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Impact of microplastics on human health and aquatic species

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Abstract. Microplastics (MPs) have emerged as a pervasive environmental challenge, with significant implications for both marine ecosystems and human health. This study delves into the adverse effects of MPs, highlighting their physical, chemical, and biological impacts on marine life, particularly fish. These impacts include physical injury, oxidative stress, and altered immune responses, which can have cascading effects on marine biodiversity and ecosystem functionality. The review also underscores the risk MPs pose to humans through direct exposure, via consumption of contaminated seafood, inhalation, or dermal contact, potentially leading to oxidative stress, cytotoxic effects, and disturbances in immune function. By comprehensively examining existing research and identifying knowledge gaps, this study aims to underline the urgent need for targeted research strategies. These strategies should focus on elucidating the complex interactions between MPs and biological systems, assessing long-term health implications, and developing effective mitigation measures. Through detailed analysis of methodologies, results, and existing literature, this review aims to contribute to a deeper understanding of the multifaceted impact of microplastics, thereby guiding future research directions and informing policy decisions for the protection of marine ecosystems and human health. ***keywords*:** Microplastics, Ecotoxicity, Marine pollution, Human health impacts, Fish health Toxicological effects.

1 Introduction

The impact of Microplastics on human health and aquatic species has become an increasingly concerning topic over the past few decades. Microplastics, defined as plastic particles less than 5mm in size, are ubiquitous in the environment, resulting from the degradation of plastic waste and industrial discharges. Within the oceanic ecosystem, Microplastics represent a diverse collection of particles less than 5 millimeters in size, exhibiting a range of sizes, forms, and chemical structures. They are present in various marine settings, including sediments, on the surface of the ocean, throughout the water column, and within marine organisms [1,2]. Among these, polyethylene and polypropylene are identified as the most frequently produced plastics [1]. Microplastics are typically classified into two categories: primary and secondary. Primary Microplastics are those that are intentionally manufactured to be less than 5 millimeters, such as the microbeads used in cosmetic products [3]. Although there is a global shift away from their use, it was estimated that in 2015, daily, the United States alone discharged eight billion microbeads into aquatic environments [4, 5]. Additional primary microplastic sources include industrial cleaning agents and the plastic pellets used as raw material in the production of larger plastic goods. On the other hand, secondary Microplastics originate from the disintegration of bigger plastic items into smaller fragments, commonly through processes such as weathering [6, 7]. This includes microfibers shed from textiles, particles from tire wear, and breakdown of larger plastics. It is noted that even if all plastic production and disposal into the ocean were to cease, the amount of marine Microplastics would still rise due to the ongoing fragmentation of existing plastic debris into secondary Microplastics [3, 8-10]. Regarding their physical and chemical characteristics, marine Microplastics are mainly found as small beads, broken pieces, or threads made from a variety of polymers [11-13]. Some of these materials, such as polyamide, polyester, polyvinyl chloride (PVC), and acrylic, are denser than sea water, leading them to settle on the ocean floor. Conversely, others like polyethylene, polypropylene, and polystyrene are less dense and tend to remain afloat on the sea's surface. These tiny particles have been detected in various habitats, from mountain peaks to the depths of the oceans, affecting a wide range of aquatic organisms, from microorganisms to marine mammals. Research indicates that Microplastics can be ingested by aquatic species, leading to adverse effects such as reduced growth, altered reproduction, and even mortality [14,15]. In humans, exposure to Microplastics, primarily through the ingestion of contaminated seafood, drinking water, and air, raises concerns due to their potential to cause endocrine disruptions,

