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The impact of environmental microplastics as emerging carcinogens: A public health concern

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Abstract Microplastics, small plastic particles less than 5 millimeters in size, have become common in the environment and occur in air, water, and food sources. Possible effects on human health, particularly as carcinogens, have become a growing concern. This review aims to investigate the mechanisms by which microplastics may contribute to cancer development and the implications for public health. A comprehensive literature review was conducted, focusing on studies from 2010 to 2024. The data were collected from various sources, including Google Scholar, PubMed, Web of Science and Scopus. The key areas examined include biological mechanisms of carcinogenesis, human exposure pathways, and risk assessment models. Microplastics can induce carcinogenesis through multiple pathways, including oxidative stress, inflammation, and cellular damage pathways. Research both in vivo and in vitro has demonstrated that microplastics can cause DNA damage and disrupt cellular processes, potentially leading to cancer. Human exposure occurs primarily through ingestion, inhalation, and dermal contact in the absence of data, and epidemiological studies indicate a link between increased levels of microplastic exposure and a greater risk of cancer. Microplastics represent a coming class of environmental carcinogens with significant public health implications. More investigations are needed to completely explain their carcinogenic mechanisms and to develop effective strategies to reduce human exposure. Public health policies must evolve to mitigate the risks connected with microplastic pollution, protecting future generations from its potential health impacts.

Keywords: cancer, public health, oxidative stress, inflammation, DNA damage, exposure pathways

1. Introduction

One of the most important environmental issues facing the world today is microplastic pollution, which has drawn much attention. Microplastics are tiny plastic particles that are less than 5 mm in size (Lamichhane et al., 2023). They are found in various forms, including microbeads in personal care products, fragments from larger plastic debris, and fibers released from synthetic textiles. Worldwide, there is a wide range of microplastic pollution in the air, water, and land (Emenike et al., 2023). The presence of microplastics in the environment is a result of various sources, including industrial and domestic waste, improper disposal, and the breakdown of larger plastic items. The impact of environmental microplastics as emerging carcinogens and understanding the mechanisms through which they can pose risks to human health (Osman et al., 2023). Microplastics have become a cause for concern due to their potential to carry pollutants and transfer them to other organisms. These pollutants can include heavy metals, polycyclic aromatic hydrocarbons, and strong organic pollutants, which are known to be carcinogenic or have carcinogenic properties (Campanale et al., 2020). These particles are widespread in our surroundings, from the air we breathe to the food we eat and the water we drink (Osman et al., 2023). The impacts on the environment and human health are becoming more apparent, and there is growing concern about the potential of these compounds to act as carcinogens and contribute to the development of cancer. Cancer is a complex disease characterized by uncontrolled cell growth and growth, leading to the formation of tumors (Virolainen et al., 2023). Although the exact causes of cancer are still being studied, environmental factors play a significant role in its development. Carcinogens are substances that can promote the formation of cancer by damaging DNA and disrupting cellular processes. It is well-established that exposure to certain chemicals, such as tobacco smoke and asbestos, can increase the risk of cancer (Piña-Sánchez et al., 2021).

The potential of microplastics to act as carcinogens. These tiny plastic particles can accumulate in various tissues and organs in the body, leading to inflammation and oxidative stress (De-la-Torre, 2020). Microplastics contain toxic chemicals, such as phthalates and bisphenol, which have been linked to cancer development. When these chemicals leach out of plastics and into the environment, they can pose a risk to human health (Kannan & Vimalkumar, 2021). The mechanisms by which microplastics can promote cancer development are still not fully understood. According to certain studies, these particles can disrupt hormonal signaling pathways, leading to the uncontrolled growth of cells (Su et al., 2019). Microplastics can induce inflammation and oxidative stress, which are known to contribute to cancer progression. The collection of microplastics in the

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body can impair immune function, making it more difficult for the body to fight cancerous cells (Caputi et al., 2022). The public health implications of the impact of environmental microplastics as emerging carcinogens are significant. As these particles become more prevalent in our environment, the risk of cancer development may increase (Coffin et al., 2021). As these particles can accumulate in animal tissues and be ingested by humans, the presence of microplastics in the food chain is dangerous to human health. Since more research is required to fully understand the impact of microplastics on human health, the long-term effects of exposure to microplastics are still unknown (Cverenkárová et al., 2021).

2. Routes of Human Exposure to Microplastics

There are several ways for these particles to enter the human body, posing potential health risks. Understanding these routes of exposure is important for monitoring the impacts of microplastics on human health and developing strategies to reduce these exposures (Yee et al., 2021). Ingestion is one of the primary ways humans are exposed to microplastics. This occurs through the use of contaminated food and water. Seafood, especially shellfish, is a significant source of dietary microplastics (Kannan & Vimalkumar, 2021). Shellfish such as mussels, oysters, and clams filter large volumes of water to feed, during which they can accumulate microplastic particles. As humans consume these shellfish, the microplastics present in them are ingested (Farabegoli et al., 2018). Many seafood products sold for human consumption contain microplastics, making them a notable route of exposure. Worldwide, microplastics have been detected in both tap and bottled water. Numerous bottled water brands contain microplastic particles, frequently in higher concentrations than those found in tap water (Alberghini et al., 2022). Microplastics are pervasive in the water supply, regardless of the source. Damage can occur during the bottling process or through the degradation of plastic containers over time. In addition to seafood and water, microplastics have been detected in a variety of other food products, including honey, sugar, and salt (Issac & Kandasubramanian, 2021). These findings indicate that microplastic pollution is widespread in the food supply. Pollution can occur through various pathways, such as during food processing, packaging, or from environmental sources such as soil and air (Pironti et al., 2021). Inhalation represents another important route of microplastic exposure. Airborne microplastics can be inhaled from household dust, urban air, and occupational environments. Indoor environments are significant sources of airborne microplastics. These particles can originate from synthetic textiles, furnishings, and household item (Nawab et al., 2024). Tiny particles are released into the air through regular activities such as cleaning, wearing clothes, and using household products. Once airborne, these particles can be inhaled and enter the respiratory system. Outdoor air in urban areas can also contain microplastics (Torres-Agullo et al., 2021). These particles may have come from emissions from moving cars, construction activities, and industrial processes. For instance, tire wear from vehicles releases microplastics that can become airborne and inhaled. Urban dwellers are likely to regularly inhale microplastics, especially in areas with high traffic and industrial activity (Mayer et al., 2024). Certain occupations may expose workers to higher levels of airborne microplastics. Industries such as textile manufacturing, plastic production, and waste management can generate significant amounts of microplastic particles. Workers in these environments may inhale greater amounts of microplastic in comparison to the general population, potentially increasing their risk of health impacts (Cho & Choi, 2021).Numerous personal hygiene items, such as cleansing scrubs, toothpaste, and shower gels, contain tiny plastic microbead particles added for their abrasive properties. These products come into direct contact with the skin when used, which could expose the skin to microplastics (Emenike et al., 2023). Regulatory measures have been introduced in some areas to outline the use of microbeads in goods and cosmetics containing these particles are still available in many markets. Activities such as swimming, surfing, and other water-based recreation can lead to dermal exposure to microplastics present in contaminated water bodies (Guerranti et al., 2019). Beaches and coastal areas are often hotspots for tiny particle pollution due to plastic debris from the ocean. Individuals participating in these activities can come into contact with microplastics through their skin. Like inhalation, certain occupations may involve dermal exposure to microplastics (Critchell et al., 2019). Workers handling plastic materials or waste or engaging in cleaning activities in environments with high microplastic pollution can experience skin contact with these particles. Wearing personal protective equipment and maintaining good hygiene are important for reducing this kind of exposure (Verbeek et al., 2020). Microplastics that are swallowed or breathed can cause the body to become inflamed and mount an immune response. Chronic inflammation is a known risk factor for various diseases, including cancer. Microplastics may disrupt normal immune system function, potentially increasing susceptibility to infections and other health complications (Blackburn & Green, 2022). Hazardous substances from the environment, including heavy metals, persistent organic pollutants (POPs), and chemicals that disrupt hormones, can be absorbed and concentrated by microplastics. Toxic exposure may result from ingesting or breathing these adsorbed chemicals, which can then be released into the body (Ali et al., 2024).

Chemical toxicity associated with microplastics is a significant concern due to the potential for long-term health effects. The physical characteristics of microplastics can potentially harm organs and tissues. Inhaled microplastics can accumulate in the respiratory system, which may cause respiratory issues (Campanale et al., 2020). Ingested microplastics can cause abrasion and damage to the gastrointestinal tract. The long-term effects of such physical damage are still being studied, but they may contribute to various health issues over time. Humans are exposed to microplastics through ingestion, inhalation, and dermal contact, each of which presents unique pathways and risks (Zhu et al., 2024). Understanding these routes of exposure is essential for assessing the potential health impacts of microplastics and developing methods to lessen these risks. Regulatory measures, improved waste management, public awareness, and continued research are important components of a comprehensive response to the emerging issue of microplastic pollution. By addressing the sources and pathways of microplastic exposure, we can work toward reducing the potential health impacts on the population and protecting environmental health (Coffin et al., 2021).

2.1. Microplastics and carcinogenic potential: A growing concern

Microplastics, which are small plastic particles less than 5 mm in size, are present in the environment and infiltrate air, water, and soil. With increasing concern over their potential health impacts, scientists have turned their attention to the possibility that microplastics could act as carcinogens (Pastorino & Barceló, 2023). Carcinogens can cause cancer by changing cellular processes or damaging genetic material. Although the precise mechanisms through which microplastics might lead to cancer are still under investigation, several real pathways have been identified (Smith et al., 2020). The ability of microplastic to physically harm tissues and cells is one of the main concerns. Due to their small size, microplastics can penetrate biological barriers and group up in various organs. For instance, microplastics ingested through food or water can enter the gastrointestinal tract, while inhaled microplastics can be used in lung tissue. This physical presence can cause mechanical stress and inflammation (Zhao et al., 2024). This can lead to a cycle of continuous cell damage and repair, increasing the likelihood of mutations. If these mutations affect the genes that regulate cell division and growth, they may result in unchecked cell proliferation, which is a common feature of cancer. The physical irritation caused by microplastics can disrupt normal cellular functions and contribute to an environment conducive to cancer development (Greten & Grivennikov, 2019).

