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The impact of microplastic pollution on human health - current issues

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Abstract. In recent years, the pervasive presence of microplastics in various environments has raised global concern. These tiny plastic fragments, less than 5mm in size, have infiltrated terrestrial, aquatic, and atmospheric ecosystems, posing threats to biodiversity, human health, and ecological balance. Understanding microplastic pollution has become crucial for scientists, policymakers, and stakeholders. This paper offers a comprehensive overview of microplastics, covering their sources, distribution, fate, and ecological implications. By synthesizing existing knowledge and identifying research gaps, this paper aims to deepen our understanding of microplastic's global impact and support sustainable environmental management. The objective of this study is to explore the prevalence, distribution, environmental implications, and potential mitigation approaches related to microplastics across diverse ecosystems, with a specific emphasis on their impact on human health and well-being. To obtain up-to-date information concerning trends in the topic of microplastics, a review of the PubMed and Google Scholar databases, along with the latest legislative reports in both Europe and Poland, was performed. Microplastics pose a significant environmental and health threat, disrupting soil properties, biochemical cycles, and ecosystems globally. Despite extensive research, gaps remain in understanding their behavior. Effective management requires comprehensive waste strategies and regulatory measures to mitigate their impact. Addressing this challenge demands interdisciplinary collaboration and heightened public awareness for a sustainable future.

Keywords: microplastics, bioaccumulation, contamination, health hazards, additives, environment

1. Introduction

Plastic is a material whose production became widespread in the 1950s. It found very broad application in many areas of life due to its properties, such as durability, resistance to high temperatures, lightness, and low production cost compared to paper or glass (Lee et al., 2022; Jadhav et al., 2021). The term "microplastic" refers to particles made of synthetic material with a diameter not exceeding 5 mm (Arthur et al., 2009; Yang et al,. 2022). It is formed as a result of the fragmentation of larger elements (secondary microplastic) as well as being commercially synthesized in its micro size (primary microplastic) (Barceló et al., 2023).

Due to the many unquestionable advantages of plastic, its global production and utilization have gradually increased. This resulted in the production of a total of 6.3 billion tons of plastic between 1950 and 2015, of which only 9% was recycled, 12% was incinerated, and the remaining 79% was either landfilled or released directly into the natural environment. Current plastic production exceeds 380 million tons annually, with 407 million tons produced in 2015 alone, of which 164 million tons were used for various types of packaging (Aslam et al., 2023; Lebreton et al., 2019). From such a vast amount of produced plastic, microplastics and nanoplastics are generated. These particles enter the natural environment, posing a danger to both animals and humans (Aslam et al., 2023; Chae et al., 2018). Due to their size, microplastics are particularly widespread. They show the greatest tendency to accumulate in aquatic environments. They have been detected in oceans, seas, the atmosphere, soil, sea salt, seafood, and many other food products, as well as in the digestive tracts of marine animals (Barceló et al., 2023; Ragusa et al., 2021).

Due to the prevalence of plastic, people are directly exposed to contact with it in their daily lives through routine activities such as drinking water, consuming contaminated foods, and even through contact with atmospheric air, where it can also be found (Barceló et al., 2023; Fan et al., 2023). The smallest particles are capable of penetrating individual cells, disrupting their proper functioning and inducing an inflammatory response. However, it is not known whether the amount of accumulated microplastics in organs is sufficient to cause serious consequences and dysfunctions

(Barceló et al., 2023; Sorci et al., 2022). The ambiguity of information partly stems from ethical limitations on human sample collection and inadequate availability of appropriate research techniques (Yang et al., 2022; Barceló et al., 2023; Aslam et al., 2023). Nevertheless, it is crucial to thoroughly understand the effects of microplastics on the human body, given the increasing trend of its production and presence in the environment. The threat to humans depends on the duration of exposure, the type of material, and the properties of the exposed tissue (Yang et al., 2022). Harmful effects of microplastic exposure may affect individual cells, tissues, as well as entire organs and systems in the human body (Yang et al., 2022; Barceló et al., 2023; Sorci et al., 2022).

2. Study area - impact on the natural environment

In today's world, microplastics have become the primary pollutant in the environment. Their distribution is widespread, with their presence noted in water, atmosphere, soil, ice, and even in human feces, placenta, and blood. Surprisingly, microplastics have been found in Antarctica, proving their presence even in the most remote corners of the Earth (Fan et al., 2023; Bhatt et al., 2023; González-Pleiter et al., 2020).