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inflammatory reactions, and other toxic impacts [16, 17]. Epidemiological and toxicological studies suggest a link between exposure to Microplastics and various health problems, although a full understanding of the underlying mechanisms and the extent of the impact remains to be established [18-20]. Microplastics originate from various sources, including consumer products, synthetic textiles, fishing gear, and the degradation of larger plastic waste in the environment. Their small size allows them to travel easily through ecosystems, making them almost ubiquitous in both aquatic and terrestrial environments. Studies have detected Microplastics in locations as remote as the Arctic and the deepest ocean trenches, highlighting their global distribution [21-28]. Exposure to Microplastics among aquatic species varies significantly by species and habitats, with potentially devastating effects on marine biodiversity. The bioaccumulation of Microplastics in the food chain poses a direct risk to top predators, including humans, who consume seafood [10, 29-40]. The impacts on human health related to the ingestion or inhalation of Microplastics include potential risks to the gastrointestinal system, the respiratory system, and even the crossing of these particles through biological barriers to reach the blood and other organs [26, 41-45]. In response to these challenges, scientific research has intensified to better understand the pathways of contamination, the mechanisms of health impact, and the methods of assessing risks associated with Microplastics. Simultaneously, policies and regulations aimed at reducing plastic waste production and improving waste management have begun to emerge globally. Initiatives such as the ban on microbeads in consumer products, the improvement of recycling systems, and the development of biodegradable alternative materials are steps towards reducing microplastic pollution [24, 46-52].

This study aims to synthesize current knowledge on the impact of Microplastics on the health of aquatic ecosystems and humans, focusing on the latest findings, research gaps, and future perspectives to mitigate these harmful effects. We will examine the pathways of exposure to Microplastics, assess their toxicity, and discuss potential strategies to reduce their presence in the aquatic environment and limit human exposure.

2 Methodological approach

Bibliometric analysis stands as a quantitative methodology aimed at assessing the scientific impact of research within specific fields or on particular topics. It involves a detailed scrutiny of bibliographic data, including citations, publication trends, authorship, and other pertinent metrics, to map the academic landscape of a specific discipline. Key aspects of this analysis encompass citation review, monitoring publication evolution over time, authorship analysis, evaluation of scientific journals, keyword study, as well as network and geographical analyses [53, 54]. This approach provides researchers, policymakers, and institutions with invaluable insights into the academic panorama, highlighting prevailing trends, key contributors, and research gaps. Its significance is increasingly recognized for shaping research directions, evaluating scientific outputs, and informing decision-making processes in the academic sphere and beyond [54]. This research aims to uncover the main trends concerning the impact of Microplastics on human health and aquatic species over the last decade, utilizing bibliometric and visualization tools for a comprehensive understanding of the academic field [55, 56]. Specifically, it focuses on reviewing relevant publications, assessing their features, and presenting the findings. To ensure the study's rigor, a careful selection of high-quality articles was made from the Scopus database, excluding conference presentations and proceedings [57]. In February 2024, a thorough analysis was conducted using keyword searches in titles, abstracts, or keyword lists, selecting the "Subject" option [58]. This analysis included English-language articles and all available search results. Keywords such as "impact of Microplastics on human health and aquatic species" and related terms were employed. The choice of Scopus as the database for this study on the impact of Microplastics on human health and aquatic species was due to its advanced features for visualizing, analyzing, and tracking research developments across diverse disciplines, including the humanities, technology, and science [59]. Consequently, 42 articles were retained for more detailed analysis. The analytical research framework is presented in Figure 1.

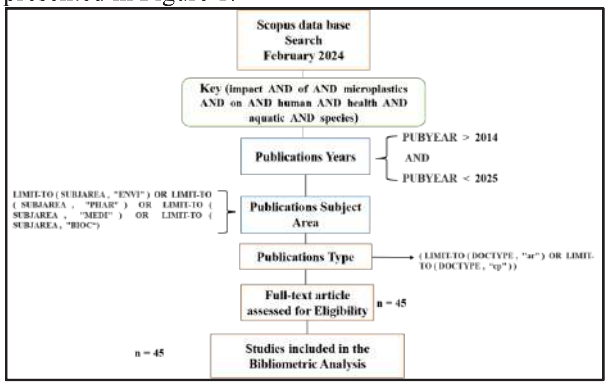

Fig. 1. Framework for Analysis in the Study.

3 Trends in Research on the Impact of Microplastics in Fish and Humans

Microplastic pollution represents an emerging environmental threat to the health of both fish and humans. Fish across the globe are being contaminated with Microplastics, which then enter the human body through consumption [60]. Recently, numerous scientists have turned their attention to the impacts of Microplastics on fish and human health [61]. Although there is an increasing number of publications, the potential effects remain largely unclear [62].