Microplastics can also cause oxidative stress, which is another mechanism by which they can cause cancer. When there is an imbalance between the body's ability to neutralize reactive oxygen species (ROS) and the amount of ROS produced, oxidative stress occurs (Arfin et al., 2021). Microplastics can generate ROS either directly, due to their physical properties, or indirectly, by acting as carriers for pro-oxidant chemicals. Lipids, proteins, and DNA are some of the cellular components that can be severely damaged by ROS (Osman et al., 2023). DNA damage is particularly concerning because it can lead to mutations if not properly given. Mutations in certain genes, such as tumor suppressor genes or oncogenes, can initiate the development of cancer. The strong oxidative stress induced by microplastics might control cellular repair mechanisms, increasing the probability of cancerous transformations (Basu, 2018). Due to their high surface area to volume ratio, plastic particles can absorb heavy metals and a number of toxic chemicals from their surroundings (Patel et al., 2020).

Microplastics can be ingested or inhaled, and these harmful substances may be released into the body. The leached chemicals can interfere with normal cellular processes, including those that regulate cell division and repair. For example, PAHs can intercalate into DNA, causing mutations, while heavy metals can bind to proteins and enzymes, disrupting their function (Haleem et al., 2024). Together, these harmful substances have the potential to greatly increase the risk of carcinogenesis. The possible carcinogenic effects of microplastic have important ramifications for public health. Reducing exposure is especially important because microplastics are widely present in the environment (Blackburn & Green, 2022). Regulatory measures can play a vital role in this effort. For example, limiting or banning the use of microplastics in consumer products such as cleaning products and cosmetics can reduce the amount of plastic released into the environment (Mitrano & Wohlleben, 2020). Reducing the amount of plastic pollution that already exists can help prevent microplastics from entering the food chain, especially in marine environments. Since microplastics can cause cancer, there is growing concern about them (Pothiraj et al., 2023). Microplastics can cause physical damage to cells, harm DNA and cause stress from oxidation, and release toxic chemicals that contribute to cancer development. Given the widespread presence of tiny particles in the environment and their potential health risks, it is essential to take precautionary measures to reduce exposure and protect public health (Pizzino et al., 2017).

2.2. Mechanisms of microplastic-induced carcinogenesis

As their presence in the ecosystem increases, attention to their potential health impacts, particularly their role in carcinogenesis is growing. The process by which healthy cells transform into cancerous cells is known as tumor development and involves multiple steps and mechanisms (Yuan et al., 2022). Research has identified several pathways by which microplastics may contribute to cancer development, including physical interactions and cell damage, oxidative stress and DNA damage, and chemical leaching and adsorption (Prata et al., 2020).

2.3. Physical Interactions and cellular damage

Because of their small size and diverse shapes, microplastics can penetrate biological barriers and accumulate in various tissues within the human body. Once ingested or inhaled, microplastics can pass through the gastrointestinal tract or respiratory system and enter the bloodstream (Ziani et al., 2023). It is distributed to various organs and tissues. The liver can become collected with microplastics, kidneys, and even the brain, causing localized physical damage. Microplastics can cause physical abrasion to cellular structures as they move through tissues (Ziani et al., 2023). Abrasion can disrupt cell membranes and organelles, leading to cellular stress and damage. Microplastics can act as chronic irritants, causing sustained damage over time. The physical damage caused by microplastics often triggers an inflammatory response. The body's normal response to harm or other foreign invaders (Daussy & Wodrich, 2020). While acute inflammation is a protective response, chronic inflammation can have detrimental effects. Persistent inflammation can create a pro-carcinogenic environment by promoting cellular mutations and supporting an environment that fosters tumor growth. Inflammatory cells release various chemicals, including cytokines and growth factors, which can induce DNA damage and support the proliferation of mutated cells (Chen et al., 2017). Oxidative stress is a significant mechanism through which microplastics can induce carcinogenesis. It involves the production of reactive oxygen species (ROS), which are chemically reactive molecules containing oxygen. Microplastics can generate ROS directly through their physical presence or indirectly by interacting with cellular components (Juan et al., 2021).

The formation of ROS can be catalyzed by the surface of microplastics, which can cause an imbalance in the body's antioxidant defenses. ROS can induce numerous mechanisms of DNA damage, such as base modifications, single-strand breaks, and double-strand breaks (de Almeida et al., 2022). DNA damage, if not properly repaired, can result in mutations. Mutations in key genes that control cell growth and division, such as oncogenes and tumor suppressor genes, can initiate carcinogenesis. Persistent DNA damage and the resulting mutations are important steps in the development of cancer (Alhmoud et al., 2020). ROS can also induce lipid peroxidation, a process that damages cell membranes and modifies proteins, impairing their function. These changes can disrupt cellular homeostasis and signaling pathways, further contributing to carcinogenesis. Damaged lipids and proteins can interfere with normal cellular processes and promote an environment conducive to cancer development (Su et al., 2019). Due to their high surface area to volume ratio, microplastics can concentrate and absorb a wide range of environmental pollutants. A number of dangerous substances, such as polycyclic aromatic hydrocarbons, can be absorbed by microplastics from the environment (PAHs), polychlorinated biphenyls (PCBs), and heavy metals such as cadmium and lead (Ali et al., 2024). These substances are known for their carcinogenic properties. Once inside the body, microplastics can release adsorbed chemicals. The desorption process can occur due to changes in pH, temperature, or other physiological conditions. The released chemicals can then enter cells and tissues, leading to toxic exposure (Osman et al., 2023). Additionally, some of these chemicals, such as PAHs and PCBs, can directly interact with DNA, causing mutations. These mutations can cause healthy cells to develop into malignant cells. The combination of physical stress, oxidative stress, and chemical exposure can have synergistic effects, amplifying the carcinogenic potential of microplastics (Hatta et al., 2021). Concurrent exposure to multiple carcinogenic factors can overwhelm the body's defense mechanisms, increasing the likelihood of cancer development. The potential carcinogenic mechanisms of microplastics involve complex interactions between physical damage, oxidative stress, and chemical toxicity. These mechanisms can work individually or synergistically to promote cancer development (Sharifi-Rad et al., 2020).

2.4. Epidemiological evidence and public health implications of microplastic exposure

Epidemiological evidence linking the potential carcinogenic mechanisms of microplastics to cancer in humans is still in its infancy. The challenges in assessing long-term exposure and health outcomes make it difficult to establish a direct connection (Caliri et al., 2021). However, the ubiquity of microplastics and their potential health risks underscore the urgent need for comprehensive epidemiological studies to evaluate the cancer risk associated with microplastic exposure. Microplastics have only recently been recognized as significant environmental pollutants (Rahman et al., 2021a). Long-term epidemiological data are scarce, and there has not been enough time to conduct extensive studies on their health impacts over prolonged periods. Accurately, determining human exposure to microplastics is difficult. There are several ways that microplastics can enter the body, such as through food, breathing or skin contact (Fairchild et al., 2018). Quantifying the levels of microplastics in these different exposure pathways and correlating them with health outcomes poses a significant challenge. The detection and measurement of microplastics in human tissues and bodily fluids require advanced analytical techniques (Domenech & Marcos, 2021). Standardized methods for sampling, detecting, and quantifying microplastics are still being developed, which hinders the ability to compare results across different studies and populations. Numerous confounding factors can influence the relationship between microplastic exposure and cancer risk (Prata et al., 2019).

These include lifestyle factors, genetic predispositions, and exposure to other environmental pollutants. Isolating the specific impact of microplastics from these confounding factors is a major challenge in epidemiological studies. Numerous studies have investigated the possibility of the presence of microplastics in seafood, especially shellfish (Virolainen et al., 2023). Populations with high seafood consumption may have higher levels of microplastic exposure. Epidemiological studies in these populations could provide valuable insights into the long-term health impacts of microplastics. For example, research on communities that rely heavily on seafood for their diet might reveal correlations between high microplastic exposure and increased cancer incidence (Zurub et al., 2024). Certain occupations, such as those in the plastic manufacturing, recycling, and waste management industries, involve greater exposure to microplastics. Workers in these industries may serve as sentinel populations for studying the health impacts of microplastic exposure (Yang et al., 2022). Epidemiological studies focusing on these high-exposure groups could help identify potential health risks, including cancer. Environmental studies have detected microplastics in various environmental compartments, including air, water, and soil (Ngoc et al., 2022).

Long-term monitoring of these environments and correlating microplastic levels with health data from nearby populations could provide indirect evidence of health impacts. For instance, communities living near heavily polluted water bodies or industrial areas might show higher rates of health issues linked to microplastic exposure (Zhang et al., 2022). The potential carcinogenic effects of microplastics have significant public health implications. Addressing these concerns requires a multifaceted approach involving regulation, research, public awareness, and preventive measures. Governments and regulatory bodies play important roles in mitigating microplastic pollution (Blackburn & Green, 2022). Implementing regulations to limit the use of microplastics in consumer products, such as cosmetics and personal care items, can significantly reduce environmental pollution. Additionally, policies that promote the reduction of plastic waste and encourage the use of biodegradable alternatives can help decrease the overall impact of microplastics (Mitrano & Wohlleben, 2020). Improving waste management practices is essential for reducing microplastic pollution. This includes implementing better recycling programs, ensuring proper disposal of plastic waste and minimizing the use of plastics. Efficient waste management can prevent plastic debris from breaking down into microplastics and contaminating the environment (Thompson, 2018). Educating the public about the sources and risks of exposure to microplastics is critical to encouraging behavioral changes that can alleviate this problem. Public awareness campaigns can motivate individuals to reduce their use of single-use plastics, opt for products with minimal plastic packaging and support initiatives aimed at reducing plastic pollution (Iroegbu et al., 2021).

Individuals can reduce their exposure to microplastics by cutting down packaged and processed foods, using filtered drinking water, and avoiding products with microbeads. In workplaces, implementing safety protocols such as using protective gear and ensuring proper ventilation can help lower the risk of microplastic exposure for workers (Thacharodi et al., 2024). Although current epidemiological evidence linking microplastic exposure to cancer in humans is limited, the potential health risks should not be overlooked. The difficulties in assessing long-term exposure and its health effects emphasize the need for thorough and well-designed epidemiological studies. Due to the widespread occurrence of microplastics and their potential to cause harm, measures must be taken to minimize exposure and protect public health (Leslie & Depledge, 2020).

