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Posted Date: 2 September 2024

doi: 10.20944/preprints202409.0032.v1

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Microplastics and Their Impact on Human Health

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Abstract: Increasing awareness of the potential health risks associated with microplastics (MPs) presence in the environment has led to significant rise in research focused on these particles over the past few years. This review focuses on research on MPs presence and spread, pathways of exposure and toxicological effects on human health and legal framework related to MP challenges. Several research projects have aimed to assess their potential harm to human health. Toxicological effects have been noticed at high concentrations of MPs, specifically polystyrene, the most widespread typical MP, but only short-term effects have been mostly studied. Significant quantities of consumed MP have been discovered to have diverse detrimental effects, posing a threat to human welfare. The exact concentrations of microplastics that are inhaled and swallowed and then build up in the human body are still not known. Further investigation is necessary to evaluate the impact of MP contamination at minimal concentrations and for prolonged durations.

Keywords: pollution; microplastics; nanoplastics; polypropylene; polyethylene; polystyrene

Introduction

Plastic pollution represents the accumulation in the environment of synthetic polymer materials and has become one of the most important threats to human health. The increasingly manufacturing of plastic materials and the lack of suitable methods of disposal just overwhelms the ability to deal with them. Even that we recognize the many uses of plastic materials, we need to be aware about the highly increased pollution and the health impact of these materials. The UN report from 2021 was mentioning that around 400 million tons of plastic are manufacturer each year (UN Environment Programme 2021). Furthermore, the same document is a living proof that the highest quantity of plastic was produced after 2000': $9.2x10^9$ metric tons of plastic are estimated to have been manufactured between 1950 and 2017, and out of these more than half has been produced since 2004. Even worst, each year, around 8 million tons of processed plastic are disposed into the ocean. Unfortunately, all these new materials contains additives (e.g., functional substances, colorants, reinforcement, fillers etc.) that can extend the life of products, with some estimates ranging to at least 400 years to break down.

Plastics persistence for extended periods can lead to contamination of multiple distinct environmental components, such as surface waters, sediment, ground waters, soils, and the atmosphere itself (Wang 2021, Fan 2022). The problem is compounded by their inadequate recycling, which, according to current estimates, only involves approximately 9% of plastic waste, meaning that the remaining 91% stays in the environment (Dong 2022). Out of the 30% of the produced plastics

 doi:10.20944/preprints202409.0032.v1

remain in use, resulting in the generation of around 6.9 billion tonnes of primary plastic waste around the world (Geyer 2020). This plastic waste is made up of 81% polymer resin, 13% polymer fibres and 32% additives. The environment currently contains various kinds of plastics, the most frequent of which are polyethylene (PE)>, polypropylene (PP)>, polystyrene (PS)>, polyvinylchloride (PVC)>, poly-ethylene terephthalate (PET), mainly the polymer categories also found in freshwater (Koelmans 2019).

The place where the plastic pollution reaches its peak is definitely the sea and the ocean of the Earth. It is estimated that the plastic litter that reach the oceans' water originates from the rivers, carrying more than 2 million tons of MP each year (Sarkar 2020). Once these materials arrive in the water, they are exposed to different process like UV radiation from the sunlight, air exposure from the wind and, of course water contact. All these actions will determine the degradation of these materials into small particles, having a dimension of less than 5 mm which are named *microplastics* (MP) or less than 1 µm which are name *nanoplastics*. Furthermore, these particles break down into even smaller particles that are these days spread everywhere: environment, water, air, even including our human body (blood, lungs, even faeces). These materials persist in the environment for extended periods, hence their widespread presence in the ecosystems worldwide (Alimi 2018). Although unable to absorb larger size microplastics, most plants and organisms living in the soil can easily do so, thus threatening the natural world (Ma 2013). Soil is the primary component of all terrestrial ecosystems, serving as a crucial source of vital nutrients for plant development, decomposition of plant matter, and transportation of biomass. Soil plays a crucial role as a natural buffer in the movement of chemical elements and compounds in the atmosphere, hydrosphere, and biota (Nedelescu 2018). To improve the effectiveness of how cells absorb nanoparticles and gain a deeper understanding of the physiological process, it is crucial to study the specific mechanisms by which nanoparticles interact with cell membranes.

Taking all these in consideration, the present narrative review aims to show the importance of human acknowledgement about the importance of decreasing the high rate of plastic pollution. This uncontrolled phenomenon led to presence of microplastics in the environment, which further negatively impact our health. Also, we explained the path exposure to these materials and the impact that they have on our health.

Plastic—Life Process and Degradation

The life of plastic materials starts with raw materials extraction, which is further processed, shaped, moulded in different forms and shapes so we can have in the end the final product that we further use (Figure 1).

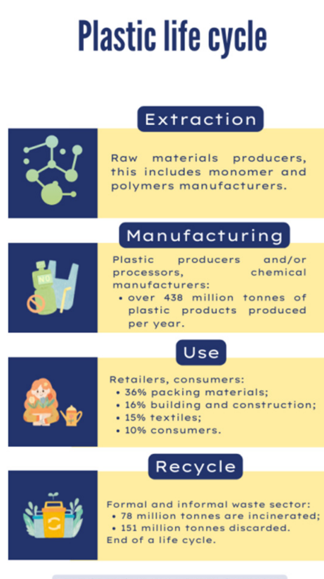

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Figure 1. Plastic life cycle.

This cycle should end with the collection of the plastic waste that should, after this, enter into a friendly environment recycling process. Unfortunately, the re-enter of plastic into a second life-cycle is not increasing with the amount of plastic materials manufacture. Arthur Zuckerman presented in his article from 2020 that more than 33% of waste in high-income countries end up in open dumpsites, and United States of America produces the most trash around the world. On the other hand, Germany has the highest recycling rate of any country in the world at 66.1% (Zuckerman 2013). Based on the statics we found, the top 10 countries with highest recycling rate are: Germany, Singapore, Wales, South Korea, Austria, Taiwan, Slovenia, Belgium, Switzerland, and The Netherlands (Figure 2).