3.1 Annual Productions

An examination of the publication timeline for articles concerning this subject between 2015 and 2023 has been conducted. The analysis indicates a significant increase in the volume of these articles in the latter years of the period. For instance, the year 2023 alone accounts for approximately 18 publications focused on the topic, marking a notable peak compared to just a single publication in 2015. The progression of publications has seen a steep incline, particularly from 2020 onwards, with the count rising from around 3 to 18 by 2023. This surge in scholarly attention is graphically represented in the line graph, referred to as Figure 2 in this context. Furthermore, this upward trajectory suggests an intensifying research interest and scholarly focus on the issue of microplastic production within marine ecosystems, with a projection of continued growth in the literature.

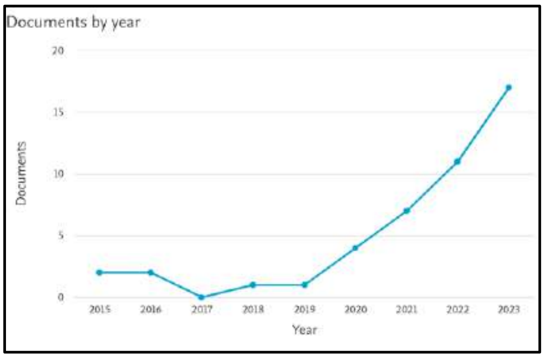

Fig. 2. Publication distribution from 2015 to 2023.

3.2 Distribution of keywords

The principal research terms associated with the investigation of the effects of Microplastics on human health and aquatic life throughout the past ten years were identified. These terms were pinpointed through the application of a keyword co-occurrence analysis, where "all keywords" were considered collectively. Consequently, a total of 1,246 keywords emerged, as depicted in Figure 3. Employing this co-occurrence strategy enables the isolation of the most prevalent keywords within the realm of marine Microplastics production research. Such an approach allows for an in-depth appreciation of the pivotal themes and evolving patterns within this area of study over the referenced time frame.

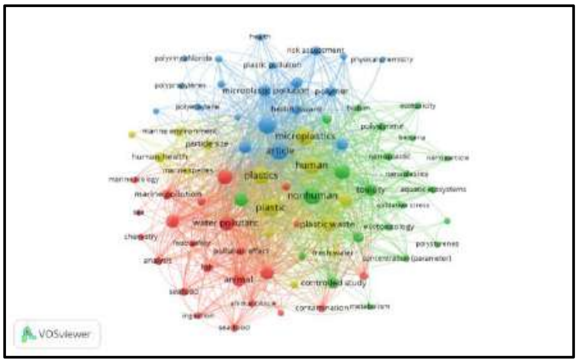

Fig. 3. Findings from the analysis of publications based on keywords.

Upon analyzing the keyword network visualization, it's evident that certain terms like "Microplastics," "human," and "marine pollution" are prominently featured, indicating a high frequency of use in the literature. These central terms, along with "marine species" and "water pollutant," suggest a strong focus on the environmental and biological impacts of Microplastics. In contrast, terms such as "polyvinyl chloride," "polypropylene," and "polyethylene" appear less frequently, which may reflect a more specific or technical aspect of the research that garners less attention in the overall bibliometric analysis. The prevalence of terms relating to health and the environment underscores the research community's prioritization of understanding how Microplastics influence living organisms and ecosystems. This study, encompassing a review of 45 research publications sourced from the Scopus database, presents a thorough investigation into the impacts of Microplastics on human health and aquatic species through content analysis and bibliometric methods. Trend analysis within this body of work indicates a burgeoning interest in research related to the effects of Microplastics, marking this field as an emergent and promising area of study. Examination of the publication sources suggests that interdisciplinary fields, particularly those examining the connections between Microplastics and their ecological and health consequences, are significantly engaging with the impacts of Microplastics on marine organisms and human health.