Aquatic environments are the main accumulation sites for microplastics. This is caused by two processes: the breakdown of larger plastic particles and their transport from rivers and wastewater treatment plants (Lee et al., 2022; Chae et al., 2018). Microplastic particles are dispersed throughout the hydrosphere due to their composition, with those of higher density, such as polyamide (PA) and polyvinyl chloride (PVC), settling on the ocean floor, while lighter ones like polyethylene (PE) and polypropylene (PP) float on the water's surface (Yang et al,. 2022; Fan et al., 2023). The presence of plastics in water bodies also has an undeniable impact on the living organisms inhabiting these environments. Approximately 70% of microplastics in the hydrosphere accumulate in the tissues of aquatic organisms (Chae et al., 2018; Yang et al., 2021). Consumption of microplastics has been reported in about 150 species of freshwater and marine fish (Barceló et al., 2023; Jabeen et al., 2017), which could pose threats to subsequent levels of the food chain, including humans (Lee et al., 2022). Furthermore, it has been found that animals exposed to microplastics produce abnormal eggs and sperm, resulting in a 41% reduction in offspring compared to organisms inhabiting uncontaminated waters (Lee et al., 2022, Cressey et al., 2016).

In the pedosphere, similar to the hydrosphere, there are also microplastic particles, affecting both flora and fauna (Chae et al., 2018, Stapleton et al., 2023). The presence of plastics may be caused by activities such as tourism. Such activity generates a large amount of plastic waste, predominantly single-use bags, which are then improperly disposed of and decompose, releasing microplastics into the soil, where an estimated 300 million tons can be found (Chae et al., 2018; Lebreton et al., 2017). Another major cause of soil pollution with microplastics is agricultural activity. In this case, the use of fertilizers coated with microplastics, slow-release fertilizers, organic fertilizers, garden mulch, and the use of water contaminated with microplastic particles are the reasons (Chae et al., 2018; Lian et al., 2021).

Microplastics in the soil alters its physicochemical properties and affects enzyme activity, thereby influencing the biochemical cycles within it. This disrupts plant growth and impairs the functioning of microorganisms, resulting in changes throughout the ecosystem (Qiu et al., 2022). In the atmosphere, particles with low density and small sizes can be transported by wind over long distances, but ultimately settle in the pedosphere or hydrosphere, often due to atmospheric precipitation (Stapleton et al., 2023; Camarero et al., 2017). The presence of micro-particles in the air poses a health threat and affects the functioning of living organisms due to the possibility of entering the respiratory tract (Fan et al., 2023; Tourinho et al., 2019).

The occurrence, accumulation, and persistence of plastics in the form of microplastics in terrestrial and marine environments have become a global problem. Most current research focuses on its role and impact on the aquatic environment. However, there is insufficient information regarding the transport, accumulation, and distribution of microplastics in the pedosphere and atmosphere. Therefore, future research should concentrate on these environments due to their significant influence on microplastic transport to the aquatic environment and their overall impact on the ecosystem (Stapleton et al., 2023; Lian et al., 2021). Proper management of plastic waste, recycling, and the introduction of biodegradable plastics such as polyhydroxyalkanoates (PHA) and polylactic acid (PLA), which can be derived from microorganisms and microalgae, are necessary (Chia et al., 2020). It is also important to raise public awareness and implement appropriate legal regulations to address the growing global problem of environmental pollution with microplastics, thereby reducing their transfer to living organisms (Stapleton et al., 2023; Kiran et al., 2022).

3. Sources and Categories of Microplastics

Plastics exceeding dimensions of 5mm are categorized as macroplastics (Fan et al., 2023; Lechthaler et al., 2020). Exposure to environmental elements initiates a process of weathering and degradation, culminating in the formation of microplastics comprising fragmented particles smaller than 5mm. A notable challenge arises in their removal from the environment post-introduction due to their diminutive size. Beyond micro and macroplastics, the classification extends to mesoplastics (0.5-5cm) and megaplastics (>50cm) based on fragment size (Fan et al., 2023; Stapleton et al., 2023; Zhang et al., 2021). Fig. 1 illustrates how plastic has been categorized based on the size of its particles.

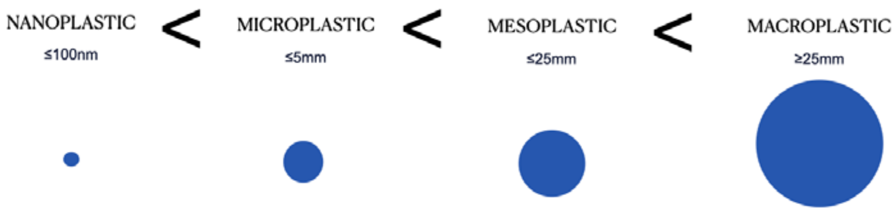

Fig. 1 Sizes of plastic (Fig. own).