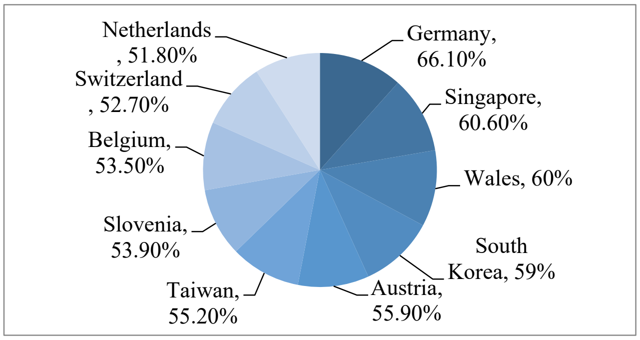

Figure 2. Top 10 countries with the highest recycling rate.

From a chemical point of view, plastic is a composite material with a matrix based on synthetic or semi-synthetic polymers. Polymers are molecules of considerable size (macromolecules) with a molecular weight in most cases in the range from 104 to 106, built by repeating monomer residues. Plastic degradation process can be classified by two major types: physical degradation (that refers to structure changes) and chemical degradations (that refers to molecular changes—cleavage of chemical bonds in the main chain of a macromolecule) (Chamas 2020). Usually, the second type of degradation involves either hydrolysis or oxidation (Figure 3).

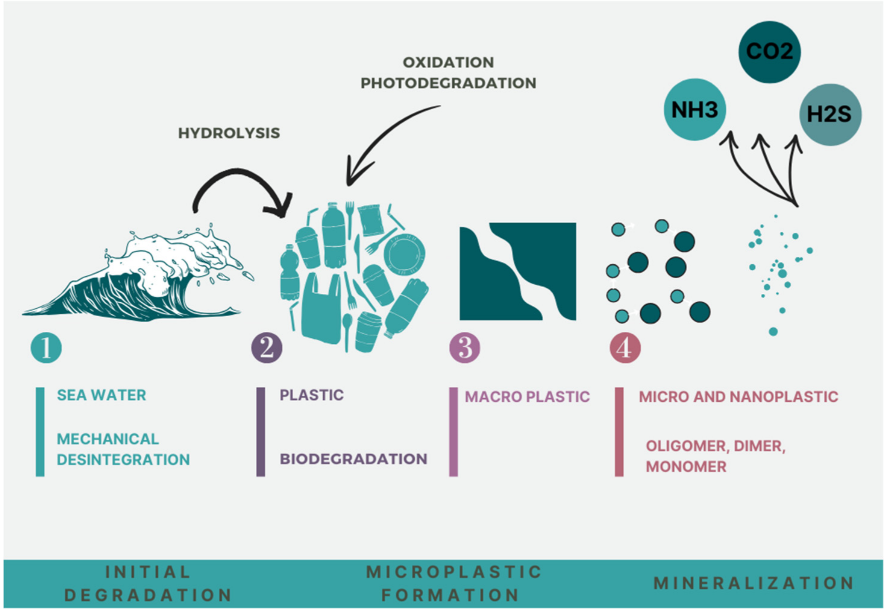

Figure 3. Plastic from water sources degradation pathways.

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However, both mechanisms may be accelerated by microbes, heat, light or any combinations of those. The results of these processes are the micro- and nanoplastic particles.

Depending on their original shape, degradation processes taking place on the plastic exterior, and their persistence in the surrounding environment, microplastics can be found under multiple forms, such as fibres, fragments, spheres, beads, films, flakes, pellets, and foam (Zhang 2021).

Microplastics—Existence and Over-Abundance

The presence of microplastic pollution in the marine ecosystems was first described in the 1970s, when spherical, disk-shaped, and pellet-like particles were discovered on the surface of the Sargasso Sea, along the shores of New England, and in surface waters of both the Atlantic and Pacific Oceans (Carpenter 1972, Colton 1974, Wong 1974). Taking into account that, on one hand, sea products (fish, shellfish and sea salts) are among the primary sources of human food (Walkinshaw 2020), and that, on the other hand, shellfish such as crustaceans and bivalves, as well as edible fish species are frequently subject to microplastic contamination, the marine environment has been extensively researched for microplastic pollution. Microplastics were found in oysters (average MP concentration: 0.33 ± 0.23 n/g), mussels (average MP concentration: 1.21 ± 0.68 n/individual), and Manila clams living on the Korean shoreline (Cho 2021).

The primary sources of MP contamination in aquatic settings are plastic wastes inappropriately disposed of on land. Additionally, though to a smaller extent, certain maritime activities such as the fishing industry also contribute to pollution with plastic equipment (Ricciardi 2021). Due to certain atmospheric phenomena such as winds, ocean currents, river outflows, and drift, atmospheric and land microplastic particles can be transported to distant regions. This is the basis for the recent inclusion of microplastics among airborne contaminants (Eriksson 2013, Barnes 2009, Ambrosini 2019).

In addition to sea waters however, research has currently been expanded to include the study of wastewater, rivers, and lakes (Wong 2020, Li 2020). Furthermore, Yanping Tan et al. presented in their study from 2023 that the major pollution sources of MPs in rivers are wastewater treatment plants, urban and industrial wastewater effluents, atmospheric deposition, and agricultural drainage (Yanping 2023).

As far as the presence of microplastics in the soil is concerned, the primary sources are plastic mulch films used in gardening, compost and municipal solid waste derived from large communities, the resulting bio solids such as anaerobic processes and sewage sludge, irrigation and flooding of wastewaters and atmospheric deposits. However, to have an actual picture of the sources of microplastic pollution of the soil, one should not overlook the illegal disposal of trash and use of plastic-coated fertilizers (Hurley 2018, Talvitie 2017). The annual quantity of plastics accumulated into the soil is considerably higher than the amount released into the oceans (Horton 2017).

In addition, we present some evidence of the amount of microplastic found as results of several studies that we were able to find during our research. This data explains that the concentration of MP found in rivers, seas, and oceans overflows the amount of fish, plankton and larval fish, approximately ~30:1 (Table 1) (Genevieve 2022, Converton 2019, Homin 2023).

Table 1. Microplastic contamination in different waters and their biota.