4 Microplastics Bioavailability to Fish

Microplastics are present in almost all aquatic environments, where they share a similar size with sediments and some planktonic species. This makes them accessible to various aquatic organisms, especially fish. The accessibility of Microplastics to fish is determined by various factors. Fish that filter feed or consume deposits are believed to be more susceptible to ingesting Microplastics compared to predatory fish, owing to their indiscriminate feeding habits. [63] Investigated the connections between tidal fish feeding behaviors and the likelihood of microplastic ingestion, finding that omnivorous fish consumed more Microplastics than herbivorous and carnivorous fish. Types of fish that utilize vision for feeding are more prone to consuming microplastic particles that mimic the appearance of their natural food. Specifically, white Microplastics were found to be ingested more frequently by the species Pomatoschistus microps compared to particles of black and red. Moreover, the form or size of Microplastics can significantly influence their ingestion by fish, with certain dimensions being more likely to be consumed. Research by [64, 65] highlighted that Microplastics within the size range of 1–2.79 mm were predominantly ingested by Myctophidae in the North Pacific Central Gyre, a size that closely matches the plankton which serves as the main food source for these fish. The vertical distribution of Microplastics (MPs) in the water column is largely influenced by their density, which can alter the likelihood of different fish encountering them in their respective habitats [66]. For instance, pelagic fish, which live in the open water, are more likely to encounter plastics that float or remain suspended due to their low density. In contrast, bottom-dwelling, or demersal, fish are more susceptible to encountering denser Microplastics that settle on the seafloor [67]. Additionally, the specific factors that influence fish's dietary preferences for consuming Microplastics are not well understood. The mechanisms of interaction between Microplastics and fish require further comprehensive investigation.

5 Magnification and Transfer across Food Chains

The phenomenon of biomagnification has been documented across various fish species and those further up the food web. the study [64] found Microplastics in plankton-eating fish, which were then bioaccumulated in larger predators preying on these fish. Notably, species like bluefin tuna, albacore tuna, and swordfish in the Mediterranean Sea have shown signs of biomagnification. The study [68] reported trophic transfer of Microplastics from mackerel (Scombrus scombrus) to grey seals (Halichoerus grypus). While some fish can expel low-density Microplastics as pseudofeces, many particles remain within the gastrointestinal tract [69-71].This same mechanism could potentially lead to the transfer of Microplastics from marine life to humans. Despite some studies on biomagnification, the research is sparse. To truly understand the extent of biomagnification and trophic transfer, further comprehensive studies are necessary.

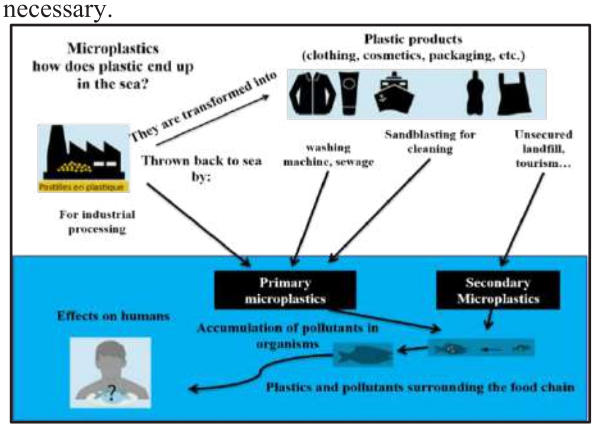

Fig. 4. Possible origins and pathways of Microplastics in fish [72].

6 Effects of Microplastics on Fish

Research into the effects of microplastic (MP) exposure on marine life, particularly fish, has increasingly highlighted both physiological and ecological concerns. Laboratory studies form the bulk of this research, utilizing fish from diverse aquatic environments, primarily marine, to understand the consequences of MP ingestion. Accumulation of MPs in the fish's gastrointestinal tract can lead to blockages, impairing their ability to feed and potentially causing anatomical and functional changes within their digestive systems. These alterations may result in nutritional deficiencies and developmental challenges, contributing to a decrease in survival rates, especially in juvenile fish before reaching maturity. Species like Danio rerio have been extensively studied, with findings indicating that MPs can cause oxidative stress, reduced mobility, disruption of gene expression, and harm to reproductive organs. The impact of MPs is not limited to Danio rerio; Oryzias melastigma has also been significantly affected, showing symptoms such as growth inhibition, gut dysbiosis, weight reduction, oxidative stress in the liver, and damage to reproductive organs. Another species, Sparus aurata, commonly consumed by humans, has shown vulnerability to MPs, with effects including stress, oxidative damage, behavioral changes, and compromised immune system functionality. These findings underscore the urgent need for further research to fully understand the breadth of MPs' impacts on marine ecosystems and the potential long-term effects on both aquatic life and human health through the consumption of contaminated seafood. For a more detailed exploration of this topic, and [73] provide comprehensive insights into the multifaceted effects of Microplastics on fish species. These references detail the methodologies and findings of laboratory experiments that reveal the extent to which Microplastics can disrupt aquatic ecosystems and the health of fish populations.