2.5. Regulatory and public health responses to microplastic pollution

As the world becomes increasingly aware of the pervasive presence of plastic particles and what they could have health effects, regulatory and public health responses have become imperative. Governments, organizations, and researchers are implementing a number of measures to reduce the risks associated with microplastics, focusing on regulation, waste management, and enhanced research efforts (Coffin et al., 2021). The regulatory measures implemented or proposed, the role of waste management in reducing microplastic pollution, and the importance of health for everyone initiatives in addressing this new problem should be explored. Governments worldwide have started to recognize the need for stringent rules to manage the consumption and disposal of plastics, particularly microplastics. One of the most direct regulatory actions has been the banning of microbeads in personal care products (Hassan, et al., 2024). Small plastic particles called microbeads are present in products such as toothpaste and facial scrubs. They do not decompose naturally and significantly increase the amount of microplastic pollution. A number of countries including the US, Canada, the UK and several European countries, have passed laws that prohibit the manufacture or sale of goods that contain microbeads (Anagnosti et al., 2021).

The goal of these restrictions is to prevent microplastics from contaminating food chains and water sources. Another important regulatory measure is the restriction of single-use plastics. Many countries have introduced laws that limit or outright ban single-use plastic items such as bags, straws and cutlery (Mamun et al., 2023). For example, the Single-Use Plastics Directive, which is enforced by the European Union, requires member states to reduce their consumption and strengthen their recycling programs while banning certain single-use plastic products. By reducing the overall amount of plastic in the environment, these efforts help minimize the formation of microplastics (Kiessling et al., 2023). The extended producer responsibility (EPR) principle, in which manufacturers are responsible for the entire life cycle of their products, including disposal, is implemented in a number of countries. EPR pushes manufacturers to reduce waste, increase recycling rates and develop more environmentally friendly goods and packaging. The amount of plastic waste that turns into microplastics can be significantly reduced with this method (Tumu et al., 2023). Regulatory bodies are also working to improve the labeling and standards for plastic products. Clear labeling can inform users about the plastic content of goods and promote more environmentally friendly decisions. Additionally, setting standards for biodegradability and recyclability can ensure that plastic products have less environmental impact (Filiciotto & Rothenberg, 2021). Effective waste management is important for addressing microplastic pollution. Improved waste management procedures can aid in preventing the entry of plastics into the environment and the breakdown of plastics into microplastics. Improving recycling programs is essential for managing plastic waste effectively. This includes increasing the capacity for recycling facilities, ensuring proper sorting of plastics, and promoting the recycling of a broader range of plastic types. Public education campaigns can also encourage higher participation rates in recycling programs (Ahmed et al., 2024).

Reducing the production of plastic waste from the very beginning is an important step in the fight against this problem. Policies that encourage the use of reusable and biodegradable alternatives can help achieve this goal. One way to significantly reduce plastic waste is to promote the use of refillable household containers and cloth bags as alternatives to plastic (Evode et al., 2021). Waste-to-energy technologies such as pyrolysis and incineration can help manage plastic waste by turning it into energy. Although these technologies can reduce the amount of plastic waste produced, they must be used carefully to limit the release of harmful emissions and not to worsen air pollution (Kalair et al., 2021). Marine litter cleanup initiatives are important for removing existing plastic pollution from oceans and waterways. Community-based cleanup efforts, as well as larger-scale initiatives such as the Ocean Cleanup project, can aid in lowering the quantity of plastic waste that breaks down into microplastics. From a public health perspective, it is important to enhance monitoring and research efforts to understand the extent of the health effects of human exposure to microplastics. It is essential to carry out epidemiological research to evaluate the long-term health effects of microplastic exposure (Sivadas et al., 2022).

To determine any possible connections between exposure to plastic particles and health effects, including cancer, asthma, and other chronic illnesses. Longitudinal studies tracking populations with high exposure levels, such as those consuming large amounts of seafood, can provide valuable data. The development of methods to monitor microplastic levels in human tissues and bodily fluids is vital for assessing exposure. Techniques such as biomonitoring can help measure the presence of microplastics in blood, urine, and other samples, providing insights into the extent of human exposure (Seewoo et al., 2023). In-depth risk analyses are required to assess the potential health risks associated with exposure to microplastics. These assessments should consider variables such as the size, shape and chemical composition of microplastics in addition to exposure levels and pathways. Safety protocols and regulatory requirements may be affected by the findings. To encourage behavioral changes that can reduce exposure, the public needs to be educated about the causes and dangers of exposure to microplastics. Public awareness campaigns can emphasize the value of minimizing plastic use, proper waste disposal and choosing goods with little or no plastic packaging (Zarus et al., 2021). These campaigns can help customers learn more about the effects of microplastics on the environment and human health. Global cooperation is needed to address microplastic pollution. International agencies such as the World Health Organization (WHO) and the United Nations Environment Program (UNEP) can help countries work together to share best practices, research results and knowledge (Jain et al., 2023).

International agreements and treaties can also help standardize regulations and efforts to combat microplastic pollution globally. Growing concerns about microplastics have led to a range of regulatory and public health responses aimed at mitigating their impact on recyclable plastics (Ahmed et al., 2024). Regulations such as banning microbeads, reducing single-use plastics, increasing producer accountability, and improving labeling and standards are important steps in controlling plastic pollution. Effective waste management practices, including enhanced recycling, plastic waste reduction, waste-to-energy technologies, and marine litter cleanup initiatives, are essential for preventing plastics from breaking down into microplastics (Knoblauch & Mederake, 2021).

3. Results

Small plastic particles smaller than 5 millimeters, known as microplastics, have gained considerable attention due to their widespread presence in the environment. They can be found in rivers, soil, air and oceans. The breaking of larger plastic objects, the shedding of synthetic fibers from clothing, and the use of microbeads in personal care products are some of the sources of these tiny particles. Due to their small size, microplastics can easily enter the food chain and pass through natural systems, which could ultimately be harmful to human health. Figure 1 shows the effects of microplastics on human beings and nature. Humans can be exposed to microplastics in a number of ways, the most direct of which is ingestion. Many food products contain microplastics, but seafood such as shellfish is one of the main sources of microplastics in the diet. Microplastics have been found in drinking water from both tap and bottled sources, suggesting widespread pollution. Another significant route of exposure is inhalation, as people can inhale microplastics from urban air and household dust. In addition, contact with contaminated water while swimming or using cosmetics containing microspheres can lead to dermal exposure. The health effects of microplastics, especially their potential to cause cancer, have attracted much attention from researchers. Substances known as carcinogens can alter cell functions or damage the genetic material of a cell. Although the exact mechanisms by which microplastics may cause cancer are still unclear, a number of theories exist. These include oxidative stress that damages DNA, physical harm to cells and tissues, and the leaching of heavy metals and hazardous chemicals that have been adsorbed onto microplastic surfaces. Because microplastics are very small, they may accumulate in various tissues and pass through biological barriers. Once within the body, they have the potential to harm cellular structures and physically abrade tissue. Physical stress has the potential to cause inflammation, which is a recognized risk factor for the development of cancer. Prolonged inflammation may give rise to cellular alterations and foster an atmosphere that encourages the growth of tumors. When the body's capacity to neutralize reactive oxygen species (ROS), which are hazardous byproducts, is out of balance, oxidative stress results. By producing ROS, microplastics can cause oxidative stress, which can result in protein modification, lipid peroxidation, and damage to DNA. Damage to DNA can cause mutations that can start the carcinogenic process if it is not properly repaired. Heavy metals, polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs) are only a few of the environmental contaminants that microplastics can absorb and concentrate. Toxic exposure may result from these chemicals being adsorbed and desorbed in the human body. Numerous of these substances are known carcinogens that can cause cancer through endocrine disruption and direct DNA damage, among other mechanisms.

Although laboratory research has yielded important insights into the possible carcinogenic mechanisms of microplastics, there is still a dearth of epidemiological evidence connecting human exposure to microplastics and cancer. This is partly because determining long-term exposure and health effects is a difficult task, and microplastics have only recently been recognized as pollutants. However, given the widespread presence of microplastics and their potential for harm, thorough epidemiological studies are desperately needed to assess the cancer risk associated with microplastic exposure. A number of nations have restricted or outright prohibited the use of microbeads in personal hygiene products. The goal of this regulatory action is to lessen the amount of microplastics that are released into the environment and waterways. Reducing single-use plastics is becoming increasingly popular because they greatly increase environmental pollution. Many places are putting in place policies to restrict single-use plastic products such as bags, straws, and cutlery. Extended producer responsibility (EPR) programs, in which manufacturers are responsible for the full lifecycle of their products, including disposal, are being adopted by certain nations. This strategy promotes the manufacturing of less polluting and more sustainable goods. Reducing the pollution caused by microplastics requires efficient waste management. Important tactics include improving waste sorting, recycling programs, and promoting biodegradable substitutes. Waste-to-energy technology can also aid in the management of plastic waste, but it needs to be carefully managed to reduce harmful emissions. Improving research and monitoring initiatives are crucial from the standpoint of public health to comprehend human exposure to microplastics and the health consequences that follow. This entails carrying out thorough risk assessments, creating techniques to track the amount of microplastics in human tissues, and carrying out epidemiological studies. Campaigns to raise public awareness are crucial for informing people about the dangers and sources of microplastic exposure as well as for encouraging behavioral changes that will lower exposure. International collaboration is needed to combat microplastic pollution. International agencies such as the World Health Organization (WHO) and the United Nations Environment Programme (UNEP) can help nations work together, exchange best practices and knowledge, and create uniform policies and plans to address microplastic pollution.