	MP conc. in water ($MP \times L^{-1}$)	MP conc. in sediments [$MP \times (kg\ dry\ mass)^{-1}$]	MP conc. in biota[b]		
Watershed	**Surface**	**Beach[a]**	**Fish**	**Birds**	**Frogs**
Lauretian Great Lakes, USA & Canada					
Lake Erie and tributeries	<0.001-0.032	50-391	70%	1.8-9.8	
Lake Ontario and tributaries	0.002-1.5	20-4270	50%	1.8-9.8	
Lake Michigan and tributeries	<0.001-0.007		0.19.1		
Milwaukee River	0.002-.017		4.5-6.5		
Canada (Baynes Sound,	0.69 MP/L (1 L				

Vancouver Island)	samples) and 0.12 MP/L (10 L samples				
Yangtze River Basin, China					
Three Gorges Reservoir	4.7-12.6				
Yangtze River Delta inland waters	0.5-21.5				0.17-3.51
Lake Taihu	0.53-25.8		0.2-17.2		
Lake Poyang	0.24-34		0-18		
Other					
Rhine River, Europe	0.005-0.022		0.2-1.0		
Rize inland waters, Turkey	1.0-13.0				124-489 x g^{-1}
Lake Victoria, Tanzania & Uganda	0.02-2.19		20%		
Melborne inland waters, Australia	0.03-1.7		0.7		

a—beach concentrations include samples taken in ares that are never, or only temporarily submerged. b—the concentration of MP is reported as numbers of particles perindividual; where data is not available, the presence of MP is reported as either the proportion of animals contaminated (%) or as the number of particles per gram of tissue (g).

Microplastics are formed as a result of multiple, distinct processes and they are subsequently relocated by various routes to different environmental areas. Thus, they penetrate the food chain and, ultimately, the human body. In this context, it should be noted that the estimated annual maximum human exposure is 6110 microplastic particles. Taking these processes in consideration the most often exposure route for humans is the contaminated food (especially fishes and other marine dishes). Food contamination can be attributed to factors related to the environment, such as the contamination of water, soils, and air. Additionally, production procedures, namely the use of certain materials during the milk filtration process, for instance, can also contribute to contamination (Diaz-Basantes 2020, Liebezeit 2013).

Microplastic contamination can also occur as a result of the packaging materials, including bottled drinking water, beer, milk, refreshments and takeout food containers (Shruti 2020). Furthermore, some studies have been published that focus on the presence of microplastic contamination in the salt for human consumption, even if we spoke of finished product containing MP or of contamination during manufacturing and processing (Peixoto 2019, Danopoulos 2020). Table 2 summarizes the findings related to studies conducted on various brands of sea salt from Europe (Karami 2017, Iñiguez 2017, Kim 2018, Renzi 2018).

Table 2. Strength and size of different types of MPs found in various sea salt brands from Europe.

Countries	Brand (number of brands examinated)	MP conc. (particles x kg^{-1})	MP type	MP size (µm)
Europe				
France (Atlantic Ocean)	6	0–2	PE, PET PP	160–980
Portugal	3	0–10	PET, PP	160–980
Spain (Atlantic Ocean)	4 (fine salt)	50–150	PE, PET PP	30–3500
	3 (coarse salt)	95–140		
Spain (Mediterranean Sea)	7 (fine salt)	80–280	PE, PET PP	30–3500
	2 (coarse salt)	60–65		
UK	1	120	PP, PE, PVC	100–2000
Bulgaria	1	10	Nylon, PE, PP, PVC	100–4000

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Croatia	5 (fine salt)	13500–19800	PE, PP	15–4628
	1	800	Nylon, PE, PET, PP	100–5000
Italy	6 (fine salt)	22–594	PE, PP	4–2100
	2	5–50	Nylon, PE, PET, PP	100–5000

PE—polyethylene, PP—polypropylene, PE—Polystyrene, PVC—poly(vinyl chloride), PET—polyethylene terephthalate.

Having in mind that salt is utilized in various food preservation techniques, such as the preservation of fruits, cheese, cereals, and beverages, depending on their chemical properties and affordability, as well as in the cosmetic and the pharmaceutical industries, its microplastic content is an obvious reason for concern. Therefore, the level of salt contamination with plastic micro- and nanoparticles is carefully evaluated by local and worldwide studies. These have shown that microplastic concentration in salt is significantly influenced by its source. As a result, correlated with the high level of plastic pollution of sea water, sea salt has the highest degree of contamination, followed by lake salt, rock salt, and well salt, in this order. As concerns the manner in which salt becomes contaminated with plastic particles, it should be noted that bulkier plastic objects are broken down and further turned into microplastics through all three types of environmental degradation (biological, photolytic and mechanical); thus, salt has been demonstrated to serve as a transporter of microplastics.

Contamination with plastic particles also affects fresh water, which is the primary source of potable water for human usage. It has been revealed that freshwater contains polyethylene (PE) and polypropylene (PP), which make up more than 90% of MPs in drinking water. Additionally, other materials often used for fabrication of various products, such as polyethylene terephthalate (PET), polystyrene (PS), polyvinyl chloride (PVC), polyester (PES), polyamide (PA), polytetrafluoroethylene (PTFE), and rubber (RY), have also been detected in freshwater. These polymers are also frequently used in the packaging materials employed in the food and cosmetic industries, household goods, and toys (Zhang 2020). According to the World Health Organization, tap water contains approximately 5 particles of microplastics per litre, meaning intake of a daily dose of 10 microplastic particles for each person drinking the recommended 2 litres of water per day (WHO 2019, Cox 2019).

Drinking water, sea food, fish, and food preserved using salt, use of plastic containers and textiles are not the only sources of plastic penetrating the human body. A further source refers to the technical advancements introduced in industrial milk processing, aiming to improve sanitary conditions and thus decrease potential harms to human health. This, however, has had significant impact on milk composition, which may introduce microplastics into fluid milk samples. The discharge of microplastics from milk consumption is a significant reason for concern, primarily considering that young children, the most vulnerable age group, are the main demographic category of milk users (Burke 2018). In addition, there is evidence that infant feeding bottles, typically composed of polypropylene, have the potential to leak microplastics into milk (Li 2020).