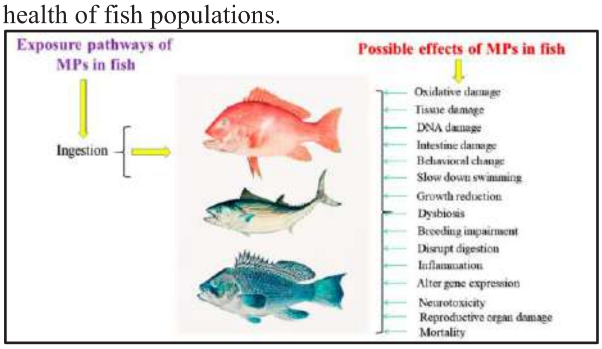

Fig. 5. Potential impacts of Microplastics on the physiology of fish following consumption [74].

7 Presence of Microplastics in Human Bodies

The presence of Microplastics (MPs) in seafood represents a significant hazard to human health. Seafood, being a vital component of human diets, raises major concerns when contaminated with MPs. The infiltration of these particles into the intestinal system carries the risk of spreading to other parts of the body through mechanisms such as endocytosis and persorption. This situation poses toxicological risks that could adversely affect the health of fish, which is particularly concerning for individuals who rely on fish as a staple in their diet. The detrimental effects might also negatively impact fishing activities, by decreasing the quantity and quality of fish catches, leading to significant economic and ecological repercussions. Furthermore, MPs can serve as vectors for other pollutants, such as heavy metals and persistent organic pollutants, thereby increasing the risk of bioaccumulation of toxic substances in the food chain. This bioaccumulation could have long-term health effects on humans, including endocrine, neurological, and immune system disorders. Current research highlights the need for further investigation into the realistic levels of MPs and associated pollutants in aquatic ecosystems and their impacts on human health and fish populations. There's a critical need for developing management and pollution reduction strategies to protect public health and marine biodiversity. Special attention should be given to improving sustainable fishing practices and reducing plastic pollution at its source to mitigate this growing environmental issue.

8 Toxicological Impacts on Human Health

The accumulation of Microplastics (MPs) and nanoplastics in tissues can result in swelling and blockage. In vitro experiments have indicated that MPs tend to accumulate in the gills, stomachs, and metabolic systems of crustaceans, leading to adverse cellular changes in fish. Moreover, these particles have been found to transport microorganisms and pollutants, with the severity of their adverse effects largely dependent on an individual's level of exposure and susceptibility [75]. Exposure to MPs has been linked to oxidative stress, cytotoxicity, and their migration to other tissues. Due to their persistence in ecosystems and living organisms, animals may experience prolonged discomfort, swelling, abnormal cell growth, and immune system suppression [76]. Notably, patients with [77], and polystyrene (PS) MPs have been observed to inhibit the growth of Caco-2 cells over time [78].

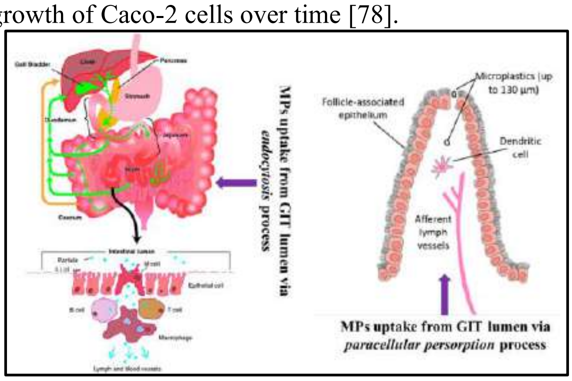

Fig. 6. Different process of MPs uptake from gastrointestinal tract (GIT) after exposure [74].