Microplastic contamination can be distinguished into primary and secondary classifications based on their origins. Primary microplastics are deliberately manufactured in sizes below 5mm for specific purposes, while secondary microplastics are derived from larger plastic materials within the macroplastics category. These secondary microplastics undergo gradual fragmentation into smaller particles influenced by various intricate environmental factors (Stapleton et al., 2023; Guo et al., 2020; Hays et al., 1974).

Primary microplastics include plastic pellets and exfoliating particles used in the cosmetic industry, such as those found in exfoliating scrubs and facial cleansers. Microbeads are also added to toothpaste, hand soaps, nail polishes, and other personal hygiene products and cosmetics (Fan et al., 2023; Alomar et al., 2016). Additionally, primary microplastics encompass synthetic materials used in sandblasting as abrasives, as well as microplastics utilized in the pharmaceutical industry as drug carriers (Fan et al., 2023; Guo et al., 2020; Hays et al., 1974).

Secondary microplastics originate from various aspects of daily life. Common sources include laundry activities, synthetic fibers, and textile production (Fan et al., 2023; Stapleton et al., 2023; Boucher et al., 2017). The wear and tear of rubber car tires on roads also constitute a significant source of environmental release and pollution.

Plastic packaging for food, plastic clothing, and furniture are also significant contributors to secondary microplastic pollution. These materials lead to the suspension and settling of dust in the air. This category also includes dust released during the production and incineration of various types of plastics, as well as dust emissions associated with traffic and fishing activities (such as nets and lines) (Fan et al., 2023; Camarero et al., 2017; Xue et al., 2020; Zhang et al., 2022).

During the COVID-19 pandemic, there was a significant increase in the use of personal protective equipment, such as single-use face masks. To reduce costs, these masks are often made from plastic, typically polypropylene. Considering the long-term effects of such personal protective measures, it is noteworthy that medical waste related to COVID-19 has also become a significant source of environmental microplastic pollution (Stapleton et al., 2023; Dey et al., 2023; Mohana et al., 2023). Plastics are also used in the production of test kits for detecting SARS-CoV-2 and syringes for vaccines (Lee et al., 2022).

It is important to note that the breakdown of macroplastics into smaller elements, resulting in the formation of microplastics, occurs under the influence of environmental factors such as wind, UV light (causing photodegradation of plastic and consequently its fragmentation into smaller elements), and temperature. This also applies to the degradation of single-use plastic cutlery, cups, containers, and widely used plastic bags (Fan et al., 2023; Zhang et al., 2021; Guo et al., 2020).

Based on the chemical composition and density of microplastics, six types can be distinguished: polypropylene (PP), low-density polyethylene (LDPE), high-density polyethylene (HDPE), polystyrene (PS), polyvinyl chloride (PVC), and polyethylene terephthalate (PET). In addition to these main types, there is also a category of "other," which includes polyester, for example (Fan et al., 2023; Coyle et al., 2020). Polypropylene (PP) is sourced not only from single-use face masks but also from straws, fishing nets and lines, and carpets. Polystyrene (PS) is found in cosmetics, plastic packaging, and single-use cutlery (Fan et al., 2023; Stapleton et al., 2023; Prata et al., 2020). Microplastics can be categorized based on their shape, including microbeads, nurdles, fibers, foam, and fragments (Fan et al., 2023).

4. Exposure pathways to microplastics - The continuous cycle of microplastics

Microplastic pollution is ubiquitous, with its presence observed in aquatic environments such as oceans, lakes, and rivers, as well as in the air, soil, and terrestrial environments [see Fig. 2].

