID-19-related personal protective equipment [9, 10]. Weathering and degradation processes, like photooxidation, biodegradation, and microbial action, contribute to the generation of microplastics and nanoplastics over time [11].

2.1 Human Exposure Routes

Humans are exposed to microplastics through various routes, primarily ingestion, inhalation, and dermal contact. The major sources of exposure include:

- **Ingestion:**

- Consumption of contaminated food, especially seafood and marine products
- Drinking water, with bottled water being a significant source (estimated 22-fold higher exposure than tap water)
- Diet, including seafood, salt, and honey (estimated average ingestion of 0.1-5 g/week of MPs up to 1 mm in size)

- **Inhalation:**
  - Exposure to airborne microplastics, particularly in occupational settings like synthetic fiber industries
  - Indoor air and dust, with indoor air having 5-10 times higher MP concentrations than outdoor air (estimated inhalation exposure doses of 6.5-8.97 $g/kg - bw/day$)
- **Dermal Contact:**
  - Use of cosmetics containing microbeads
  - Release of microfibers from synthetic textiles during washing

Estimates suggest that humans may be ingesting tens of thousands to millions of microplastic particles annually, or on the order of several milligrams daily. Microplastics have been detected in human organs, including the placenta of newborn babies, and in blood and feces. While the long-term health impacts are still unknown, potential issues include respiratory irritation, cardiovascular problems, and exposure to harmful chemicals. Smaller microplastics and nanoplastics can be more readily absorbed by cells and tissues, causing oxidative stress, inflammation, and metabolic disorders [12, 13].

3. Potential Health Impacts

The COVID-19 pandemic has exacerbated the existing plastic pollution crisis, leading to a surge in single-use plastic waste generation. This pandemic-related plastic waste can release microplastics and nanoplastics, posing potential threats to aquatic organisms, soil organisms, and human health (Fig. 3) [14].

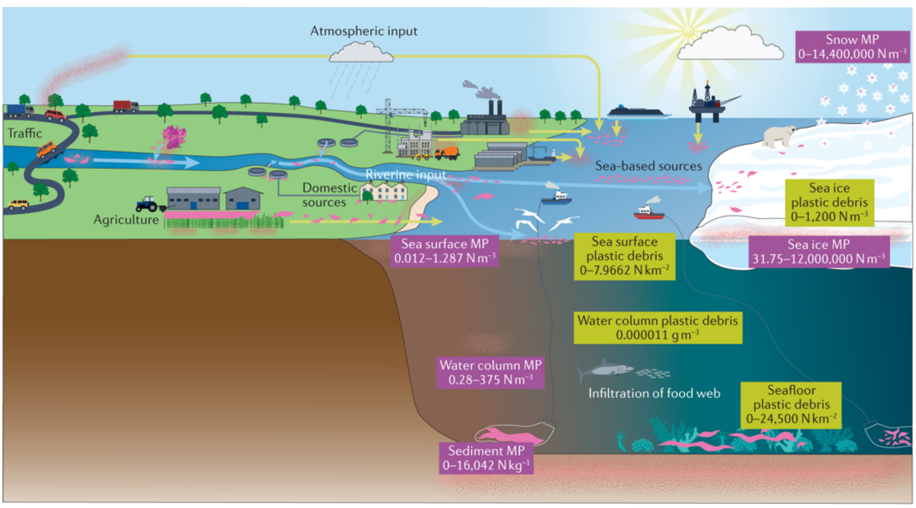

Figure 3. Overview of the pathways of plastic pollutants.

The impacts of microplastics and nanoplastics on aquatic organisms are concerning, including:

- Reduced photosynthesis in marine diatoms
- Accumulation in the digestive tracts of various species
- Reduced fecundity (reproductive capacity) in marine copepods

Similarly, soil organisms are affected, with hindered reproduction and growth in springtails and suppressed spermatogenesis (sperm production) in earthworms.

When ingested by marine life, microplastics (MPs) can have toxic and mechanical effects, leading to:

1. Reduced food intake
2. Suffocation
3. Behavioral changes
4. Genetic alteration

Microplastics are associated with serious health impacts, especially in women, including changes to:

- Human genetics
- Brain development
- Respiration rates

Moreover, MPs can release plastic additives such as phthalates, bisphenols, and organotins, which can cause adverse effects through:

- Activation of nuclear receptors
- Disruption of lipid and energy metabolism

Maternal transfer of MPs to the developing fetus has been demonstrated, and animal studies show that maternal exposure to MPs can alter energy and lipid metabolism in offspring. Alarmingly, the increase in global plastics production over the past 50 years is in line with the rate of increase in overweight and obesity in human populations, suggesting that MPs and their additives may be potential obesogens [15].