Fruits and vegetables have been found to contain microplastics as well (1.36-3.19 μm). The detected levels have been between 52600-307,750 particles/g for fruits and 72,175-130,500 particles/g for vegetables. Among the samples studied, apples and carrots were the most contaminated. The projected daily intake of microplastics from these fruits and vegetables ranged from 2.96×10^4 to 1.41×10^6 particles/kg/day (Conti 2020).

Pathways of Exposure of Human Body to Microplastics

Ingestion, inhalation, and skin absorption are the three pathways (Figure 4) via which microplastics can infiltrate into the human body and cause toxicity (Prata 2020).

- *Ingestion* seems to be the main route of exposure, taking in consideration the contamination of different food and water sources. Nanoparticles are prevalent across all levels of the food chain

 doi:10.20944/preprints202409.0032.v1

and have been detected in numerous consumer goods, including salt, sugar, honey, soft drinks, beer, milk, fruit, and water.

- *Inhaled* microplastics can cross the respiratory tract epithelium through diffusion, direct cellular penetration, or active cellular uptake (Wright 2017). If compared, it should be noted that the quantity of microplastics inhaled was 3 to 15 times greater than the amount ingested. Therefore, the human intake of MPs through ingestion is minimal in comparison to the overall exposure (Catarino 2018).
- Exposure to microplastics through *direct contact* with the skin is considered a less relevant pathway, but even so, epithelial cells experience oxidative stress when exposed to both micro- and nanoplastics (Schirinzi 2017, Valavanidis 2013).

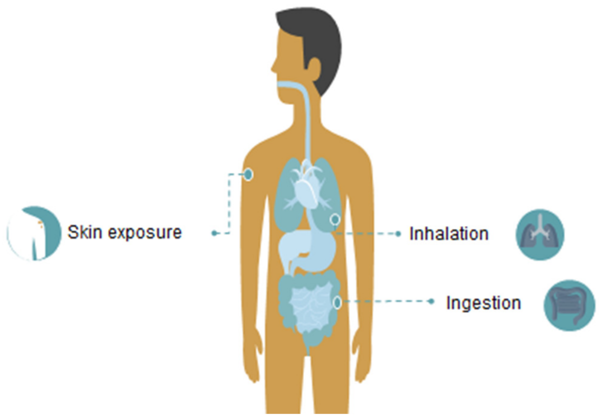

Figure 4. Pathways of human exposure of MPs**.**

In vitro and in vivo recent research has outlined the various toxicological profiles of exposure to pollution, specifically microplastics (Pironti 2021, Gualtieri 2005). Their toxic effect on organic cellular and molecular components (so far, mainly aquatic organisms, invertebrates and certain rodents, but humans as well) and the environment in general have been clearly demonstrated. Strong factors influencing microplastics harmful effects on human immune response and cytotoxicity are exposure time and pollutant size, dose and concentration (Yee 2021, Prata 2018, Kremer 1994).

In vivo studies carried out have shown the potential of microplastics to adversely affect organisms (Deng 2017). The first to be studied in that respect have been aquatic animals (Dris 2017), whose organism have been found to contain cotton and polymers such as nylon, ethylene-propylene, polyethylene, polypropylene, polyethersulphone, and polyester (Nelms 2019, Meaza 2019).

The source of pollutants bio-accretion in water animals lies not only in their specific diet but also in their characteristic, somatic features such as water-repelling surface and higher ratio of surface area-to-volume. Aquatic mammals are usually exposed to microplastic toxicity by skin, oral, intraperitoneal, subcutaneous, and intravenous routes (Isobe 2019, Fendall 2009, Andrady 2017). The route of exposure to microplastics strongly influences their degree of toxicity. Thus, direct contact is the cause of acute toxicity, whereas indirect contact though the food chain leads to organ chronic toxicity (Wibowo 2021, Campanale 2020, Baeza-Martinez 2022).

Next, distribution routes in aquatic organisms were studied, showing that microplastics are distributed mostly to the gastrointestinal tract, in the gills, and muscles, where they also accumulate (Farghali 2022, Huang 2021). Due to in vivo research, it has been shown that, in sea animals, microplastics adversely impact the physiology of their gastrointestinal tract causing, for instance, dysbiosis of intestinal microbiota, distorting healthy metabolism, villi cracking and enterocyte splitting, among other things. In addition, pollution may lead to depression of their immune system and detoxification carried out by means of the signalling pathways involving the c-Jun N-terminal kinases and extracellular signal-regulated kinases. Level of oxidative stress and general stress response also becomes higher, as revealed in intestinal tissues by altered glutathione concentrations and elevated superoxide dismutase and catalase amounts (Braniste 2010).

Cytotoxicity is also markedly increased and differential gene expression is affected as well. Furthermore, growth of sea organisms (invertebrates included) is clearly negatively influenced. These finding have been confirmed by outcomes of in vivo research performed on other organisms such as nematodes, earthworms, arthropods, and rodents. Among these, exposure of nematodes to microplastics has resulted in marked down regulation in gene expression with harmful effects on gamma-aminobutyric acidergic and cholinergic neurons. On the other hand, in mice, exposure to microplastics alters neurotransmission. Also in mice, microplastic tissue accretion has been shown to be size-dependent, significant accumulations occurring mainly in the kidneys and intestines (Hale 2020).

The above and other research findings revealing the harmful potential of pollution with microplastics on inferior organism have highlighted the imperative for human health of a sound understanding of human organism response to exposure to microplastic pollution, its sources and circulation (Akhbarizadeh 2018).

Main sources of microplastic exposure in humans are food contamination (with certain fish and seafood, particularly) and MP containing water consumption, as well as, though less impacting, skin contact or ingestion via the airways (Jin 2018, Bouwmeester 2015, Deng 2020). Based on the emerging importance of the impact of microplastics pollution on the human body, research has been intensified seeking mainly to elucidate its toxic potential of microplastics harm to humans. Therefore, epidemiological data lacking, in vitro studies have been performed. These have used human biological samples (e.g., sputum, meconium, faeces, colectomy samples, human placenta), and have demonstrated the accretion of microplastics (Messing 2021, Huang 2022, Acquavella 1988).