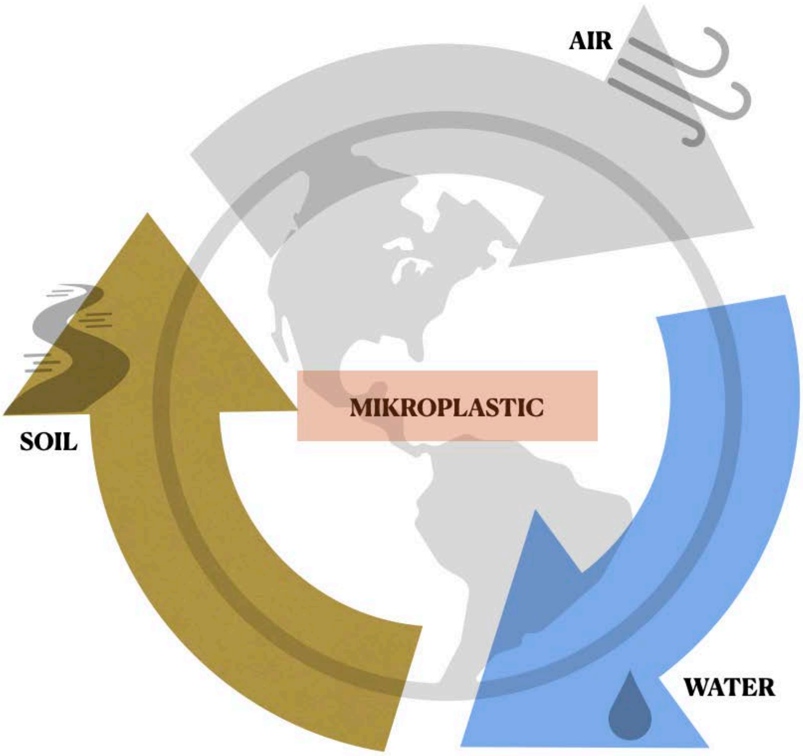

Fig. 2 The continuous cycle of microplastics (Fig. own).

Traces of microplastics have even been found in Arctic ice, demonstrating that humans are exposed to them from all directions and encounter them at every turn (Blackburn et al., 2022; Hirt et al., 2020). Various types of microplastics have been detected in human feces, unequivocally indicating that microplastics can infiltrate the human body and exert an influence (Shruti et al., 2020). The transfer of microplastic particles can occur through various pathways, with one of them being the dietary route via consumed food and beverages (Shruti et al., 2020).

The presence of microplastics has been identified in various food products. Food contamination with microplastics can occur in several ways. One of them is the ingestion of plastic particles by marine and terrestrial organisms. Through this route, organisms such as chickens, fish, and other animals, including marine species (e.g., shellfish), may become potential sources of microplastics for humans. Another way food can become contaminated is through the widespread use of plastics in packaging production. Additionally, a significant route is the secondary absorption of microplastics into natural resource contamination. This includes water in aquatic reservoirs, which remains contaminated, leading to the subsequent contamination of bottled water and other beverages (Jabeen et al., 2017; Cressey et al., 2016; Kedzierski et al., 2020; Hernandez et al., 2019).

The presence of microplastics has been reported in bottled drinking water, possibly originating from bottle caps, among other sources. Microplastics have also been found in beer, milk, energy drinks, and other non-alcoholic beverages (Blackburn et al., 2022; Shruti et al., 2020; Kosuth et al., 2018). Microplastics have also been found in wine. Besides bottle caps, materials used in packaging production are potential sources of microplastic contamination. Plastics (including PET), used to produce bottles for water and other non-alcoholic beverages, gradually degrade over time, becoming a direct source of organism exposure. As a result of this degradation, plastic particles leach into the liquid and subsequently into the human body (Jabeen et al., 2017; Shruti et al., 2020; Schymanski et al., 2018).

Another source of potential microplastic consumption is fruits and vegetables. According to studies, apples may be among the most contaminated (Karami et al., 2017). Various amounts of microplastics have also been identified in honey, sugar, dairy products, and eggs. This underscores how practically impossible it has become for humans to avoid exposure to plastics and how significant of a problem it has become.

Consumption of seafood and fish also represents one of the pathways of human exposure (Shruti et al., 2020; Kadac-Czapska et al., 2023; Alma et al., 2023).

An important source through which small plastic particles enter the human body is table salt. The salt production process involves the purification of seawater, which, due to environmental pollution, is already contaminated with microplastic particles (Woo et al., 2023). Studies have confirmed the presence of microplastic contamination in table salt in Europe, Asia, and America (Karami et al., 2017). Plastics, as previously mentioned, are extensively utilized in the food industry for packaging production. A distinct advantage is their low production costs, coupled with their lightweight and durable nature. Consequently, their widespread use unfortunately leads to the infiltration of various amounts of microplastics into packaged food products (Jadhav et al., 2021; Aslam et al., 2023; Kadac-Czapska et al., 2023). The release of plastic particles can occur during contact with food both during its production and during packaging and transportation (Jadhav et al., 2021; Aslam et al., 2023; Kedzierski et al., 2020; Hernandez et al., 2019). Containers, bottles, films, and bags are commonly made from high-density polyethylene (HDPE), low-density polyethylene (LDPE), polypropylene (PP), polyethylene terephthalate (PET), and polystyrene (PS) (Jadhav et al., 2021; Kadac-Czapska et al., 2023).