9 Effects of Oxidative Stress and Cell Toxicity

The main toxic effects of Microplastics (MPs) in inhalation exposure experiments are believed to be due to oxidative stress, leading to subsequent inflammatory and cytotoxic impacts, as highlighted in various studies (Table 1). MPs are capable of inducing oxidative stress by generating oxidizing agents that adhere to their surface, as well as reactive oxygen species produced by the host in response to inflammation, as demonstrated by [79, 80]. Studies such as [81] have exposed A549 lung cells and human gastric cancer cells to nanoparticles to trigger pro-inflammatory responses. [82] reported that larger polyethylene particles (0.3–10 µm) could enhance the secretion of cytokines like IL-6, IL-1b, and TNF-α, which are inflammatory agents. MPs contain reactive oxygen species due to their polymerization and processing. However, interactions with UV radiation or the presence of reactive metals may significantly amplify these free radicals. The aging of MPs has also led to the creation of free radicals that oxidized target tissues, as reported. Indicates that polystyrene nanoparticles adhere to the surface of intestinal epithelial cells and induce oxidation of these cells. Furthermore, prostheses for limbs and joints containing MPs have been shown to release acute toxins and free radicals due to severe inflammatory reactions, causing polymer degradation, cracking, and leakage, as noted by [83]. The cytotoxic effect of MPs is a result of oxidative damage and inflammation (refer to Table 1). Animal studies and in vitro tests have shown that MPs can be ingested by specific cells, such as macrophages, leading to potential damage to intracellular organelles due to their non-membrane-bound nature, as reported by [84] and [85]. In vitro studies have also confirmed the cytotoxic nature of MPs particles.found that concentrations of MPs ranging from 0.05 to 10 mg/L generated high levels of reactive oxygen species, contributing to cytotoxicity in human brain and epithelial cells. Additionally, in vitro exposure of macrophages and lung epithelial cells to nanoplastics increased reactive oxygen species production, leading to aggregation of misfolded protein particles in the endoplasmic reticulum and cytolysis. [86] Discovered that polystyrene particles were cytotoxic to adenomatous cells of the small intestine. Therefore, individuals exposed to MPs may experience cytotoxicity and oxidative damage. However, several in vitro studies, such as those by [87] and [88], have not found significant cytotoxic effects, even at high levels. Additionally, the environmental impact of Microplastics (MPs) extends beyond direct cytotoxic effects. Studies have shown that MPs can accumulate in the food chain, affecting not only aquatic organisms but also terrestrial species, including humans, as these plastics make their way from organisms at lower trophic levels to predators at higher levels. This bioaccumulation raises concerns about long-term exposure to MPs and the potential for chronic health effects, including endocrine disruption and carcinogenesis, as suggested by some research. Moreover, the interaction between MPs and other environmental pollutants is of growing concern. MPs can act as vectors for heavy metals, persistent organic pollutants (POPs), and other hazardous substances, absorbing and transporting these chemicals within ecosystems. This can lead to increased toxicity of MPs when they are ingested by organisms, as the pollutants concentrated on the surface of MPs may be more readily absorbed by the body than when they are present in the environment alone. The impact of MPs on microbial communities is another area of emerging research. Preliminary studies suggest that MPs can alter the composition and function of microbial communities in the environment, which can have further implications for nutrient cycling, ecosystem functioning, and the spread of antibiotic resistance genes. Lastly, the issue of Microplastics is not only an environmental concern but also a socio-economic one. The persistence and ubiquity of MPs in the environment pose challenges for waste management and water treatment processes. The economic costs associated with cleaning up MPs from water bodies, beaches, and other affected areas are significant. Furthermore, there is a growing public health concern, which may require increased healthcare costs and new regulatory policies to address the issue effectively. In summary, the problem of MPs in the environment is multifaceted, involving direct biological effects as well as broader ecological, economic, and social dimensions. The ongoing research into the impacts of MPs highlights the need for a multidisciplinary approach to understand and mitigate their effects comprehensively.

10 Altering the Body's Metabolic Processes and Energy Dynamics

Microplastics (MPs) can directly affect metabolism by modifying metabolic enzymes or indirectly by disrupting energy balance. They influence metabolism by either increasing or decreasing energy expenditure, reducing nutrient absorption, and affecting the regulation of metabolic enzymes, as outlined in Table 1. However, humans have greater energy needs and more complex metabolic systems than the organisms examined, which could alter the metabolic effects detailed in Table 1.