Such studies have focused on several types of human cells (among which dermal fibroblasts, pulmonary epithelial, peripheral blood mononuclear, the adenocarcinoma cell line), were studied in vitro to assess their adverse effects on the body. Thus, microplastics accumulations have been found in the human circulatory systems (Forte 2016, Garcia-Vazquez 2021). Although not extensive, existing research data have shown the prevalence of certain predominant microplastic contaminants as follows: high-density polyethylene in human faeces, polyurethane, polypropylene, polyethylene and polystyrene in the placenta and meconium. Presence of microplastic contaminants in colectomy specimens has been very marked.

Mass spectrometric analysis was performed to evaluate microplastic content such as polycarbonate and polyethylene terephthalate in faecal samples of adults and children. Contamination with 15 different microplastics has been shown in human faces samples used, indicating ingestion as route of exposure. The most frequent microplastic contaminants have been polyamide polyethylene and terephthalate. The amount of polycarbonate content was similar in both categories of samples, with children being however more susceptible to exposure because of their more significant interaction with microplastics in their daily activities (mainly objects used for drinking, feeding and playing) (Levermore 2020, He 2021).

Currently, research on presence of plastic polymers in faeces samples is challenging mainly because of the lack of standardized methods for their extraction and the difficulty of discriminating inorganic from organic material. In addition, extraction procedures also have to take into account the fragility of plastic particles, which are sensitive to high temperatures and potent chemical reactions. At present, extraction techniques involve digestion of faecal compounds such as lipids, proteins, bacteria etc., using various enzymes as well as NaOH, HNO_3, KOH or H_2O_2. For identification, Fenton's reagents have been suggested, whereas breakdown can be performed with ethyl alcohol and nitric acid. Residue on microplastic particles found may be cleaned using ethyl alcohol (Yang 2020).

Although a clear causal relation could not be established, a greater content of microplastics has been found in faeces samples from patients with inflammatory bowel disease, but the severity of the disease seems to grow with the presence of these contaminants. Presence of microplastics in saliva, sputum, and lung lavage fluid points to air exposure and inhalation. The air may be contaminated by several routes, one of which may be textile washing leading to leakage of microfibres into the water cycle, but also, even is less noticeable, direct release from clothing and other textile materials (Hou 2021, Amato-Lourenço 2021, Brown 2001).

However, one study has indicated the superiority of hair and skin samples in comparison to saliva with respect to indicating microplastic contamination in humans (Abbasi 2022, Goodman 2021). Examination of these biological samples has been found to trigger ROS release, resulting in altered cohesiveness, proliferation and metabolism of pulmonary cells. Data revealed by analysis for microplastic content in lung lavage fluid have confirmed the suspected potential of contamination with plastic particles to decrease and damage the lung function[86]. The number of plastic particles identified in these types of samples is significantly greater than those revealed in human faeces (21 as compared to 15), mostly polyurethane particles.

The presence of contaminant particles in the lungs and the airways can be identified using bronchoalveolar lavage fluid. This involves performing a scanning electron microscopy-energy dispersive spectroscopy and Fourier transform infrared spectroscopy on a saline solution previously instilled into the lungs (Hirt 2020).

The most revealing biological sample for contamination with plastic particles is the blood; not directly exposed to plastics and if extracted avoiding plastic instruments, it can show unadulterated level of contamination. In spite of this lack of direct contact with microplastics, methyl methacrylate, styrene polymers, polyethylene and polyethylene terephthalate have demonstrated bioavailability in blood circulation.

Fresh discovery of plastic particles in human placenta using Raman microspectroscopy has been a source of concern for the potential to affect in utero development (Cahng 2010). Careful sample examination in a strictly controlled environment to avoid cross-contamination of samples has identified 12 types of plastic particles.

A recent meta-regression analysis performed by Danopoulos et al. (2020) using secondary data resulting from various in vitro studies on human cells has revealed several categories of toxic effects of exposure to microplastics, i.e., genotoxicity and cytotoxicity, source of oxidative stress, increased/decreased immunological response, altered barrier functions, four of which have also been confirmed as direct effects of microplastics (Danopoulos 2020). Thus, immunological response affectation and cytotoxicity have been found to be in relation with microplastics irregular shapes. At the same time, studies of the adenocarcinoma cell line have clearly demonstrated the harm of microplastics on cell viability (Bouwmeester 2015).

In spite of all challenges related to the best methods, techniques and procedures for the extraction, preparation, conservation and analysis of biological samples used to identify microplastic contamination, future research is required to identify causal mechanisms as well as to confirm and continue investigation its harmful potential on human (Hale 2020, Guerranti 2019, Calero 2021). In addition, for optimum effectiveness in health practice, research has to be broadened with studies of human exposure to plastic particles and the related risk factors.

Microplastics in Urban Zones—Current Challenges

Reports have thoroughly documented the presence of plastic contamination in natural aquatic ecosystems spanning from tropical to Arctic regions. Nevertheless, the extent of microplastic fragments in drinkable water sources, such as water obtained from centralized distribution infrastructure, water that is bottled (such as spring water), the water from wells (groundwater used for diverse uses), and other refreshments consumed by people, is not adequately documented in comparison to natural water bodies. The widespread presence of microplastics in various forms of water, including groundwater, surface water, and wastewater, has prompted inquiries about the potential contamination of water for human consumption. Although drinking water is a significant component of the everyday diet as it provides necessary minerals and trace vitamins and nutrients, there is not a lot of information regarding the contamination of potable water by microplastics (Koelmans 2019). Moreover, the exposome reflects the impact that the environmental factors will influence the human health (Negrei 2023).

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Contemporary civilization is unavoidably reliant on polymers from plastic to such an extent that, up to now, plastics are the foremost sources of pollution on a global scale. MPs were found in numerous ecological matrix structures, especially drinking water sources designated for consumption by people such as rivers, lakes, and groundwater (Gambino 2021).

The process of microplastic fragment can be linked to several factors such as stress from mechanical contact, UV radiation, poor material quality, aging, and atmospheric accumulation. In addition to these, MP serves as a repository for a variety of chemicals and has the ability to keep additional intricate substances from its environment. This exacerbates the complexity of microplastic pollution and renders their precise detection in a singular method more challenging. Furthermore, a prevalent habit within communities involves the frequent and prolonged use of plastic water bottles and food containers, which leads to the release of microplastics and poses possible health risks to consumers (Muhib 2023).