Human exposure to microplastics also occurs through inhalation. Their presence has been detected in both indoor and outdoor air environments (Hirt et al., 2020; Alma et al., 2023). Fragments and fibers of polypropylene (PP), polystyrene (PS), and polyethylene terephthalate (PET) have been identified in the atmosphere (Woo et al., 2023; Karami et al., 2017). Their suspension in the air makes the respiratory system a key exposure route. It is believed that urban dust and particulate matter are among the primary contributors to such significant air pollution (Woo et al., 2023; Jenner et al., 2022). It is probable that only a fraction of inhaled microplastic fibers can be removed from the respiratory system, while the remainder may induce inflammation or damage to the airways. Therefore, understanding the importance of reducing exposure to plastics is crucial in current times, as it has become a global issue (Blackburn et al., 2022).

The human body also comes into contact with microplastics through the skin, primarily due to the presence of primary microplastics in everyday cosmetic products. These include facial cleansers, exfoliating scrubs, and toothpaste, which primarily utilize exfoliating properties. Microbeads are also used in anti-aging creams, shampoos, soaps, and sunscreens, further exemplifying the ubiquity of microplastics (Hirt et al., 2020).

5. Potential health impact of microplastics

Contamination with synthetic materials and their presence in oceans is becoming an increasingly significant issue. Plastic fragments, upon entering the natural environment, undergo numerous transformations there. This can occur under the influence of physical, chemical, and biological forces (Arthur et al., 2009; Fan et al., 2023; McGivney et al., 2020; Galloway et al., 2017). Once they reach the aquatic environment, their colonization by microorganisms begins rapidly (even within a few minutes or hours) (McGivney et al., 2020; Harrison et al., 2014). Subsequently, this colonization leads to the development of a biofilm on the surface of the plastics, which differs from that formed on natural substrates (Ragusa et al., 2021; McGivney et al., 2020; Harrison et al., 2014). Microbial colonization of microplastics can stimulate their transformation or degradation (McGivney et al., 2020; Dussud et al., 2018). It has been demonstrated that the biofilm on the surface of synthetic materials, serving as a reservoir for microorganisms, can also facilitate horizontal gene transfer among microorganisms. This process may involve, among other things, the exchange of genes conferring resistance to antibiotics. If acquired by pathogenic bacteria, these genes can contribute to significant negative consequences for human health (Wu et al., 2019).

A key concern associated with microplastic pollution is the potential health effects it may have on human health and life. What raises doubts is how little is currently known about the long-term effects of exposure to plastic particles. Therefore, identifying the consequences of this exposure and finding ways to prevent it has become a crucial task in modern times (Campanale et al., 2020; Vethaak et al., 2021). Considering the physicochemical properties of microplastics, those smaller in size are generally considered more hazardous to human health (Yang et al,. 2022; Ebrahimi et al., 2022). This may be due to research suggesting that the effectiveness of capturing microplastic particles by the respiratory or gastrointestinal epithelium likely increases as the size of these particles decreases (Vethaak et al., 2021).

The adverse effects of microplastics on the body can be divided into three categories: physical, biological and chemical [Fig. 3]. The former depends on the physical properties of microplastics, including their shape and size. The latter depends primarily on various chemical substances that these microplastics may contain. These substances can include chemicals absorbed from the environment or intentionally added during plastic production to impart and/or enhance specific properties, including increased resistance to degradation (Campanale et al., 2020). A significant portion of health hazards associated with plastics may arise from exposure to these toxic additives (Landrigan et al., 2023).

The extent of exposure and the potential impact of plastics on various tissues and organ systems are becoming increasingly concerning and raise questions about the health of the entire human population. The smaller the particle, the greater the chance of it reaching other areas of the human body. For example, particles ≤ 10 μm are primarily capable of passing through cell membranes (Barceló et al., 2023; Zurub et al., 2024).