11 Deregulation of the Immune System

It has been observed that Microplastics (MPs) trigger systemic or localized immune reactions following exposure, influenced by their distribution and individual human responses. Moreover, environmental exposure to MPs has been found to compromise the immune function in individuals particularly susceptible to biological stress, potentially leading to autoimmune diseases or a weakened immune response, as noted in various studies (refer to Table 1). [89] suggested that chronic cellular damage, the release of immune-modulating substances, and inappropriate activation of immune cells can all contribute to the development of MP-related autoimmune conditions, leading to the production of antibodies that attack the body's own tissues [89]. Furthermore, the link between MP exposure and conditions such as autoimmune rheumatic diseases and systemic lupus erythematosus has been established [90, 91]. While there is an indication that MPs could impact human immune functions, conclusive evidence is still lacking. Therefore, further investigations are necessary to fully understand the effects of MPs on the human immune system.

Table 1. Potential harmful impacts of micro- and nano-sized plastics on human health.

Toxicity	Characteristics of Plastic Particles	Particle Size	Details	Refs
Inflammation	Polystyrene nanoparticles Unaltered/Carboxylated polystyrene/nanoparticles Carboxylated and amino-modified polystyrene particles Unaltered polyethylene particles Polyethylene particles from plastic prosthetic implants Polystyrene MPs particles	• 202 and 535 nm • 20, 44, 500, • and 1000 nm • 120 nm • 0–3 µm,10 µm • 0.2 and 10 µm • 5 and 20 µm	Expression of IL-8 is increased Inflammation was induced in human A549 lung cells Expression of IL-6 and IL-8 is increased Multiple human cancers have increased inflammation Scavenger receptor expression is altered Periprosthetic bone resorption occurred as a result Induced inflammatory reaction around the implant The liver is inflamed as a result of the inflammation	[74, 81, 92-94]
Oxidative Stress and Apoptosis	Amine-modified polystyrene nanoparticles Cationic polystyrene nanoparticles Unaltered or functionalized polystyrene polyvinyl chloride (PVC) and poly (methyl methacrylate) (PMMA)	• 60 nm • 60 nm • 20, 40, 50, and 100 nm	Mucin has strong interaction and aggregation Apoptosis was induced in all intestinal epithelial cells ROS production and ER stress are both induced Autophagic cell death in mice macrophages and lung epithelial cells has Been induced Apoptosis was induced in a variety of human cell types	[95-97]
Metabolic Homeostasis	Pristine and fluorescent polystyrene MPs Anionic carboxylated polystyrene nanoparticles Polystyrene nanoparticles Cationic polystyrene nanoparticles Pristine polystyrene microparticles MPs	• 5 µm • 20 nm • 30 nm • 50 and 200 nm • 5 and 20 µm • and 5 µm	Amino-addition and bile-addition metabolism changes Induced dysbiosis of the gut microbiota and intestinal barrier failure Ionic homeostasis and altered ion channel function Basolateral K+ channels that have been activated Cl− and HCO3− ion outflow is induced	[98-100]

12 Migration of Cells to Different Tissues

Following exposure, MPs can migrate to remote tissues through the bloodstream. The entry of MPs into the cardiovascular system can trigger inflammatory responses, cytotoxic effects on blood cells, vascular inflammation, blockages, and elevated blood pressure in the lungs, as referenced in various studies (Table 1).

In vitro studies have shown that exposure to nanoparticles can lead to the coagulation of red blood cells and adherence to the endothelial walls. MPs have been found to promote hemolysis and increase the release of histamine, a molecule that promotes inflammation. A primary pathway for MP migration involves the increased permeability of the epithelial membrane due to inflammation. Additionally, [101] demonstrated that nanoparticles of 240 nm in size could

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easily traverse the placental barrier in a human placenta perfusion model.

13 Toxic effects on the nervous system

Ongoing exposure to fine particles, especially Microplastics (MPs), has been linked to neurotoxic effects in organisms. This could be attributed to the stimulation of immune cells and the creation of oxidative stress in the brain, as detailed in Table 1.
Neurotoxicity could result from either direct contact with the particles that have moved into the body or from the action of circulating pro-inflammatory cytokines, leading to long-term harm to brain cells, as reported in study. Furthermore, MPs have been identified as having a detrimental impact on both the functioning and behavior of neurons in living organisms.
Research by Deng et al indicates that MPs increase the activity of acetylcholinesterase (AChE) in the brain and cause changes in the levels of serum neurotransmitters. Moreover, studies conducted in vitro have shown that nanoplastics can exert toxic effects and compromise the metabolic functions of different types of brain cells, attributed to their high concentration of bioactive substances.