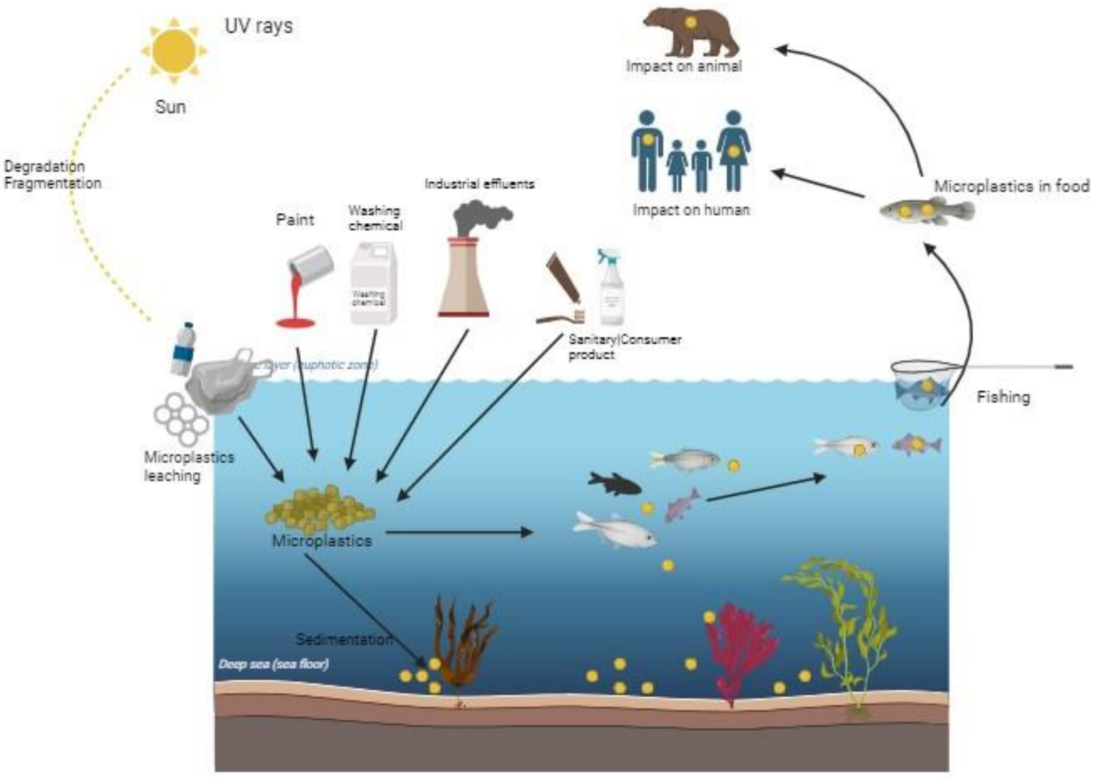

Figure 1 Effect of microplastics on human beings and nature.

4. Discussion

The increasing recognition of microplastics as pervasive environmental pollutants has generated serious worries about how they might affect people's health. While initial studies have focused on the environmental distribution and ecological impacts of microplastics, more recent research has focused on understanding their implications for human health, particularly their potential as emerging carcinogens (Lee et al., 2023). The possible carcinogenic effects of microplastics involve several mechanisms, including physical interactions with cellular structures, oxidative stress, and chemical leaching of toxic substances. Because of their small size, microplastics can pass through biological barriers, which is one of the main causes of concern. Once ingested by humans, microplastics can gather in different body tissues. They may cause physical abrasion and damage to cellular structures (Osman et al., 2023). One known risk factor for cancer is chronic inflammation, which can result from this mechanical stress. Chronic inflammation creates a microenvironment that can result in cellular mutations and promote tumor growth. This mechanism highlights the importance of understanding how microplastics interact with human cells at the microscopic level and the potential long-term effects of such inter actions (Greten & Grivennikov, 2019).

Microplastics can cause oxidative stress through the production of reactive oxygen species (ROS). Oxidative stress occurs when there is an imbalance between the production of ROS and the body's ability to detoxify these reactive intermediates or repair the resulting damage. ROS can damage cellular components such as lipids, proteins, and DNA (Das, 2023). DNA damage, if not adequately repaired, can lead to mutations that initiate the carcinogenic process. This mechanism underscores the need for further research into the oxidative stress response triggered by microplastics and the subsequent cellular damage that may occur. Microplastics can adsorb and concentrate various environmental pollutants, including polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and heavy metals. These adsorbed chemicals can desorb in the human body, leading to toxic exposure. Many of these chemicals are recognized carcinogens that are capable of initiating or promoting cancer through mechanisms such as endocrine disruption and direct DNA damage (Chatterjee & Walker, 2017). The ability of microplastics to act as vectors for these harmful substances adds another layer of complexity to their potential health impacts. Recognizing the ways in which microplastics and these chemicals interact is important for assessing the full extent of their carcinogenic potential. Humans come into contact with microplastics in various ways, such as through eating, breathing, or skin contact. Ingestion occurs when food or water that has been tainted is consumed. Studies have detected microplastics in various food items, particularly seafood such as shellfish, which are significant dietary sources of microplastics (Rahman et al., 2021b). Drinking water, both bottled and tap, has also been found to contain microplastics, indicating widespread pollution. Inhalation represents another important exposure pathway, as airborne microplastics can be inhaled from household dust and urban air. Additionally, dermal exposure can occur through the application of makeup containing microbeads or contact with contaminated water during recreational activities. Understanding these exposure routes is essential for developing effective strategies to mitigate human exposure to microplastics (Gambino et al., 2022). Table 1 shows the advantages, disadvantages and objectives of past microplastic studies.

Table 1 Advantages, disadvantages and objectives of past microplastics studies.

Author(s) & Year	Objective	Advantages	Disadvantages
Zhang et al. (2023)	Conduct an epidemiological study to assess cancer risk connected with microplastic exposure.	First large-scale study linking microplastic exposure to cancer risk; important public health insights.	Early stage; findings need further validation; control of confounding factors was challenging.
Wang et al. (2022)	Examine the relationship between chronic inflammation caused by microplastics and cancer development.	Linked inflammation to cancer risk; added to the understanding of microplastics' health impacts.	Animal studies; direct causation in humans remains to be proven.
Mason et al. (2020)	Analyze the presence of microplastics in drinking water and assess potential health risks.	Provided comprehensive data on microplastics in both bottled and tap water; highlighted pollution risks.	Did not investigate long-term health outcomes; mainly focused on presence and levels.
Silva et al. (2022)	Assess the potential for microplastics to cause genotoxic effects in human cells.	Identified specific genotoxic effects; relevant for understanding cancer risk mechanisms.	In vitro study; limited real-world applicability.
Rahman et al. (2021)	Investigate the impact of microplastic exposure on endocrine function in animals.	Showed potential endocrine-disrupting effects; relevant for understanding hormonal impacts.	Animal study; direct human relevance needs further investigation.
Sobhani et al. (2021)	Investigate the ability of microplastics to penetrate biological barriers and accumulate in human tissues.	Demonstrated microplastic accumulation in tissues; important for understanding exposure risks.	Mostly based on animal models; direct evidence in humans was limited.
Prata et al. (2021)	Review regulatory measures and public health responses to microplastic pollution.	Summarized current policies; provided recommendations for future regulation and public health actions.	Lacked empirical data; mainly a synthesis of existing policies and recommendations.
Rochman et al. (2021)	Study the adsorption and desorption of toxic chemicals on microplastic surfaces in the environment.	Highlighted the role of microplastics as vectors for other pollutants; important for risk assessment.	Focused on environmental chemistry; did not directly connect to human health outcomes.

Rochman et al.(2021)	Study the adsorption and desorption of toxic chemicals on microplastic surfaces in the environment.	Highlighted the role of microplastics as vectors for other pollutants; important for risk assessment.	Focused on environmental chemistry; did not directly connect to human health outcomes.
Carr et al. (2020)	Study the presence of microplastics in soil and potential uptake by plants.	Highlighted soil and plant pollution; relevant for food chain considerations.	Did not address health outcomes; focused on environmental presence.
Fadare et al. (2020)	Review the role of microplastics in transporting environmental pollutants.	Highlighted the role of microplastics as pollutant carriers; important for risk assessment.	Review study; lacked new empirical data.
Kim et al. (2020)	Examine microplastic-induced oxidative stress in human liver cells.	Provided insights into liver-specific effects; identified potential mechanisms of damage.	In vitro study; real-world exposure scenarios not considered.
Barboza et al. (2020)	Investigate the impact of microplastics on fish liver and kidney function.	Showed organ-specific effects; relevant for understanding bioaccumulation in food sources.	Animal study; implications for human health not directly addressed.
Barboza et al. (2020)	Investigate the impact of microplastics on fish liver and kidney function.	Showed organ-specific effects; relevant for understanding bioaccumulation in food sources.	Animal study; implications for human health not directly addressed.
Patel et al. (2020)	Study the long-term effects of dietary microplastic exposure in rodents.	Provided long-term exposure data; relevant for understanding chronic health impacts.	Animal study; findings may not fully translate to humans.
Wright and Kelly, (2020)	Assess the potential for microplastics to induce oxidative stress and DNA damage in human cells.	Identified specific pathways for oxidative stress and DNA damage; provided basis for further research.	In vitro study; actual exposure levels in humans were not considered.
Li et al. (2020)	Analyze the mechanisms by which microplastics can cause cellular damage and inflammation.	Detailed mechanistic insights into physical and chemical interactions with cells.	Conducted in vitro, limiting applicability to real-world human exposure scenarios.
Green et al. (2019)	Evaluate the impact of microplastics on human lung cells.	Demonstrated direct effects on lung cells; relevant for inhalation exposure.	In vitro study; limited real-world exposure relevance.
Luo et al. (2019)	Examine the impact of microplastics on gut microbiota in animal models.	Highlighted gut health impacts; relevant for dietary exposure considerations.	Animal study; human gut microbiota effects need further research.
Thompson et al. (2019)	Examine the pathways and levels of human exposure to microplastics through food and water.	Comprehensive assessment of various exposure routes; raised awareness of widespread pollution.	Lacked long-term health outcome data; exposure levels varied widely across samples.
Smith et al. (2018)	Investigate the presence and effects of microplastics in marine organisms.	Provided early evidence of microplastics in seafood; highlighted potential human exposure routes.	Limited to marine organisms; did not address human health impacts directly.
Hernandez et al. (2018)	Assess microplastic pollution in urban air samples.	Highlighted air as a significant exposure pathway; relevant for urban environments.	Did not assess health outcomes; focused on pollution levels.

While laboratory studies offer insightful information about the potential carcinogenic mechanisms of microplastics, there is limited epidemiological evidence connecting exposure to microplastics to cancer in humans. This knowledge gap is partly due to the relatively recent recognition of microplastics as pollutants and the challenges connected with assessing long-term exposure and health outcomes. Comprehensive epidemiological studies are urgently needed to evaluate the association between cancer risk and microplastic exposure. These studies should consider various factors, including the types and sizes of microplastics, exposure levels, and individual susceptibility (Toporcov & Filho, 2018). Various regulatory measures have been implemented or proposed in response to growing concerns about microplastics. Several countries have restricted or outlawed the use of microbeads in cosmetics to reduce their introduction into water bodies and the environment. Additionally, there is increasing advocacy for reducing single-use plastics, which contribute significantly to environmental pollution (Nøklebye et al., 2023). Policies aimed at limiting single-use plastic items, such as straws, bags, and cutlery, are being implemented in many regions. Efficient handling of waste is important for curbing microplastic pollution. Enhanced recycling programs, better waste sorting, and the promotion of biodegradable alternatives are essential strategies. Moreover, waste-to-energy technologies can aid in the management of plastic waste. but must be carefully controlled to minimize toxic emissions (Iroegbu et al., 2021).