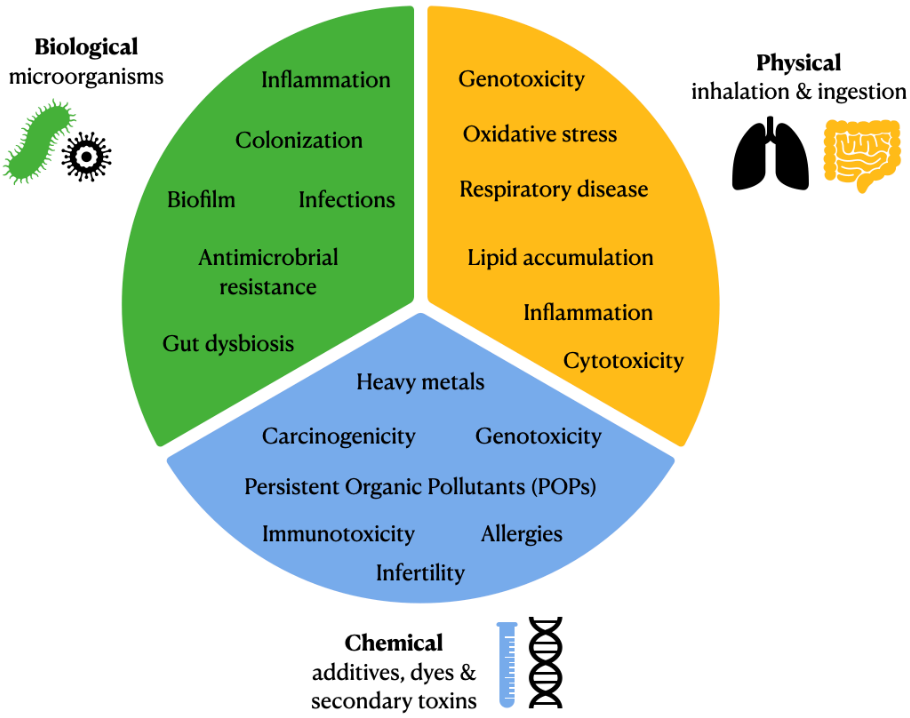

Fig. 3 Potential human health effects (Fig. own inspired by Blackburn et al., 2022).

6. Detection of plastic in human biological samples

Microplastics have been isolated from various human biological samples, including blood, urine, feces, sputum, and breast milk (Barceló et al., 2023; Sorci et al., 2022; Jenner et al., 2022; McGivney et al., 2020; Galloway et al., 2017). Absorption of microplastics, whether through ingestion or inhalation, can lead to diverse reactions. Microplastics in the human body can induce various effects, such as inflammation, oxidative stress, cell apoptosis, immune system reactions, as well as other physical damage and disruptions in cellular metabolism (Yee et al., 2021; Qiao et al., 2019). After absorption in the intestines, microplastics can enter the bloodstream and then accumulate in organ tissues such as the liver and kidneys. Accumulation of microplastics has also been identified in the spleen and colon. Microplastics can also settle in the lungs, leading to the development of inflammation. The smallest plastic particles can penetrate the brain and even cross the placenta to reach the fetus. According to the latest reports, they essentially reach all organs. Besides the circulatory system, they are also capable of entering the lymphatic system (Barceló et al., 2023; Shruti et al., 2020; Jenner et al., 2022; Harrison et al., 2014; Gautam et al., 2022).

The threat associated with microplastics has begun to gain socio-demographic significance. It has been demonstrated that exposure to microplastic particles may affect male fertility, hindering the possibility of conceiving a child by significantly impacting semen quality (Barceló et al., 2023; D’Angelo et al., 2021). Microplastics can also penetrate the placenta and accumulate there. Its presence has been confirmed in both natural childbirth placental tissue and cesarean section deliveries (Ragusa et al., 2021; Yee et al., 2021; Jung et al., 2022; Braun et al., 2021).

It is crucial to note that some compounds found in microplastics are considered endocrine-disrupting chemicals (EDCs), which can affect the functioning of the endocrine system and alter it, thereby also affecting other systems. The consequences of chronic exposure to these compounds can be harmful and should not be underestimated (Yang et al,. 2022; Vandenberg et al., 2017). These substances can disrupt the synthesis, secretion, transport, and elimination of natural hormones necessary to maintain organismal homeostasis (Landrigan et al., 2023; Yilmaz et al., 2020). Endocrine-disrupting compounds may pose a particular threat to pregnant women, as they can pass through the placenta. In this way, they may negatively impact the child's development, for example, by accumulating in their brain tissue, which can have various negative effects (Landrigan et al., 2023; Denuzière et al., 2022).

7. Emerging contaminants: plastic additives and microplastics

Chemical substances routinely used in the production of plastics include Bisphenol A (BPA), a synthetic compound (C15H16O2) exhibiting significant estrogenic activity. It has been shown that BPA can disrupt the normal functioning of the human hormonal system, as its entry into the human body, for example through ingestion or inhalation, can significantly harm health (Yang et al,. 2022; Campanale et al., 2020; Braun et al., 2021; Vandenberg et al., 2017). This substance has been approved as "of serious concern," and studies have shown its association with reproductive system disorders and breast cancer (Campanale et al., 2020; Braun et al., 2021). It is worth mentioning that women working in factories involved in plastic production show a significantly increased risk of breast cancer and reproductive system diseases. This demonstrates that exposure to plastics and the substances added to them indeed has health consequences (Landrigan et al., 2023; Dematteo et al., 2013). There is also a correlation between the level of exposure to BPA during pregnancy and reduced offspring birth weight (Yang et al,. 2022; Miao et al., 2011). A high level of Bisphenol A may also be associated with a higher risk of obesity in humans (Yang et al,. 2022).