In urban areas, the lifestyle has changed a lot in recent years, as well as the diet. A series of plastic products are used especially in the food sector, such as: bottles for drinking water or soft drinks, baby feeder, plastic tableware or food containers. Further in our article we summarized the impact that MP from different sources impact the human and animal health:

- Microplastics in water containers;
- Microplastics in water from pipes;
- Microplastics in food packaging.

Microplastics in Water Containers

The consumption of bottled water has experienced a significant explosion, over 6000 million gallons per year, in recent decades (Luo 2018). Bottled water is commonly used in several places worldwide due to its high level of cleanliness, natural flavour, and convenient portability (Salazar-Beltran 2017).

Although significant measures have been taken to guarantee the safety of bottled water, it is important to acknowledge the potential for the accumulation of microplastic during different stages of production and consumption, which cannot be disregarded (Guart 2014). The container's body and top are believed to be the likely sources of microplastic contamination in bottled drinking water. Researchers proposed that reusing plastic containers for water exhibit a higher level of microplastics compared to one-time-use and recently manufactured containers (Schymanski 2018). UV radiation from sunlight may additionally increase the absorption potential of plastic particles and their agents during the process of shipping and storing them. The researchers discovered that the water from the bottle exposed to sunshine has 326.2 microplastic particles per litre, whereas the bottled water not exposed to light involves a total of 180.7 microplastic particles per litre (Hadeed 2022). Light from the sun or ultraviolet (UV) radiation has the capacity to extract microplastics from beverage containers and lets them to spread into the beverage. The principals routes of plastic contamination originating from beverage containers: leaching, repeated washing, squeezing, thermos-degradation, industrial wash.

Bottled drinking water is packed utilizing glass as well as plastic constituents. Plastic containers are made up of PC (polycarbonate), PET (polyethylene terephthalate), and HDPE (high-density polyethylene). A total of 259 containers of mineral water were gathered from 11 zones and the researchers discovered that the polymer that was most plentiful in their study was polypropylene, and it was characterized by a fibrous structure. The mean concentration of microplastics among them ranged from 0 to 10,000 pieces per litre, with a mean of 350 units per litre (Manson 2018). Another study examined 11 prominent Iranian market packaged mineral water brands. Contamination with microplastics was found in 9 out of 11 brands, with the majority being in the form of fragments (93%). The mean amount of microplastics was 8.5 ± 10.2 pieces per litre. The predominant plastics identified

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in this research were polyethylene terephthalate (PET), polystyrene (PS), and polypropylene (PP) (Makhdoumi 2021).

Microplastics in Water from Pipes

The existence of waste plastic particles in water from the tap is caused by pollution in the system that distributes water, such as originating from either processing operations or from the pipes directly, or by textile water pollution.

Utilized granular activated carbon (GAC) is used to filter tiny particles of microplastic and it suggests having an efficiency range of 56-61%. A recent study analysed the plastic particles quantities in water supply systems and was concluded that the release of microplastics from pipes is a significant factor that should not be disregarded (Chu 2022). The most identified routes of plastic contamination originating from tap water: textile source, water treatment plant, pipeline, atmospheric source.

Microplastics in Food Packaging

The quantity of microplastics found in alimentary packaging is linked to the process of production and the sort of plastic used. The exaggerated utilization of plastic based packaging for food, baby feeders, throwaway glasses, and glasses presents the real danger of plastic particles leaching into aliments (Jadhav 2021). This problem could potentially be exacerbated since the COVID-19 epidemic amplifies the utilization of packaging made from plastic for the transportation of food. Additionally, a separate study indicated that a significant quantity of microplastics, numbering in the millions, may originate from plastic containers, single-use cups, or clear and flexible food containers when they come into contact with boiling water and food that is heated (Liu, Guo et al. 2022). The presence of hot water or hot meals may contribute to the movement of microplastics into the meal (Zarfl 2011). Supplementary research has demonstrated that bisphenol A (BPA), fluorescent components, and other substances that disrupt the endocrine system can also be released from plastic packaging, coupled with microplastics, when exposed to high temperatures (Hernandez 2019).

The presence of oil in fried food and the incorrect utilization of plastic wrapping, such as using it for micro-wave cooking or freezing, may result in the release of microplastics into the meal, hence elevating the potential for contamination by humans and associated risks (Liu, Wang et al. 2022).

Nevertheless, the comparatively smaller quantity of microplastics in tap water as compared to freshwater sources suggests an important level of elimination of MPs in drinking water treatment facilities.

Legal Framework Related to Microplastic Challenges

Since the issues related to microplastic pollution are growing larger and larger, and are impacting all types of environment, all over the earth, legal measurements need to be in place in order to protect and prevent the spread of these contaminants. Their persistence and pervasive nature lead to harmful impacts on wildlife, marine ecosystems, and potentially human health through the food chain. Addressing this issue requires comprehensive legal frameworks that regulate the production, use, and disposal of plastics, specifically targeting microplastic pollution. Such regulations are crucial for mitigating environmental contamination, protecting biodiversity, and ensuring the safety and well-being of current and future generations. Taking this in consideration, several legal bodies already implemented different measures to prevent the plastic pollution: international and national level. Further, we presented a short overview for each important legal body and their actions against plastic pollution.

a) United Nations Environment Programme (UNEP):

The United Nations Environment Programme plays a crucial role in addressing the global issue of microplastic pollution through various initiatives, partnerships, and publications. We mentioned below some of the most important actions conducted by UNEP related to microplastics:

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Global Partnership on Marine Litter (GPML): launched in 2012, the GPML is a voluntary multi-stakeholder partnership that aims to protect the global marine environment, human well-being, and animal welfare by addressing the global problem of marine litter, including microplastics. The GPML facilitates the coordination and implementation of activities to prevent and reduce marine litter (UN Environment Programme).

Clean Seas Campaign: this campaign (launched in 2017) aims to engage governments, the general public, and the private sector in the fight against marine plastic pollution. The campaign encourages commitments from various stakeholders to reduce the production and consumption of single-use plastics and to address microplastic pollution (Cleanseas).