3.1 Toxicity Mechanisms

Microplastics and nanoplastics can exert toxic effects on organisms through various mechanisms. One major concern is their ability to release harmful chemicals, such as phthalates and bisphenol A (BPA), which can disrupt hormones and endocrine functions. These substances are known to have toxic effects on various organisms, including humans [16].

Furthermore, nanoplastics, due to their minuscule size, can cross biological barriers and potentially interact with cellular components, impacting gene expression and cellular processes. This ability to penetrate cells and tissues raises concerns about their potential to cause adverse effects at the molecular level [17].

Another toxicity mechanism involves the adsorption and transportation of toxic chemicals by microplastics and nanoplastics (MNPs). These particles can act as carriers for persistent organic pollutants (POPs), heavy metals, and other contaminants, facilitating their uptake by aquatic organisms. When ingested by zooplankton, fish, and shellfish, MNPs can lead to:

1. Reduced growth rates
2. Impaired reproduction
3. Decreased survival

This bioaccumulation of MNPs and associated contaminants can magnify their negative impacts as they move up the food chain, posing risks to higher trophic levels and potentially affecting human health through seafood consumption [18].

4. Environmental Impacts

Microplastics pose a significant threat to terrestrial, aquatic, and atmospheric ecosystems, with far-reaching consequences for various organisms and the environment (Fig. 4). Here are some key impacts:

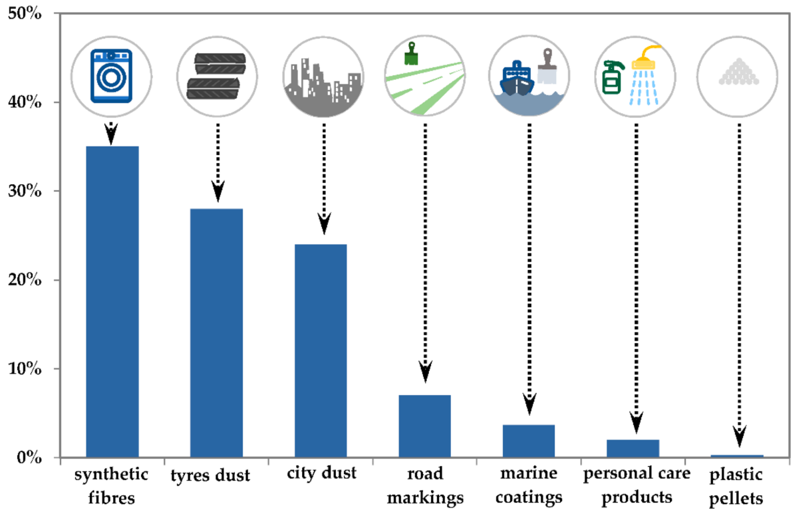

Figure 4. Global evaluation of sources for primary microplastics.

1. **Terrestrial Ecosystems:**
    - Microplastics can affect soil properties, disrupt soil biota, and be transported through the food chain.
    - They have been detected in atmospheric fallout, indicating their presence in the air.
    - Microplastics and nanoplastics are entering the food chain, adversely affecting soil fauna like earthworms, mites, and larvae that maintain soil fertility.
    - Sewage sludge applied as fertilizer is a major source of microplastics in soils, with 80-90% of plastic particles in sewage ending up in the sludge.
2. **Aquatic Ecosystems:**
    - Marine organisms can ingest microplastics, leading to gastrointestinal, liver, and reproductive toxicity.
    - Microplastics can act as carriers for harmful chemicals, facilitating their uptake by aquatic organisms.
    - Ingestion of microplastics by zooplankton, fish, and shellfish can result in reduced growth rates, impaired reproduction, and decreased survival.
    - Bioaccumulation of microplastics and associated contaminants can magnify their negative impacts as they move up the food chain.
3. **Global Pollution and Projections:**

- In 2016, four sources of microplastics (microbeads, plastic fibers, pellets, and tire wear) accounted for 1.3 million metric tons (11%) of total ocean plastic pollution.
- High-income countries are the main contributors, accounting for more than one-third of the global total of these four microplastic sources in 2016.
- Without immediate changes, ocean microplastic pollution is projected to more than double to 3 million metric tons per year by 2040.