Public awareness campaigns are important for educating the public about the sources and risks of microplastic exposure and promoting behavioral changes to reduce exposure. Addressing microplastic pollution requires global cooperation. International organizations such as the United Nations Environment Programmed (UNEP) and the World Health Organization (WHO) can facilitate collaboration between countries, share knowledge and best practices, and develop standardized regulations and strategies to combat microplastic pollution. Through coordinated efforts and proactive measures, we can mitigate the environmental and health impacts of microplastics, ensuring a safer and healthier future for all (Ramírez et al., 2019). Human exposure to microplastics occurs through several routes, with ingestion being one of the most direct. Contaminated food items, especially seafood such as shellfish, and drinking water (both bottled and tap) have been identified as significant sources of dietary microplastics. The inhalation of airborne microplastics from household dust and urban air also represents an important exposure pathway. Additionally, dermal exposure can occur through the use of a skincare containing microbeads or contact contaminated water during recreational activities (Zuri et al., 2023). Carcinogens can cause cancer by changing cellular processes or damaging genetic material in cells. There are a few theories regarding how microplastics can cause cancer, although the precise underlying processes are still unclear. These include physical damage to cells and tissues, oxidative stress leading to DNA damage, and the leaching of toxic chemicals and consumption of heavy metals on microplastic surfaces (Alhmoud et al., 2020).

As microplastics are so small, they can accumulate in various tissues and pass through biological barriers. As they enter the body, they may physically abrade and damage cellular structures, which can result in inflammation, which is acknowledged as a potential risk for cancer. Prolonged inflammation can lead to cellular alterations and foster an atmosphere that encourages the growth of tumors. Furthermore, by producing reactive oxygen species (ROS), which can harm proteins, lipids, and DNA, microplastics can cause oxidative stress (Thacharodi et al., 2024). Damage to DNA can result in mutations that could cause cancer if it is not correctly repaired. A range of environmental pollutants, such as polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and heavy metals, can be absorbed and concentrated by microplastics. In the human body, these adsorbed chemicals can desorb, resulting in hazardous exposure and possible carcinogenic effects via endocrine disruption and direct DNA damage (Hakem, 2008). Although investigations in laboratory settings offer valuable insights into the possible carcinogenic mechanisms of microplastics, there are few epidemiological data connecting human exposure to microplastics and cancer. The recent identification of microplastics as pollutants and the difficulties in deterring human contact with tiny particles and mining the effects of long-term exposure on human health are some of the reasons for this knowledge gap. However, thorough epidemiological research is required to assess the cancer risk associated with microplastic exposure due to the common nature of microplastics and the possible risks they pose (Krewski et al., 2019). Concerns about microplastics are becoming increasingly pressing, so regulatory actions have been taken or proposed. To lessen the amount of microbeads that are introduced into water bodies and the environment, a number of nations have restricted or outright banned their use in personal care products. Furthermore, there is a growing movement to minimize single-use plastics, as they are a principal source of pollution in the environment. Many places are putting in place policies to restrict single-use plastic products such as bags, straws, and cutlery. A number of nations are implementing programs for extended producer responsibility (EPR), which make producers accountable for the whole lifespan of their goods and promote the development of less polluting and more sustainable products (Nøklebye et al., 2023).

Reduced microplastic pollution is largely dependent on efficient waste management. Effective strategies include improving waste sorting, recycling programs, and the promotion of biodegradable substitutes. Waste-to-energy technology can also aid in the control of plastic waste but it needs to be carefully managed to reduce harmful emissions (Vanapalli et al., 2021). Improving research and monitoring initiatives are important from the standpoint of public health to fully understand human exposure to microplastics and the health consequences that follow. This entails carrying out thorough risk assessments, creating techniques to track the amount of microplastics in human tissues, and carrying out epidemiological studies. To educate the public regarding the causes and risks associated with microplastic exposure and to encourage behavioral changes that will lower exposure, public awareness campaigns are also essential (Windle et al., 2019). Global cooperation is needed to combat microplastic pollution. International agencies such as the World Health Organization (WHO) and the United Nations Environment Program (UNEP) can help nations work together, exchange best practices and knowledge, and create uniform policies and plans to address microplastic pollution. We can decrease the adverse consequences of microplastics on human wellness and the natural world by working together and taking preventative action, ensuring a safer and healthier future for everybody (Coffin et al., 2021).

4.1. Limitations

There are on established methods for the sampling, detection and analysis of microplastics in various environmental and biological matrices. This inconsistency prevents comparability of results across studies and complicates assessment of exposure levels. Assessing long-term exposure to microplastics and its association with chronic health outcomes such as cancer is challenging. Longitudinal studies that track exposure and health effects over longer periods of time are needed to establish causal relationships. Microplastics vary greatly in size, shape, polymer type and chemical composition. These variations can affect their behavior, toxicity and interactions with biological systems. To fully understand the effects of various microplastic types on human health, more research is needed. There is a paucity of epidemiological data linking microplastic exposure to specific health outcomes in humans. Conducting large-scale epidemiological studies is important for determining the exact impact of tiny particles on human health. Microplastics in the environment often coincide with other pollutants, leading to complex exposure scenarios. The interplay between microplastics and other contaminants needs to be studied to understand their cumulative health impacts. Addressing the problem of microplastic pollution requires interdisciplinary approaches that integrate environmental science, toxicology, public health, and policy. A collaborative effort is needed to develop comprehensive solutions.

5. Final Considerations

Human exposure to microplastics occurs through eating or drinking tainted food or water, inhalation of particles in the air, and dermal contact with cosmetic products or contaminated water. Although the exact carcinogenic mechanisms of microplastics are not fully understood, they can induce cancer by physically damaging cells, causing oxidative stress, and releasing toxic chemicals. Due to their small size, microplastics can accumulate in tissues above physical barriers, leading to inflammation and genetic mutations. Despite findings from laboratory studies, epidemiological evidence linking microplastics to cancer in humans is limited, highlighting the need for comprehensive research. In response, regulatory measures such as banning microbeads and encouraging the use of green substitutes for disposable plastics have been introduced. Effective public education efforts and garbage disposal are important for mitigating microplastic pollution. Global collaboration, facilitated by organizations such as the UNEP and WHO, is essential for developing standardized regulations and methods to address this problem and protect healthcare.

Ethical Considerations

Not applicable.

Conflict of Interest

The authors declare no conflicts of interest.

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References

Ahmed, S. F., Islam, N., Tasannum, N., Mehjabin, A., Momtahin, A., Chowdhury, A. A., Almomani, F., & Mofijur, M. (2024). Microplastic removal and management strategies for wastewater treatment plants. *Chemosphere*, *347*, 140648. https://doi.org/10.1016/j.chemosphere.2023.140648

Alberghini, L., Truant, A., Santonicola, S., Colavita, G., & Giaccone, V. (2022). Microplastics in Fish and Fishery Products and Risks for Human Health: A Review. *International Journal of Environmental Research and Public Health*, *20*(1), 789. https://doi.org/10.3390/ijerph20010789

Alhmoud, J. F., Woolley, J. F., Al Moustafa, A.-E., & Malki, M. I. (2020). DNA Damage/Repair Management in Cancers. *Cancers*, *12*(4), 1050. https://doi.org/10.3390/cancers12041050

Ali, N., Khan, M. H., Ali, M., Sidra, Ahmad, S., Khan, A., Nabi, G., Ali, F., Bououdina, M., & Kyzas, G. Z. (2024). Insight into microplastics in the aquatic ecosystem: Properties, sources, threats and mitigation strategies. *Science of The Total Environment*, *913*, 169489. https://doi.org/10.1016/j.scitotenv.2023.169489

Anagnosti, L., Varvaresou, A., Pavlou, P., Protopapa, E., & Carayanni, V. (2021). Worldwide actions against plastic pollution from microbeads and microplastics in cosmetics focusing on European policies. Has the issue been handled effectively? *Marine Pollution Bulletin*, *162*, 111883. https://doi.org/10.1016/j.marpolbul.2020.111883

Arfin, S., Jha, N. K., Jha, S. K., Kesari, K. K., Ruokolainen, J., Roychoudhury, S., Rathi, B., & Kumar, D. (2021). Oxidative Stress in Cancer Cell Metabolism. *Antioxidants*, *10*(5), 642. https://doi.org/10.3390/antiox10050642

Barboza, L. G. A., Lopes, C., Oliveira, P., Bessa, F., Otero, V., Henriques, B., Raimundo, J., Caetano, M., Vale, C., & Guilhermino, L. (2020). Microplastics in wild fish from North East Atlantic Ocean and its potential for causing neurotoxic effects, lipid oxidative damage, and human health risks associated with ingestion exposure. *The Science of the Total Environment*, *717*, 134625. https://doi.org/10.1016/j.scitotenv.2019.134625

Basu, A. K. (2018). DNA Damage, Mutagenesis and Cancer. *International Journal of Molecular Sciences*, *19*(4), 970. https://doi.org/10.3390/ijms19040970

Blackburn, K., & Green, D. (2022). The potential effects of microplastics on human health: What is known and what is unknown. *Ambio*, *51*(3), 518–530. https://doi.org/10.1007/s13280-021-01589-9

Caliri, A. W., Tommasi, S., & Besaratinia, A. (2021). Relationships among smoking, oxidative stress, inflammation, macromolecular damage, and cancer. *Mutation Research. Reviews in Mutation Research*, *787*, 108365. https://doi.org/10.1016/j.mrrev.2021.108365

Campanale, C., Massarelli, C., Savino, I., Locaputo, V., & Uricchio, V. F. (2020). A Detailed Review Study on Potential Effects of Microplastics and Additives of Concern on Human Health. *International Journal of Environmental Research and Public Health*, *17*(4), 1212. https://doi.org/10.3390/ijerph17041212

Caputi, S., Diomede, F., Lanuti, P., Marconi, G. D., Di Carlo, P., Sinjari, B., & Trubiani, O. (2022). Microplastics Affect the Inflammation Pathway in Human Gingival Fibroblasts: A Study in the Adriatic Sea. *International Journal of Environmental Research and Public Health*, *19*(13), 7782. https://doi.org/10.3390/ijerph19137782