Assessment Reports and Research: UNEP conducts and publishes comprehensive assessments on the state of plastic pollution, which includes also the challenge of microplastics disposed in the environment. These reports provide scientific evidence on the sources, pathways, and impacts of microplastics, guiding policy development and implementation (UN Environment Programme, Marine plastic debris&microplastics).

Furthermore, UNEP has established different important collaborations to grow the awareness related to plastic and microplastic pollution, to enhance the research and implement different projects that aim to reduce the pollution. Moreover, UNEP works with governments to develop and enforce regulations to control microplastic pollution.

b) European Union (EU)

EU is an important and active body that conducts different actions and projects to fight against the plastic pollution and improving the quality of our environment. For the past few years EU implemented different measures to help reduce the plastic pollution.

Directive (EU) 2019/904 on the reduction of the impact of certain plastic products on the environment (*Single-Use Plastics Directive*) (Directive EU 2019/904): this directive targets the reduction of single-use plastics, which are major contributors to marine litter and microplastics. It bans specific single-use plastic products for which alternatives are readily available (for example: cutlery, plates, straws etc.). It also mandates Member States to achieve a reduction in the consumption of single-use plastic products and to implement extended producer responsibility schemes to cover the costs of waste management and clean-up.

REACH Regulation: the EU's REACH (ECHA) (Registration, Evaluation, Authorisation and Restriction of Chemicals) regulation includes measures to control the use of intentionally added microplastics in products. In 2019, the European Chemicals Agency (ECHA) proposed restrictions on microplastics added to products (for example: cosmetics, detergents, and agricultural products). These restrictions aim to prevent microplastics from entering the environment by requiring that alternatives are used or that products are reformulated to eliminate microplastic content.

Marine Strategy Framework Directive (MSFD) (Directive 2008/56/EC): this strategy aims to achieve Good Environmental Status (GES) of the EU's marine waters and protect the resource base upon which marine-related economic and social activities depend. Furthermore, Member States are required to monitor and assess the impact of microplastics on the marine environment.

Circular Economy Action Plan (COM/220/98)*:* as part of the European Green Deal, the Circular Economy Action Plan aims to reduce waste and ensure that resources are kept in use for as long as possible. It includes measures to prevent plastic waste, promote the use of recycled plastics, and reduce the leakage of plastics into the environment. The European strategy of circular economy was adopted in 2018.

Furthermore, EU implements different research and innovation programs (for example: *Horizon 2000* and *Horizon Europe*) as well as education and awareness campaigns. Through these comprehensive measures and on-going initiatives, the EU aims to significantly reduce microplastic pollution, safeguard marine environments, and promote a sustainable circular economy.

c) European Food Safety Authority (EFSA)

The Organization has been actively researching and evaluating the potential risks of microplastic pollution, particularly concerning food safety. EFSA conducts risk assessments to understand the potential health impacts of micro- and nanoplastics in food. The focal point is the seafood since it is considered to be the major dietary source that is exposed to plastic pollution. The assessments concentrate on toxicity evaluation, level of exposure and health risks associated with the intake of microplastics. In 2016, EFSA published their scientific opinion over the presence of plastics (micro- and nanoplastics) in food, especially in seafood.

Over their research, EFSA established two major potential health risks associated with in the ingestion of microplastics: chemical contaminants (micro- and nanoplastics can absorb and transport different harmful chemical substances such as heavy metals, plastic additives and persistent organic pollutants) and physical effects (the presence of these chemicals in the gastrointestinal tract could cause inflammatory diseases or other severe adverse effects, although more research is need to strongly confirm these effects in humans) (EFSA Journal 23 June 2016, Silano 2019).

Unfortunately, EFSA also identified some major gaps in the current knowledge over the health impact of micro- and nanoplastics. For example, does still not fully understand the toxicological impact on the human body, the behaviour in the gastrointestinal tract and especially the long-term effects. Due so, we should prioritize the research and conduct multiple studies on the occurrence of microplastics in various foods, and also to study closely their toxicokinetics as well as the health impact of these contaminants.

However, EFSA advises caution but does not recommend specific dietary changes due to the uncertainties surrounding the health risks of microplastic ingestion. The authority continues to review new scientific evidence and update its guidance as more information becomes available.

d) U.S. Food and Drug Administration (FDA)

The U.S. Authority plays a major role in addressing microplastic pollution, particularly focusing on the safety of food, beverages, water, and cosmetics that may contain microplastics (Microbead-free waters act of 2015, Food&Drug Administration Site). The FDA collaborates with other federal agencies, academic institutions, and international organizations to conduct and support research on micro- and nanoplastics. This research aims to better understand the sources, prevalence, and health effects of microplastics in food and cosmetics, and also to gain knowledge on how to decrease the harmful potential that these contaminants have.

Furthermore, as other important international organizations, FDA is conducting periodically risk assessments in order to evaluate the impact of microplastic on human body, especially after contaminated food intake. These reports talk about different factors such as: concentration of contaminants in food and cosmetics, their chemical structure and composition and the risk associated with these contaminants. In the future, FDA is planning to develop and implement more specific regulations or guidelines to increase the safety of products that are under their jurisdiction. One good example is represented by the guidance issued to food and cosmetic industries on best practices for minimizing microplastic contamination. This includes recommendations for ingredient sourcing, manufacturing processes, and product testing.

Related to FDA findings and concerns, the Authority is continuously reviewing the health risks and exposure level of the population to microplastics. While studies have shown that microplastics can carry harmful chemicals and pathogens, the extent of their impact on human health through food and cosmetic exposure remains uncertain. The factors taken in consideration are: size, shape, and chemical composition of microplastics, as well as the likelihood of human ingestion or absorption.

FDA acknowledges the need for more research to determine the potential toxicological effects of microplastics and to develop standardized methods for their detection and analysis.

e) U.S. Environmental Protection Agency (EPA)

EPA has recognized microplastic pollution as a significant environmental issue and has been actively involved in research, monitoring, and developing strategies to address it. Taking this in consideration, the Agency conducts and supports research to understand the sources, fate and most important the effects of microplastics in the environment and human body. The focus is to understand how microplastics are transported and move through water, soil, and air, as well as their impact on different ecosystems and human health. The Agency identified various sources related to microplastic pollution including plastic debris breakdown, microbeads in personal care products, synthetic fibres from clothing, and industrial processes.