In addition to BPA, other compounds in plastics, such as phthalates, which are also toxic additives, may negatively affect the reproductive system (Landrigan et al., 2023; Gore et al., 2015).

Inhaled microplastics can also harm the respiratory system, accumulating in lung tissue and prompting inflammatory responses that can result in acute and chronic respiratory ailments (Yang et al,. 2022). Plastic particles can accumulate on the surface of lung alveoli or penetrate further into other organs and systems. Their presence in the lungs can lead to tissue damage (Yee et al., 2021).

Individuals already suffering from respiratory system disorders and those working in plastic production facilities are more susceptible to the development of respiratory diseases, including interstitial lung diseases. In addition to exposure through current environmental contamination with microplastics, they have additional strong exposure to these compounds (Yang et al,. 2022; Campanale et al., 2020; Vethaak et al., 2021). The accumulation of plastic particles in lung tissue may be influenced by their physical properties, such as size, surface charge, or hydrophobicity (Yee et al., 2021).

Many additives used in plastics or in their production exhibit neurotoxic effects. Young children are particularly vulnerable to damage induced by these substances, as their brains are developing rapidly. Consequences may include neurodevelopmental disorders and decreased cognitive functions (Landrigan et al., 2023; Casey et al., 2000). Significant prenatal exposure to phthalates may, for example, be associated with an increased risk of autism spectrum disorders in children. There is also talk of increased recognition of ADHD in children of mothers exposed to phthalates during pregnancy (Landrigan et al., 2023; Ejaredar et al., 2015). Styrene has been recognized as a probable carcinogen, also exhibiting neurotoxic properties (Landrigan et al., 2023).

Additionally, an escalation in the incidence of various diseases has been observed in individuals working in facilities involved in plastics production, showing increased exposure to microplastics. For instance, among men working in vinyl chloride polymerization, there is increased mortality due to brain cancer, liver hemangiosarcoma, and malignant tumors originating from connective tissue (Landrigan et al., 2023; Creech et al., 1974).

Considering the constantly growing amount of waste and pollution derived from plastics in the present days, it has become crucial to understand the impact of microplastics on the human body. The associated threats continue to grow, and to prevent them adequately, it is essential to thoroughly understand them and take all necessary actions to mitigate this situation (Yang et al,. 2022; Sorci et al., 2022; Jung et al., 2022).

8. Current legal regulations

On October 16, 2023, new EU regulations came into effect aimed at limiting the use of microplastics and their release into the environment. The regulation applies to entities introducing synthetic polymers into circulation. The restrictions will help limit the sale of products intentionally containing plastic particles.

Bans will be phased in gradually and will cover microplastics found in products such as: exfoliating scrubs, glitter (as of October 16, 2023), rinse-off cosmetics such as shampoos, shower gels (October 2027), cleaning agents, detergents, pastes (October 2028), cosmetics remaining on the skin, hair such as creams, gels, hair pastes (October 2029), fragrance products (October 2029), makeup cosmetics, nail polishes (October 2035). The regulation also introduces changes to the granules used for filling sports surfaces (Rozporządzenie Komisji (UE) 2023/2055).

Regulations aimed at reducing the negative impact of microplastics are also being implemented in European Union countries. Similar steps are also being taken by other nations. Table 1 presents countries where the use of plastic particles in various products is prohibited (Lee et al., 2023).

Tab. 1 Legal status regarding regulations or bans on the use of microplastics at the national and international level (Lee et al., 2023).

Country	**Effective date (year)**	**Regulations**
USA	2014	Prohibition on the utilization of microplastics in cosmetics (Illinois)
	2015	Ban on the use of microplastics in personal care products (California, New Jersey, New York, etc.)
Canada	2016	Prohibition on the use of plastic particles in cleansing and exfoliating products
New Zeland	2018	

Northern Ireland	2019	Ban on production and sale of cosmetics containing plastic particles
Italy	2020	
Great Britain	2021	
Sweden	2019	Changes in the law regarding plastic particles in personal hygiene products
Taiwan	2020	
South Korea	2017	Implementation of ban on the use of microplastics in cosmetics
	2019	Preparation of tests enabling the detection of plastic particles by the Ministry of Food and Drug Safety in Korea
	2021	Detailed regulations regarding household chemical products (detergents, air fresheners, bleaches, fabric softeners)

9. Summary and conclusion

Microplastics are pervasive pollutants found in diverse ecosystems, posing significant environmental and health risks. Their small size and widespread distribution allow them to infiltrate water, soil, air, and food chains, impacting both wildlife and human populations.