Carr, A., Cullen, K., Keeney, C., Canning, C., Mooney, O., Ní Chinseallaigh, E., & O'Dowd, A. (2020). Effectiveness of positive psychology interventions: A systematic review and meta-analysis. *The Journal of Positive Psychology*, *16*, 1–21. https://doi.org/10.1080/17439760.2020.1818807

Chatterjee, N., & Walker, G. C. (2017). Mechanisms of DNA damage, repair, and mutagenesis. *Environmental and Molecular Mutagenesis*, *58*(5), 235–263. https://doi.org/10.1002/em.22087

Chen, L., Deng, H., Cui, H., Fang, J., Zuo, Z., Deng, J., Li, Y., Wang, X., & Zhao, L. (2017). Inflammatory responses and inflammation-associated diseases in organs. *Oncotarget*, *9*(6), 7204–7218. https://doi.org/10.18632/oncotarget.23208

Cho, Y. M., & Choi, K.-H. (2021). The current status of studies of human exposure assessment of microplastics and their health effects: A rapid systematic review. *Environmental Analysis, Health and Toxicology*, *36*(1), e2021004-2021000. https://doi.org/10.5620/eaht.2021004

Coffin, S., Wyer, H., & Leapman, J. C. (2021). Addressing the environmental and health impacts of microplastics requires open collaboration between diverse sectors. *PLoS Biology*, *19*(3), e3000932. https://doi.org/10.1371/journal.pbio.3000932

Critchell, K., Bauer-Civiello, A., Benham, C., Berry, K., Eagle, L., Hamann, M., Hussey, K., & Ridgway, T. (2019). Chapter 34 - Plastic Pollution in the Coastal Environment: Current Challenges and Future Solutions. In E. Wolanski, J. W. Day, M. Elliott, & R. Ramachandran (Eds.), *Coasts and Estuaries* (pp. 595–609). Elsevier. https://doi.org/10.1016/B978-0-12-814003-1.00034-4

Cverenkárová, K., Valachovičová, M., Mackuľak, T., Žemlička, L., & Bírošová, L. (2021). Microplastics in the Food Chain. *Life*, *11*(12), 1349. https://doi.org/10.3390/life11121349

da Silva, A., Jude, R., & Gallardo, R. (2022). Da Silva et al 2022—Infectious bronchitis virus—A comprehensive multilocus genomic analysis to compare DMV:1639 and QX strains. *Viruses*, *14*, 1998. https://doi.org/10.3390/v14091998

Das, A. (2023). The emerging role of microplastics in systemic toxicity: Involvement of reactive oxygen species (ROS). *Science of The Total Environment*, *895*, 165076. https://doi.org/10.1016/j.scitotenv.2023.165076

Daussy, C. F., & Wodrich, H. (2020). "Repair Me if You Can": Membrane Damage, Response, and Control from the Viral Perspective. *Cells*, *9*(9), 2042. https://doi.org/10.3390/cells9092042

de Almeida, A. J. P. O., de Oliveira, J. C. P. L., da Silva Pontes, L. V., de Souza Júnior, J. F., Gonçalves, T. A. F., Dantas, S. H., de Almeida Feitosa, M. S., Silva, A. O., & de Medeiros, I. A. (2022). ROS: Basic Concepts, Sources, Cellular Signaling, and its Implications in Aging Pathways. *Oxidative Medicine and Cellular Longevity*, *2022*, 1225578. https://doi.org/10.1155/2022/1225578

De-la-Torre, G. E. (2020). Microplastics: An emerging threat to food security and human health. *Journal of Food Science and Technology*, *57*(5), 1601–1608. https://doi.org/10.1007/s13197-019-04138-1

Domenech, J., & Marcos, R. (2021). Pathways of human exposure to microplastics, and estimation of the total burden. *Current Opinion in Food Science*, *39*, 144–151. https://doi.org/10.1016/j.cofs.2021.01.004

Emenike, E. C., Okorie, C. J., Ojeyemi, T., Egbemhenghe, A., Iwuozor, K. O., Saliu, O. D., Okoro, H. K., & Adeniyi, A. G. (2023). From oceans to dinner plates: The impact of microplastics on human health. *Heliyon*, *9*(10), e20440. https://doi.org/10.1016/j.heliyon.2023.e20440

Evode, N., Qamar, S. A., Bilal, M., Barceló, D., & Iqbal, H. M. N. (2021). Plastic waste and its management strategies for environmental sustainability. *Case Studies in Chemical and Environmental Engineering*, *4*, 100142. https://doi.org/10.1016/j.cscee.2021.100142

Fadare, O. O., Wan, B., Guo, L.-H., & Zhao, L. (2020). Microplastics from consumer plastic food containers: Are we consuming it? *Chemosphere*, *253*, 126787. https://doi.org/10.1016/j.chemosphere.2020.126787

Fairchild, G., Tasseff, B., Khalsa, H., Generous, N., Daughton, A. R., Velappan, N., Priedhorsky, R., & Deshpande, A. (2018). Epidemiological Data Challenges: Planning for a More Robust Future Through Data Standards. *Frontiers in Public Health*, *6*, 336. https://doi.org/10.3389/fpubh.2018.00336

Farabegoli, F., Blanco, L., Rodríguez, L. P., Vieites, J. M., & Cabado, A. G. (2018). Phycotoxins in Marine Shellfish: Origin, Occurrence and Effects on Humans. *Marine Drugs*, *16*(6), 188. https://doi.org/10.3390/md16060188

Filiciotto, L., & Rothenberg, G. (2021). Biodegradable Plastics: Standards, Policies, and Impacts. *Chemsuschem*, *14*(1), 56–72. https://doi.org/10.1002/cssc.202002044

Gambino, I., Bagordo, F., Grassi, T., Panico, A., & De Donno, A. (2022). Occurrence of Microplastics in Tap and Bottled Water: Current Knowledge. *International Journal of Environmental Research and Public Health*, *19*(9), 5283. https://doi.org/10.3390/ijerph19095283

Green, J., Cross, R., Woodall, J., & Tones, K. (2019). *Health Promotion: Planning & Strategies*.

Greten, F. R., & Grivennikov, S. I. (2019). Inflammation and Cancer: Triggers, Mechanisms, and Consequences. *Immunity*, *51*(1), 27–41. https://doi.org/10.1016/j.immuni.2019.06.025

Guerranti, C., Martellini, T., Perra, G., Scopetani, C., & Cincinelli, A. (2019). Microplastics in cosmetics: Environmental issues and needs for global bans. *Environmental Toxicology and Pharmacology*, *68*, 75–79. https://doi.org/10.1016/j.etap.2019.03.007

Hakem, R. (2008). DNA-damage repair; the good, the bad, and the ugly. *The EMBO Journal*, *27*(4), 589–605. https://doi.org/10.1038/emboj.2008.15

Haleem, N., Kumar, P., Zhang, C., Jamal, Y., Hua, G., Yao, B., & Yang, X. (2024). Microplastics and associated chemicals in drinking water: A review of their occurrence and human health implications. *Science of The Total Environment*, *912*, 169594. https://doi.org/10.1016/j.scitotenv.2023.169594

Hatta, M. N. A., Mohamad Hanif, E. A., Chin, S.-F., & Neoh, H. (2021). Pathogens and Carcinogenesis: A Review. *Biology*, *10*(6), 533. https://doi.org/10.3390/biology10060533

Hernandez, A. F., Green, J. B., Janmohamed, S., D'Agostino, R. B., Granger, C. B., Jones, N. P., Leiter, L. A., Rosenberg, A. E., Sigmon, K. N., Somerville, M. C., Thorpe, K. M., McMurray, J. J. V., Del Prato, S., Del Prato, S., McMurray, J. J. V., D'Agostino, R. B., Granger, C. B., Hernandez, A. F., Janmohamed, S., … Mandal, T. (2018). Albiglutide and cardiovascular outcomes in patients with type 2 diabetes and cardiovascular disease (Harmony Outcomes): A double-blind, randomised placebo-controlled trial. *The Lancet*, *392*(10157), 1519–1529. https://doi.org/10.1016/S0140-6736(18)32261-X

Iroegbu, A. O. C., Ray, S. S., Mbarane, V., Bordado, J. C., & Sardinha, J. P. (2021). Plastic Pollution: A Perspective on Matters Arising: Challenges and Opportunities. *ACS Omega*, *6*(30), 19343–19355. https://doi.org/10.1021/acsomega.1c02760

Issac, M. N., & Kandasubramanian, B. (2021). Effect of microplastics in water and aquatic systems. *Environmental Science and Pollution Research International*, *28*(16), 19544–19562. https://doi.org/10.1007/s11356-021-13184-2

Jain, R., Gaur, A., Suravajhala, R., Chauhan, U., Pant, M., Tripathi, V., & Pant, G. (2023). Microplastic pollution: Understanding microbial degradation and strategies for pollutant reduction. *Science of The Total Environment*, *905*, 167098. https://doi.org/10.1016/j.scitotenv.2023.167098

Juan, C. A., Pérez de la Lastra, J. M., Plou, F. J., & Pérez-Lebeña, E. (2021). The Chemistry of Reactive Oxygen Species (ROS) Revisited: Outlining Their Role in Biological Macromolecules (DNA, Lipids and Proteins) and Induced Pathologies. *International Journal of Molecular Sciences*, *22*(9), 4642. https://doi.org/10.3390/ijms22094642

Kalair, A. R., Seyedmahmoudian, M., Stojcevski, A., Abas, N., & Khan, N. (2021). Waste to energy conversion for a sustainable future. *Heliyon*, *7*(10), e08155. https://doi.org/10.1016/j.heliyon.2021.e08155

Kannan, K., & Vimalkumar, K. (2021). A Review of Human Exposure to Microplastics and Insights Into Microplastics as Obesogens. *Frontiers in Endocrinology*, *12*, 724989. https://doi.org/10.3389/fendo.2021.724989

Kiessling, T., Hinzmann, M., Mederake, L., Dittmann, S., Brennecke, D., Böhm-Beck, M., Knickmeier, K., & Thiel, M. (2023). What potential does the EU Single-Use Plastics Directive have for reducing plastic pollution at coastlines and riversides? An evaluation based on citizen science data. *Waste Management*, *164*, 106–118. https://doi.org/10.1016/j.wasman.2023.03.042

Kim, D., Lee, J.-Y., Yang, J.-S., Kim, J. W., Kim, V. N., & Chang, H. (2020). The Architecture of SARS-CoV-2 Transcriptome. *Cell*, *181*(4), 914-921.e10. https://doi.org/10.1016/j.cell.2020.04.011

Knoblauch, D., & Mederake, L. (2021). Government policies combatting plastic pollution. *Current Opinion in Toxicology*, *28*, 87–96. https://doi.org/10.1016/j.cotox.2021.10.003

Krewski, D.,(2019). Analysis of key characteristics of human carcinogens. In Tumour Site Concordance and Mechanisms of Carcinogenesis. International Agency for Research on Cancer. *https://www.ncbi.nlm.nih.gov/books/NBK570329/.* Accessed on April 6, 2024.