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EPA regulates pollutants under various laws that can apply to microplastic pollution, such as the *Clean Water Act* (CWA) and the *Resource Conservation and Recovery Act* (RCRA). Furthermore, EPA's *National Pollutant Discharge Elimination System* (NPDES) permits help control the discharge of pollutants, including plastics, into U.S. waters.

Also, during the past years EPA had issued some important reports and initiated programs, such as: *EPA research on microplastics* (research focuses on understanding the extent of microplastic pollution, its sources, and impacts), *Microbead-Free Waters Act of 2015* and *EPA's Trash-Free Waters Program* (EPA Trash Free Waters) (this program aims to reduce aquatic trash, including microplastics, through partnerships, policy development, and community engagement).

f) Organisation for Economic Co-operation and Development (OECD)

Another important legal body fighting against microplastic pollution is the OECD that addresses environmental issues, by promoting policies that improve the economic and social well-being of people around the world. The Organization conducts extensive research on plastic pollution (including micro- and nanoplastics), and publishes reports that provide insights into the sources, pathways, and impacts of microplastics on the environment and human health. Using these reports policy recommendations and effective policies to member countries is made. Furthermore, these documents serve as a basis for developing strategies to combat microplastic pollution.

The Organization studies the pathways through which microplastics enter and move through the environment, including their presence in marine and freshwater systems, soil, and the atmosphere. Furthermore, research supported by the OECD examines the ecological effects of microplastics on aquatic and terrestrial ecosystems which include assessing the impact on biodiversity, food webs, and ecosystem services. The OECD also investigates potential human health impacts, particularly through the ingestion of microplastics via food and water.

Taking in consideration their point of view, OECD focuses also on the economic impact of microplastic pollution, including the costs associated with clean-up, loss of ecosystem services, and public health expenditures. The Organization evaluates the effectiveness of existing policies and regulatory frameworks in member countries and provides recommendations for improvement.

As the other prior mentioned Organizations, OECD collaborates with international organizations, such as the United Nations Environment Programme (UNEP) and the European Union (EU), to address microplastic pollution on a global scale. This collaboration involves sharing research findings, harmonizing methodologies, and developing coordinated strategies. The OECD engages with a wide range of stakeholders, including governments, industry, non-governmental organizations, and academia, to develop and implement effective strategies for reducing microplastic pollution. Public-private partnerships are encouraged to drive innovation and investment in sustainable solutions.

Last, but not least OECD has published several important reports, such as OECD *Report on Microplastics in Water* (OECD 2021) (an overview of the sources, pathways, and impacts of microplastics in water bodies), *Policy Highlights on Plastic Waste and Recycling* (OECD 2018) (insights into the challenges and opportunities associated with managing plastic waste; this includes recommendations for reducing microplastic pollution through improved waste management and recycling practices). Moreover, The OECD promotes the concept of *Extended Producer Responsibility* (OECD 2024) (EPR), which holds producers accountable for the end-of-life management of their products. EPR schemes can help reduce plastic waste and microplastic pollution by encouraging more sustainable product design and production practices.

The OECD plays a vital role in addressing microplastic pollution by conducting research, providing policy recommendations, and fostering international collaboration. By promoting sustainable practices and encouraging innovation, the OECD aims to mitigate the environmental and health impacts of microplastics and contribute to global efforts to reduce plastic pollution.

The concerted efforts of global organizations and legal frameworks highlight the critical importance of addressing plastic pollution, particularly microplastics, due to their pervasive environmental and health impacts. The United Nations Environment Programme (UNEP) drives international cooperation and policy-making, emphasizing a global approach to combating plastic

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pollution. The European Union (EU) implements comprehensive regulations such as the Single-Use Plastics Directive and the REACH Regulation to reduce plastic waste and promote a circular economy. The U.S. Environmental Protection Agency (EPA) and Food and Drug Administration (FDA) focus on research, monitoring, and regulating contaminants in food, water, and cosmetics, while the Organisation for Economic Co-operation and Development (OECD) provides extensive research and policy recommendations to member countries. Collectively, these organizations and legal frameworks aim to mitigate the environmental and health risks of plastic pollution through research, regulation, innovation, and international collaboration. Their actions underscore the urgent need for sustainable solutions and effective management practices to safeguard ecosystems and public health.

Conclusions

The build-up of plastic microparticles in the environment causes ecological damage and is one of the main results of plastic pollution. Furthermore, according to some studies, consumption of food and water from various sources are considered a significant contributor to the intake of microplastic particles. High amounts of ingested microplastics have been found to have various harmful consequences, representing a hazard to human wellbeing. The precise concentrations of microplastics that are inhaled and swallowed and subsequently accumulate within the human body still remain unknown. Insufficient data currently exist about the direct impact of plastic particles on wellbeing of people. Further studies should give priority on investigating the specific impacts of microplastics on human health, at concentrations that accurately represent real-world environmental exposure.

Author Contributions: Conceptualization, C.N., D.L.B., A.M.V, A.T., O.T.P., Y.M. and C.V.A.; methodology, C.N., D.L.B, A.T.; software, Y.M., C.V.A.; validation, C.N., D.L.B., A.M.V. and A.T.; formal analysis, C.N., Y.M.; investigation, D.L.B., A.T., C.N.; resources, A.M.V.; data curation, D.L.B.; writing—original draft preparation, C.N., A.M.V., O.T.P.; writing—review and editing, C.N., A.T.; visualization, A.M.V., O.T.P, C.V.A.; supervision, C.N., A.T.; project administration, D.L.B.; funding acquisition, C.N. All authors have read and agreed to the published version of the manuscript.

Acknowledgement: Publication of this paper was supported by the University of Medicine and Pharmacy Carol Davila, through the institutional program Publish not Perish.

Conflict of interest: The authors declare no competing interests. The authors alone are responsible for the content and writing of this article.

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