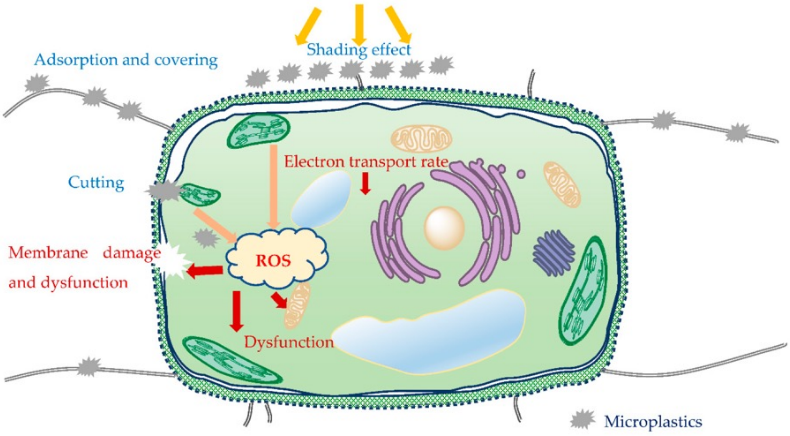

Figure 5. Schematic description of the toxicity mechanisms of microplastics to algae cell.

Total1,300,000Microplastics are widely present in the environment worldwide, including in water bodies, soil, and the atmosphere, posing a significant environmental concern. Addressing this issue requires a multifaceted approach, including reducing plastic waste, improving waste management systems, and developing innovative solutions to mitigate the release of microplastics into the environment (Fig. 5) [19].

4.1 Regulatory Efforts

Governments and international organizations have taken various steps to address the growing issue of microplastic pollution. The European Union (EU) has been at the forefront, primarily focusing on removing sources of intentionally produced microplastics from consumer use and production chains. Notably, the EU adopted a single-use plastic ban on 10 specific products, which took effect in July 2021, and is examining the regulation of nanoplastics [20].

In North America, the United States and Canada have implemented monitoring programs and regulations to better understand the nature and extent of microplastics issues. Both countries have passed federal laws banning plastic microbeads, a subset of microplastics. Canada has added plastic manufactured items to its list of toxic substances and is drafting regulations to ban certain single-use plastics. Several U.S. states have also enacted legislation banning microbeads and other forms of plastic. For instance:

- In 2018, California passed laws defining microplastics in drinking water and requiring the development of standards and testing.
- California also passed a law requiring the development of a statewide strategy to address microplastics pollution in the marine environment.
- The Interstate Technology and Regulatory Council (ITRC) is developing guidance on the nature,

distribution, health effects, sampling, and treatment of microplastics, as well as current regulations.

On a global scale, the United Nations Environmental Assembly (UNEA) issued Resolution 5/14 in March 2022, requesting the establishment of an intergovernmental negotiating committee (INC) to develop an international legally binding instrument on plastic pollution. The U.S. government, led by the State Department, is actively participating in the INC process, with the FDA's Office of Global Policy and Strategy as the agency lead. The INC is considering a broad range of measures to address plastic pollution, including reducing the production and demand for primary plastic polymers, controlling the use of certain substances in plastic products, and improving circularity and waste management [21].

While these efforts are underway, the UN has included plastics and microplastics (MPs) pollution in 13 of its 17 Sustainable Development Goals (SDGs), but only has a single indicator under SDG 14 to measure progress, which lacks an internationally accepted index. Regional organizations like the Association of Southeast Asian Nations (ASEAN) have also adopted action plans to combat marine debris, including plastics, in their regions [6].

5. Future Research Directions

Research on soil microplastics has experienced a rapid growth stage, with a surge in publications since 2018. China is the country with the most publications in this field, followed by Germany (Fig. 6). The key research areas in the field of soil microplastics can be categorized into 4 main themes:

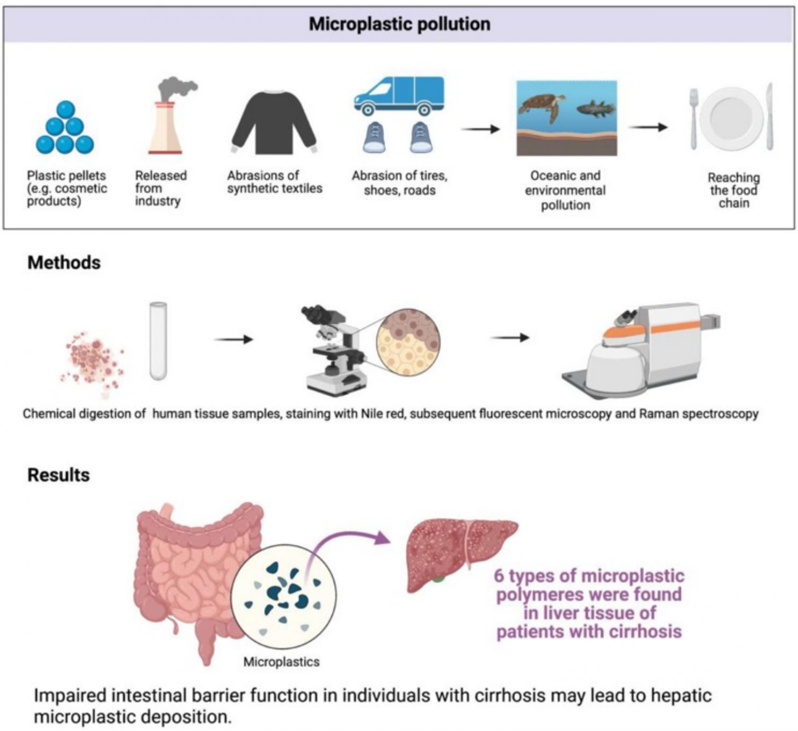

Figure 6. Microplastics detected in cirrhotic liver tissue.

1. Environmental pollution and exposure routes
2. The function and health of soil-associated media

3. The characteristics of microplastics
4. The combined pollution with other contaminants

Future research directions include:

- In-depth study ofmigration mechanisms in soil
- Development of effective removal technologies
- Establishment of standardized evaluation systems and risk assessment models
- Expanding research to ecologically sensitive areas

Ensuring that environmentalresearch data are findable, accessible, interoperable, and reusable (FAIR) is essential to inform policy and mitigation strategies. However, a bibliographic analysis shows that less than a third ofarticles contained a data sharing statement, and only 13.8% of the data were shared via a data repository (Fig. 7).

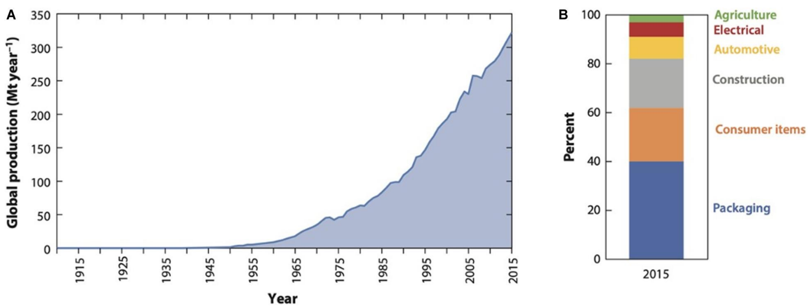

Figure 7. Evolution in total plastic production worldwide.

Recommendations to strengthen data sharing practices in the environmental research community include:

- Using available standards/practices to describe data
- Sharing raw data
- Using trusted digital repositories
- Linking datasets to publications
- Planning to share data from the onset of a study

6. Conclusion

The pervasive presence of microplastics in various environmental matrices worldwide poses a significant threat to ecosystems, organisms, and human health. From contaminating our air and water sources to infiltrating our food chains, these microscopic fragments have become a global pollutant with far-reaching consequences. Addressing this crisis requires a multifaceted approach, involving regulatory efforts, innovative solutions, and a collective commitment to reducing plastic waste and improving waste management systems. While governments and international organizations are taking steps to regulate and monitor microplastic pollution, future research is crucial to better understand its migration mechanisms, develop effective removal technologies, and establish standardized risk assessment models. Moreover, ensuring findable, accessible, interoperable, and reusable (FAIR) data sharing practices in environmental microplastics research will be essential to inform policy and mitigation strategies. Tackling this burgeoning crisis demands a collaborative effort from all stakeholders, as the impacts of microplastics transcend borders and affect us all.

References

[1] Jiana Li, Amy L Lusher, Jeanette M Rotchell, Salud Deudero, Alexander Turra, Inger Lise N Bråte, Chengjun Sun, M Shahadat Hossain, Qipei Li, Prabhu Kolandhasamy, et al. "Using mussel as a global bioindicator of coastal microplastic pollution". In: *Environmental pollution* 244 (2019), pp. 522–533.

[2] Madeleine Smith, David C Love, Chelsea M Rochman, and Roni A Neff. "Microplastics in seafood and the implications for human health". In: *Current environmental health reports* 5 (2018), pp. 375–386.

[3] Fauziah Shahul Hamid, Mehran Sanam Bhatti, Norkhairiyah Anuar, Norkhairah Anuar, Priya Mohan, and Agamuthu Periathamby. "Worldwide distribution and abundance of microplastic: how dire is the situation?" In: *Waste Management & Research* 36.10 (2018), pp. 873–897.