Lamichhane, G., Acharya, A., Marahatha, R., Modi, B., Paudel, R., Adhikari, A., Raut, B. K., Aryal, S., & Parajuli, N. (2023). Microplastics in environment: Global concern, challenges, and controlling measures. *International Journal of Environmental Science and Technology*, *20*(4), 4673–4694. https://doi.org/10.1007/s13762-022-04261-1

Lee, Y., Cho, J., Sohn, J., & Kim, C. (2023). Health Effects of Microplastic Exposures: Current Issues and Perspectives in South Korea. *Yonsei Medical Journal*, *64*(5), 301–308. https://doi.org/10.3349/ymj.2023.0048

Leslie, H. A., & Depledge, M. H. (2020). Where is the evidence that human exposure to microplastics is safe? *Environment International*, *142*, 105807. https://doi.org/10.1016/j.envint.2020.105807

Li, Y., yan, yicha, Deng, S., Zhang, C., Haq, F., Chen, T., Li, Y., Li, S., Yang, R., Zou, L., & Chen, G. (2020). *Yilang Li et al. 2020*.

Luo, X., Tong, S., Fang, Z., & Qu, Z. (2019). Frontiers: Machines vs. Humans: The Impact of Artificial Intelligence Chatbot Disclosure on Customer Purchases. *Marketing Science*. https://doi.org/10.1287/mksc.2019.1192

Mamun, A. A., Prasetya, T. A. E., Dewi, I. R., & Ahmad, M. (2023). Microplastics in human food chains: Food becoming a threat to health safety. *Science of The Total Environment*, *858*, 159834. https://doi.org/10.1016/j.scitotenv.2022.159834

Mason, C., Taggart, D., & Broadhurst, K. (2020). Parental Non-Engagement within Child Protection Services—How Can Understandings of Complex Trauma and Epistemic Trust Help? *Societies*, *10*(4), Article 4. https://doi.org/10.3390/soc10040093

Mayer, P. M., Moran, K. D., Miller, E. L., Brander, S. M., Harper, S., Garcia-Jaramillo, M., Carrasco-Navarro, V., Ho, K. T., Burgess, R. M., Thornton Hampton, L. M., Granek, E. F., McCauley, M., McIntyre, J. K., Kolodziej, E. P., Hu, X., Williams, A. J., Beckingham, B. A., Jackson, M. E., Sanders-Smith, R. D., … Mendez, M. (2024). Where the rubber meets the road: Emerging environmental impacts of tire wear particles and their chemical cocktails. *Science of The Total Environment*, *927*, 171153. https://doi.org/10.1016/j.scitotenv.2024.171153

McIlwraith, H. K., Kim, J., Helm, P., Bhavsar, S. P., Metzger, J. S., & Rochman, C. M. (2021). Evidence of Microplastic Translocation in Wild-Caught Fish and Implications for Microplastic Accumulation Dynamics in Food Webs. *Environmental Science & Technology*, *55*(18), 12372–12382. https://doi.org/10.1021/acs.est.1c02922

Mitrano, D. M., & Wohlleben, W. (2020). Microplastic regulation should be more precise to incentivize both innovation and environmental safety. *Nature Communications*, *11*, 5324. https://doi.org/10.1038/s41467-020-19069-1

Nawab, A., Ahmad, M., Khan, M. T., Nafees, M., Khan, I., & Ihsanullah, I. (2024). Human Exposure to Microplastics: A Review on Exposure Routes and Public Health Impacts. *Journal of Hazardous Materials Advances*, 100487. https://doi.org/10.1016/j.hazadv.2024.100487

Ngoc, L. T. N., Park, D., & Lee, Y.-C. (2022). Human Health Impacts of Residential Radon Exposure: Updated Systematic Review and Meta-Analysis of Case–Control Studies. *International Journal of Environmental Research and Public Health*, *20*(1), 97. https://doi.org/10.3390/ijerph20010097

Nøklebye, E., Adam, H. N., Roy-Basu, A., Bharat, G. K., & Steindal, E. H. (2023). Plastic bans in India – Addressing the socio-economic and environmental complexities. *Environmental Science & Policy*, *139*, 219–227. https://doi.org/10.1016/j.envsci.2022.11.005

Osman, A. I., Hosny, M., Eltaweil, A. S., Omar, S., Elgarahy, A. M., Farghali, M., Yap, P.-S., Wu, Y.-S., Nagandran, S., Batumalaie, K., Gopinath, S. C. B., John, O. D., Sekar, M., Saikia, T., Karunanithi, P., Hatta, M. H. M., & Akinyede, K. A. (2023). Microplastic sources, formation, toxicity and remediation: A review. *Environmental Chemistry Letters*, 1–41. https://doi.org/10.1007/s10311-023-01593-3

Pastorino, P., & Barceló, D. (2023). Microplastics and their environmental effects. *Environmental Toxicology and Pharmacology*, *104*, 104324. https://doi.org/10.1016/j.etap.2023.104324

Patel, A. B., Shaikh, S., Jain, K. R., Desai, C., & Madamwar, D. (2020). Polycyclic Aromatic Hydrocarbons: Sources, Toxicity, and Remediation Approaches. *Frontiers in Microbiology*, *11*, 562813. https://doi.org/10.3389/fmicb.2020.562813

Patel, J. A., Nielsen, F. B. H., Badiani, A. A., Assi, S., Unadkat, V. A., Patel, B., Ravindrane, R., & Wardle, H. (2020). Poverty, inequality and COVID-19: The forgotten vulnerable. *Public Health*, *183*, 110–111. https://doi.org/10.1016/j.puhe.2020.05.006

Patrício Silva, A. L., Prata, J. C., Walker, T. R., Duarte, A. C., Ouyang, W., Barcelò, D., & Rocha-Santos, T. (2021). Increased plastic pollution due to COVID-19 pandemic: Challenges and recommendations. *Chemical Engineering Journal*, *405*, 126683. https://doi.org/10.1016/j.cej.2020.126683

Piña-Sánchez, P., (2021). Cancer Biology, Epidemiology, and Treatment in the 21st Century: Current Status and Future Challenges From a Biomedical Perspective. *Cancer Control : Journal of the Moffitt Cancer Center*, *28*, 10732748211038735. https://doi.org/10.1177/10732748211038735.

Pironti, C., Ricciardi, M., Motta, O., Miele, Y., Proto, A., & Montano, L. (2021). Microplastics in the Environment: Intake through the Food Web, Human Exposure and Toxicological Effects. *Toxics*, *9*(9), 224. https://doi.org/10.3390/toxics9090224

Pizzino, G., Irrera, N., Cucinotta, M., Pallio, G., Mannino, F., Arcoraci, V., Squadrito, F., Altavilla, D., & Bitto, A. (2017). Oxidative Stress: Harms and Benefits for Human Health. *Oxidative Medicine and Cellular Longevity*, *2017*, 8416763. https://doi.org/10.1155/2017/8416763

Pothiraj, C., Amutha Gokul, T., Ramesh Kumar, K., Ramasubramanian, A., Palanichamy, A., Venkatachalam, K., Pastorino, P., Barcelò, D., Balaji, P., & Faggio, C. (2023). Vulnerability of microplastics on marine environment: A review. *Ecological Indicators*, *155*, 111058. https://doi.org/10.1016/j.ecolind.2023.111058

Prata, J. C., da Costa, J. P., Duarte, A. C., & Rocha-Santos, T. (2019). Methods for sampling and detection of microplastics in water and sediment: A critical review. *TrAC Trends in Analytical Chemistry*, *110*, 150–159. https://doi.org/10.1016/j.trac.2018.10.029

Prata, J. C., da Costa, J. P., Lopes, I., Duarte, A. C., & Rocha-Santos, T. (2020). Environmental exposure to microplastics: An overview on possible human health effects. *Science of The Total Environment*, *702*, 134455. https://doi.org/10.1016/j.scitotenv.2019.134455

Rahman, A., Sarkar, A., Yadav, O. P., Achari, G., & Slobodnik, J. (2021a). Potential human health risks due to environmental exposure to nano- and microplastics and knowledge gaps: A scoping review. *Science of The Total Environment*, *757*, 143872. https://doi.org/10.1016/j.scitotenv.2020.143872

Rahman, A., Sarkar, A., Yadav, O. P., Achari, G., & Slobodnik, J. (2021b). Potential human health risks due to environmental exposure to nano- and microplastics and knowledge gaps: A scoping review. *Science of The Total Environment*, *757*, 143872. https://doi.org/10.1016/j.scitotenv.2020.143872

Rahman, T., Hasnain, M. D. G., & Islam, A. (2021). Food insecurity and mental health of women during COVID-19: Evidence from a developing country. *PLOS ONE*, *16*(7), e0255392. https://doi.org/10.1371/journal.pone.0255392

Ramírez, A. S., Ramondt, S., Van Bogart, K., & Zuniga, R. P. (2019). Public Awareness of Air Pollution and Health Threats: Challenges and Opportunities for Communication Strategies to Improve Environmental Health Literacy. *Journal of Health Communication*, *24*(1), 75–83. https://doi.org/10.1080/10810730.2019.1574320

Seewoo, B. J., Goodes, L. M., Mofflin, L., Mulders, Y. R., Wong, E. V., Toshniwal, P., Brunner, M., Alex, J., Johnston, B., Elagali, A., Gozt, A., Lyle, G., Choudhury, O., Solomons, T., Symeonides, C., & Dunlop, S. A. (2023). The plastic health map: A systematic evidence map of human health studies on plastic-associated chemicals. *Environment International*, *181*, 108225. https://doi.org/10.1016/j.envint.2023.108225

Sharifi-Rad, M., Anil Kumar, N. V., Zucca, P., Varoni, E. M., Dini, L., Panzarini, E., Rajkovic, J., Tsouh Fokou, P. V., Azzini, E., Peluso, I., Prakash Mishra, A., Nigam, M., El Rayess, Y., Beyrouthy, M. E., Polito, L., Iriti, M., Martins, N., Martorell, M., Docea, A. O., … Sharifi-Rad, J. (2020). Lifestyle, Oxidative Stress, and Antioxidants: Back and Forth in the Pathophysiology of Chronic Diseases. *Frontiers in Physiology*, *11*, 694. https://doi.org/10.3389/fphys.2020.00694

Sivadas, S. K., Mishra, P., Kaviarasan, T., Sambandam, M., Dhineka, K., Murthy, M. V. R., Nayak, S., Sivyer, D., & Hoehn, D. (2022). Litter and plastic monitoring in the Indian marine environment: A review of current research, policies, waste management, and a roadmap for multidisciplinary action. *Marine Pollution Bulletin*, *176*, 113424. https://doi.org/10.1016/j.marpolbul.2022.113424

Smith et al., 2018: Learning about strategies and difficulties of emotion regulation increased emotional well-being and belonging in school among middle schoolers over six weeks. (n.d.). *https://www.wiseinterventions.org.* Accessed on June 4, 2024.