Current research highlights the urgency of addressing microplastic pollution through improved waste management, reduction of plastic production, and development of innovative mitigation strategies. Research on microplastics is one of the fastest-growing fields in science, with an increasing number of studies focusing on their impact on human health. Scientific reports highlight the dangerous consequences of environmental contamination by these very small plastic fragments. However, more studies are needed to analyze a large number of samples to maximize the representativeness of such findings.

To standardize databases, NOAA NCEI was established (Nyadjro et al., 2023). The application created by this organization contains information on the occurrence, distribution, and quantity of microplastics worldwide. However, this information only includes microplastics found in the marine environment. Current research shows that more than this database is needed, as microplastics have been detected not only in oceans but also in soil, groundwater, and food products (Nyadjro et al., 2023; Woodard et al., 2016). Therefore, a step that should be taken is the creation of expanded databases that encompass every ecosystem, enabling a comprehensive understanding of the presence of microplastics in our surrounding world.

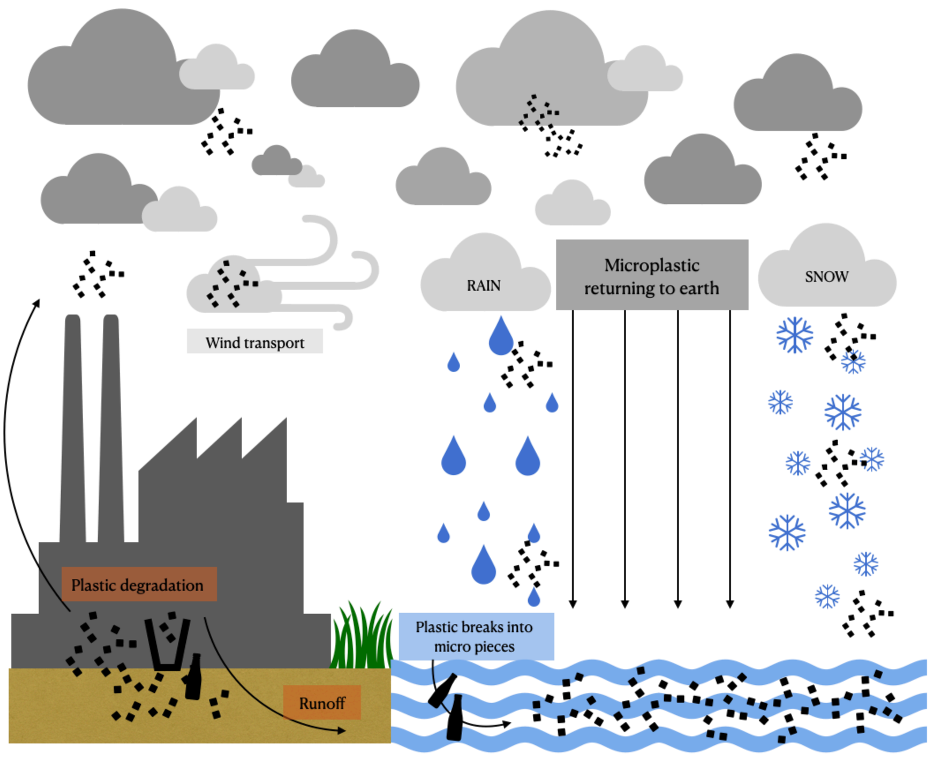

Fig. 4 Cycle of microplastic pollution (Fig. own).

As shown in Fig. 4, the microplastic pollution cycle affects all ecosystems, including land, water and air, so it poses an extremely high threat to fauna and flora, including humans. To reduce environmental pollution by microplastics, it is essential to increase awareness and education, promote recycling, implement sustainable waste management practices, and introduce biodegradable materials.

Author's contribution: Conceptualization: EK; methodology: KA, AS, WW, MK; check: KB, EK; investigation: KA, AS, WW, MK; resources: KA, AS, WW; data curation: KA, AS, WW, EK; writing – rough preparation: KA, AS, WW, MK; writing– review and editing: EK, KB; visualization: EK supervision: EK, DGD; project administration: DGD.

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