[4] Jia-Qian Jiang. "Occurrence of microplastics and its pollution in the environment: A review". In: *Sustainable production and consumption* 13 (2018), pp. 16–23.

[5] Alice A Horton and David KA Barnes. "Microplastic pollution in a rapidly changing world: Implications for remote and vulnerable marine ecosystems". In: *Science of The Total Environment* 738 (2020), p. 140349.

[6] Chibuisi Gideon Alimba and Caterina Faggio. "Microplastics in the marine environment: Current trends in environmental pollution and mechanisms of toxicological profile". In: *Environmental toxicology and pharmacology* 68 (2019), pp. 61–74.

[7] Joana Correia Prata, João P da Costa, Isabel Lopes, Armando C Duarte, and Teresa Rocha-Santos. "Environmental exposure to microplastics: An overview on possible human health effects". In: *Science of the total environment* 702 (2020), p. 134455.

[8] Nithin Ajith, Sundaramanickam Arumugam, Surya Parthasarathy, Sathish Manupoori, and Sivamani Janakiraman. "Global distribution of microplastics and its impact on marine environment—a review". In: *Environmental Science and Pollution Research* 27 (2020), pp. 25970–25986.

[9] Jacob Oliver and William Mason. "Gene Variation: The Key to Understanding Pharmacogenomics and Drug Response Variability". In: *Fusion of Multidisciplinary Research, An International Journal (FMR)* 1.2 (2020), pp. 97–109.

[10] Claudia Campanale, Carmine Massarelli, Ilaria Savino, Vito Locaputo, and Vito Felice Uricchio. "A detailed review study on potential effects of microplastics and additives of concern on human health". In: *International journal of environmental research and public health* 17.4 (2020), p. 1212.

[11] Robert C Hale, Meredith E Seeley, Mark J La Guardia, Lei Mai, and Eddy Y Zeng. "A global perspective on microplastics". In: *Journal of Geophysical Research: Oceans* 125.1 (2020), e2018JC014719.

[12] Samaneh Karbalaei, Parichehr Hanachi, Tony R Walker, and Matthew Cole. "Occurrence, sources, human health impacts and mitigation of microplastic pollution". In: *Environmental science and pollution research* 25 (2018), pp. 36046–36063.

[13] Shivika Sharma and Subhankar Chatterjee. "Microplastic pollution, a threat to marine ecosystem and human health: a short review". In: *Environmental Science and Pollution Research* 24 (2017), pp. 21530–21547.

[14] Siva Sankar Sana, Lakshman Kumar Dogiparthi, Lekshmi Gangadhar, Arghya Chakravorty, and Nalluri Abhishek. "Effects of microplastics and nanoplastics on marine environment and human health". In: *Environmental Science and Pollution Research* 27 (2020), pp. 44743–44756.

[15] Richard C Thompson. "Microplastics in the marine environment: sources, consequences and solutions". In: *Marine anthropogenic litter* (2015), pp. 185–200.

[16] Henry H. James, Razu Pawel, and Gawin Saduf. "Autonomous Vehicles and Robust Decision-Making in Dynamic Environments". In: *Fusion of Multidisciplinary Research, An International Journal (FMR)* 1.2 (2020), pp. 110–121.

[17] Anderson Abel de Souza Machado, Werner Kloas, Christiane Zarfl, Stefan Hempel, and Matthias C Rillig. "Microplastics as an emerging threat to terrestrial ecosystems". In: *Global change biology* 24.4 (2018), pp. 1405–1416.

[18] Sanjay Kumar, Mridula Rajesh, KM Rajesh, NK Suyani, A Ahamed Rasheeq, and KS Pratiksha. "Impact of microplastics on aquatic organisms and human health: A review". In: *International Journal of Environmental Sciences & Natural Resources* 26.2 (2020), pp. 59–64.

[19] Jiao Wang, Xianhua Liu, Yang Li, Trevor Powell, Xin Wang, Guangyi Wang, and Pingping Zhang. "Microplastics as contaminants in the soil environment: A mini-review". In: *Science of the total environment* 691 (2019), pp. 848–857.

[20] Alice A Horton and Simon J Dixon. "Microplastics: An introduction to environmental transport processes". In: *Wiley Interdisciplinary Reviews: Water* 5.2 (2018), e1268.

[21] Gabriel Enrique De-la-Torre. "Microplastics: an emerging threat to food security and human health". In: *Journal of food science and technology* 57.5 (2020), pp. 1601–1608.