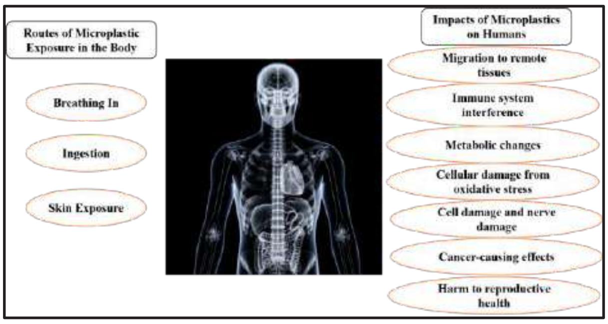

Fig. 7. Potential impacts of Microplastics on human health following exposure.

14 Cancer-causing potential

For many years, the interaction between humans and plastic products has been linked to cancer. However, definitive evidence has not been provided to date. The study indicated in [102] proposes that ongoing consumption of Microplastics (MPs) might lead to cancer due to persistent inflammation and irritation, which results in DNA damage (see Table 1). Furthermore, the study highlights that exposure to nanoplastics leads to oxidative stress and continuous irritation, showing signs of pro-inflammatory agents. These agents encourage the stimulation of blood vessels, contributing to the onset and expansion of cancerous cells.

15 Combined Impacts of Microplastics and Additional Contaminants

Since their integration into production processes, Microplastics (MPs) have been found to contain a variety of external chemical additives and dyes, including persistent organic pollutants (POPs), phthalates, bisphenol A (BPA), and other substances commonly used as plastic additives. These compounds, which are added to modify plastic properties, can leach out of MPs, contaminating the environment and living organisms. MPs act as carriers, transporting bacteria and chemicals, and can adversely impact human health by disrupting hormones even at low doses and promoting inflammatory reactions and infections. Repeated exposure to MPs can significantly increase the risk of harmful effects. Microplastics retrieved from diverse environments have been found to contain POPs such as PAHs, PCBs, and heavy metals including lead, nickel, cadmium, and zinc. These chemicals can leach out as they are not chemically bonded to the MPs matrix. Additionally, MPs can alter the diversity and function of the gut microbiome, leading to serious health implications. BPA, in particular, has been highlighted for its potential harm, including disrupting the endocrine system and contributing to obesity and the development of certain cancers.

16 Conclusion

Our study underscores the profound environmental and health implications of widespread microplastics (MPs) contamination, a direct consequence of plastic mismanagement and improper disposal. Scientific investigations have elucidated that MPs, pervasive across diverse aquatic environments, from the superficial layers of the oceans to the deepest sediments, pose substantial risks to marine life, particularly to fish species.
The ingestion and accumulation of MPs by aquatic organisms result not only in physical harm but also in the introduction of toxic substances and pathogens into the marine food web, thereby exacerbating the ecological crisis.

Our findings reveal that MPs can act as vectors for harmful chemicals and microorganisms, which, when ingested by fish, may lead to a spectrum of adverse health effects, including but not limited to, altered immune responses and oxidative stress. These effects on fish health not only have implications for the survival and reproductive success of these species but also raise concerns for human health. Humans are at the end of this contamination chain, with the consumption of contaminated seafood presenting a clear pathway for MPs and their associated toxins to enter the human body, potentially leading to chronic health issues.

The broader significance of our study lies in its contribution to understanding the intricate pathways through which MPs impact both aquatic ecosystems and human health. It underscores the urgency of developing comprehensive waste management strategies aimed at significantly reducing MPs pollution. Our research suggests the necessity for policy interventions that extend the life cycle of plastic products and enhance public awareness of the environmental and health risks associated with plastic waste. Additionally, the study highlights the need for further research to explore the long-term effects of MPs on marine life and human health, as well as to identify effective mitigation and remediation strategies. These steps are crucial for safeguarding aquatic biodiversity, ecosystem health, and, ultimately, human well-being.

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