Smith, M. T., Guyton, K. Z., Kleinstreuer, N., Borrel, A., Cardenas, A., Chiu, W. A., Felsher, D. W., Gibbons, C. F., Goodson, W. H., Houck, K. A., Kane, A., La Merrill, M. A., Lebrec, H., Lowe, L., McHale, C. M., Minocherhomji, S., Rieswijk, L., Sandy, M. S., Sone, H., … Fielden, M. (2020). The Key Characteristics of Carcinogens: Relationship to the Hallmarks of Cancer, Relevant Biomarkers, and Assays to Measure Them. *Cancer Epidemiology, Biomarkers & Prevention : A Publication of the American Association for Cancer Research, Cosponsored by the American Society of Preventive Oncology*, *29*(10), 1887–1903. https://doi.org/10.1158/1055-9965.EPI-19-1346

Sobhani, Z., Luo, Y., Gibson, C., Tang, Y., Naidu, R., Mallavarapu, M., & Fang, C. (2021). Collecting Microplastics in Gardens: Case Study (i) of Soil. *Frontiers in Environmental Science*, *9*, 739775. https://doi.org/10.3389/fenvs.2021.739775

Su, L.-J., Zhang, J.-H., Gomez, H., Murugan, R., Hong, X., Xu, D., Jiang, F., & Peng, Z.-Y. (2019). Reactive Oxygen Species-Induced Lipid Peroxidation in Apoptosis, Autophagy, and Ferroptosis. *Oxidative Medicine and Cellular Longevity*, *2019*. https://doi.org/10.1155/2019/5080843

Thacharodi, A., Hassan, S., Meenatchi, R., Bhat, M. A., Hussain, N., Arockiaraj, J., Ngo, H. H., Sharma, A., Nguyen, H. T., & Pugazhendhi, A. (2024). Mitigating microplastic pollution: A critical review on the effects, remediation, and utilization strategies of microplastics. *Journal of Environmental Management*, *351*, 119988. https://doi.org/10.1016/j.jenvman.2023.119988

Thacharodi, A., Meenatchi, R., Hassan, S., Hussain, N., Bhat, M. A., Arockiaraj, J., Ngo, H. H., Le, Q. H., & Pugazhendhi, A. (2024). Microplastics in the environment: A critical overview on its fate, toxicity, implications, management, and bioremediation strategies. *Journal of Environmental Management*, *349*, 119433. https://doi.org/10.1016/j.jenvman.2023.119433

Thompson, A. (2018). Solving Microplastic Pollution Means Reducing, Recycling—And Fundamental Rethinking. Scientific American. https://www.scientificamerican.com. Accessed on June 4, 2024.

Thompson, A., Carroll, K., A. Inker, L., Floege, J., Perkovic, V., Boyer-Suavet, S., W. Major, R., I. Schimpf, J., Barratt, J., Cattran, D. C., S. Gillespie, B., Kausz, A., W. Mercer, A., Reich, H. N., H. Rovin, B., West, M., & Nachman, P. H. (2019). Proteinuria Reduction as a Surrogate End Point in Trials of IgA Nephropathy. *Clinical Journal of the American Society of Nephrology : CJASN*, *14*(3), 469–481. https://doi.org/10.2215/CJN.08600718

Toporcov, T. N., & Filho, V. W. (2018). Epidemiological science and cancer control. *Clinics*, *73*(Suppl 1), e627s. https://doi.org/10.6061/clinics/2018/e627s

Torres-Agullo, A., Karanasiou, A., Moreno, T., & Lacorte, S. (2021). Overview on the occurrence of microplastics in air and implications from the use of face masks during the COVID-19 pandemic. *Science of The Total Environment*, *800*, 149555. https://doi.org/10.1016/j.scitotenv.2021.149555

Tumu, K., Vorst, K., & Curtzwiler, G. (2023). Global plastic waste recycling and extended producer responsibility laws. *Journal of Environmental Management*, *348*, 119242. https://doi.org/10.1016/j.jenvman.2023.119242

Vanapalli, K. R., Sharma, H. B., Ranjan, V. P., Samal, B., Bhattacharya, J., Dubey, B. K., & Goel, S. (2021). Challenges and strategies for effective plastic waste management during and post COVID-19 pandemic. *The Science of the Total Environment*, *750*, 141514. https://doi.org/10.1016/j.scitotenv.2020.141514

Verbeek, J. H., Rajamaki, B., Ijaz, S., Sauni, R., Toomey, E., Blackwood, B., Tikka, C., Ruotsalainen, J. H., & Kilinc Balci, F. S. (2020). Personal protective equipment for preventing highly infectious diseases due to exposure to contaminated body fluids in healthcare staff. *The Cochrane Database of Systematic Reviews*, *2020*(4), CD011621. https://doi.org/10.1002/14651858.CD011621.pub4

Virolainen, S. J., VonHandorf, A., Viel, K. C. M. F., Weirauch, M. T., & Kottyan, L. C. (2023). Gene–environment interactions and their impact on human health. *Genes and Immunity*, *24*(1), 1–11. https://doi.org/10.1038/s41435-022-00192-6

Wen, Y., Zhu, Y., Zhang, C., Yang, X., Gao, Y., Li, M., Yang, H., Liu, T., & Tang, H. (2022). Chronic inflammation, cancer development and immunotherapy. *Frontiers in Pharmacology*, *13*, 1040163. https://doi.org/10.3389/fphar.2022.1040163

Windle, M., Lee, H. D., Cherng, S. T., Lesko, C. R., Hanrahan, C., Jackson, J. W., McAdams-DeMarco, M., Ehrhardt, S., Baral, S. D., D'Souza, G., & Dowdy, D. W. (2019). From Epidemiologic Knowledge to Improved Health: A Vision for Translational Epidemiology. *American Journal of Epidemiology*, *188*(12), 2049–2060. https://doi.org/10.1093/aje/kwz085

Wright, S. L., Ulke, J., Font, A., Chan, K. L. A., & Kelly, F. J. (2020). Atmospheric microplastic deposition in an urban environment and an evaluation of transport. *Environment International*, *136*, 105411. https://doi.org/10.1016/j.envint.2019.105411

Yang, X., Man, Y. B., Wong, M. H., Owen, R. B., & Chow, K. L. (2022). Environmental health impacts of microplastics exposure on structural organization levels in the human body. *Science of The Total Environment*, *825*, 154025. https://doi.org/10.1016/j.scitotenv.2022.154025

Yee, M. S.-L., Hii, L.-W., Looi, C. K., Lim, W.-M., Wong, S.-F., Kok, Y.-Y., Tan, B.-K., Wong, C.-Y., & Leong, C.-O. (2021). Impact of Microplastics and Nanoplastics on Human Health. *Nanomaterials*, *11*(2), 496. https://doi.org/10.3390/nano11020496

Yuan, Z., Nag, R., & Cummins, E. (2022). Human health concerns regarding microplastics in the aquatic environment—From marine to food systems. *Science of The Total Environment*, *823*, 153730. https://doi.org/10.1016/j.scitotenv.2022.153730

Zarus, G. M., Muianga, C., Hunter, C. M., & Pappas, R. S. (2021). A review of data for quantifying human exposures to micro and nanoplastics and potential health risks. *The Science of the Total Environment*, *756*, 144010. https://doi.org/10.1016/j.scitotenv.2020.144010

Zhang, S., Wang, J., He, W., Kan, S., Liao, X., Jordan, D., Mace, E., Tao, Y., Cruickshank, A., Klein, R., Daojun, Y., Tembrock, L., & Wu, Z. (2023). *Zhang et al-2023-BMC Plant Biology*.

Zhang, Y., Wu, H., Xu, L., Liu, H., & An, L. (2022). Promising indicators for monitoring microplastic pollution. *Marine Pollution Bulletin*, *182*, 113952. https://doi.org/10.1016/j.marpolbul.2022.113952

Zhao, B., Rehati, P., Yang, Z., Cai, Z., Guo, C., & Li, Y. (2024). The potential toxicity of microplastics on human health. *Science of The Total Environment*, *912*, 168946. https://doi.org/10.1016/j.scitotenv.2023.168946

Zhu, Y., Che, R., Zong, X., Wang, J., Li, J., Zhang, C., & Wang, F. (2024). A comprehensive review on the source, ingestion route, attachment and toxicity of microplastics/nanoplastics in human systems. *Journal of Environmental Management*, *352*, 120039. https://doi.org/10.1016/j.jenvman.2024.120039

Ziani, K., Ioniță-Mîndrican, C.-B., Mititelu, M., Neacșu, S. M., Negrei, C., Moroșan, E., Drăgănescu, D., & Preda, O.-T. (2023). Microplastics: A Real Global Threat for Environment and Food Safety: A State of the Art Review. *Nutrients*, *15*(3), 617. https://doi.org/10.3390/nu15030617

Zuri, G., Karanasiou, A., & Lacorte, S. (2023). Microplastics: Human exposure assessment through air, water, and food. *Environment International*, *179*, 108150. https://doi.org/10.1016/j.envint.2023.108150

Zurub, R. E., Cariaco, Y., Wade, M. G., & Bainbridge, S. A. (2024). Microplastics exposure: Implications for human fertility, pregnancy and child health. *Frontiers in Endocrinology*, *14*, 1330396. https://doi.org/10.3389/fendo.2023.1330396