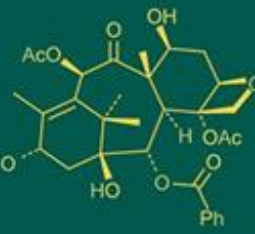
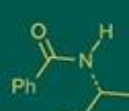
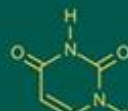
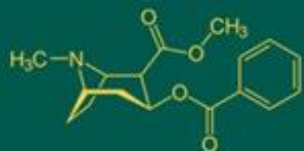


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Microplastics: The silent contaminants of our world

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Abstract

Smaller than five millimetres, the tiny fragments of plastic debris are referred to as microplastics and have emerged as a significant environmental contaminant. Because of their high bioaccumulation and resistance to breakdown, microplastics represent a serious environmental problem. Unfortunately, only a part of microplastics can be recycled, removed, or broken down; there is not enough technology available to entirely eliminate them. Moreover, it has been found recently that the fragmentation and degradation of poorly managed plastic wastes is one of the primary sources of microplastics in the environment. It can therefore be quoted here, "Microplastics may be tiny, but their impact is colossal unveiling the hidden crisis that's shaping our future." The review identifies critical research gaps and suggests innovative approaches for future investigation. In conclusion, the "little mighty" continue to have an enormous impact on our surroundings despite their seeming little size. As a result, we must act quickly to safeguard both our health and the environment.

Keywords: Millimetre, plastic, debris, pollution, environment

Introduction

According to the U.S. National Oceanic and Atmospheric Administration (NOAA) and the European Chemicals Agency Microplastics are fragments of any type of plastic, less than 5 mm (0.20 in) in length. Microplastics (MPs) considered an emerging environmental pollutant and have drawn a lot of attention because of the possible harm they could do to living organisms. The world's population growth has boosted plastic usage, which has increased garbage production and generation of microplastics. Plastic has permeated every aspect of our lives, from cleaning supplies to clothes, due to its low cost, high durability, and low weight. A significant amount of plastic trash, known as microplastics, and macroscopic plastic particles, known as big plastic wastes, are dumped into rivers and oceans. Tires, synthetic textiles, marine coatings, traffic signs, personal hygiene products, plastic pellets, and urban dust are the main sources of microplastics. Furthermore, home activities account for the bulk of microplastics with 77 percent and 23 percent of the industrial application, according to the most recent estimate of microplastics worldwide, there are 51 trillion particles, or 93-236 thousand tons, of microplastics floating on the ocean's surface due to the 79 per cent of plastic trash that is disposed of worldwide in landfills, soil acts as a major microplastic sink (Boucher and Froit, 2017)^[1]. The ability of plastics to break down into microplastics by weathering, such as mechanical, microbiological, or photodegradation, is one of the main issues and concerns surrounding plastics (Damaj et al 2024)^[2].

The two main sections of microplastics are Primary microplastics & Secondary microplastics. Primary microplastics are made specifically for use as drug vectors, cosmetic abrasives, and air blasting, among other industrial and engineering applications. Virgin plastic manufacture pellets, which are usually 3-5 mm in diameter, can also be classified as primary microplastics under the more expansive definitions of microplastics, despite some critics disputing this classification (Andrady, 2011; Costa et al., 2010)^[3, 4]. These plastics, which are commonly referred to as "microbeads" or "micro-exfoliates," can differ in size, shape, and composition based on the specific product (Fendall and Sewell, 2009)^[5]. Secondary microplastics are microscopic plastic particles that are released from bigger plastic debris during their disintegration, which can occur on land or at sea (Ryan et al., 2009; Thompson et al., 2004)^[6, 7]. Plastic waste can fragment as a result of a combination of physical, biological, and chemical activities that weaken its structural integrity over time (Browne et al., 2007)^[8]. Long-term sun exposure can cause plastics to photodegrade; ultraviolet (UV) light oxidizes the polymer matrix and creates link breakage (Andrady, 2011; Barnes et al., 2009; Browne et al., 2007; Moore, 2008; Rios et al., 2007)^[3, 9, 10, 11]. Additives intended to improve durability and corrosion resistance may leak out of the polymers as a result of this deterioration (Talsness et al., 2009)^[12].

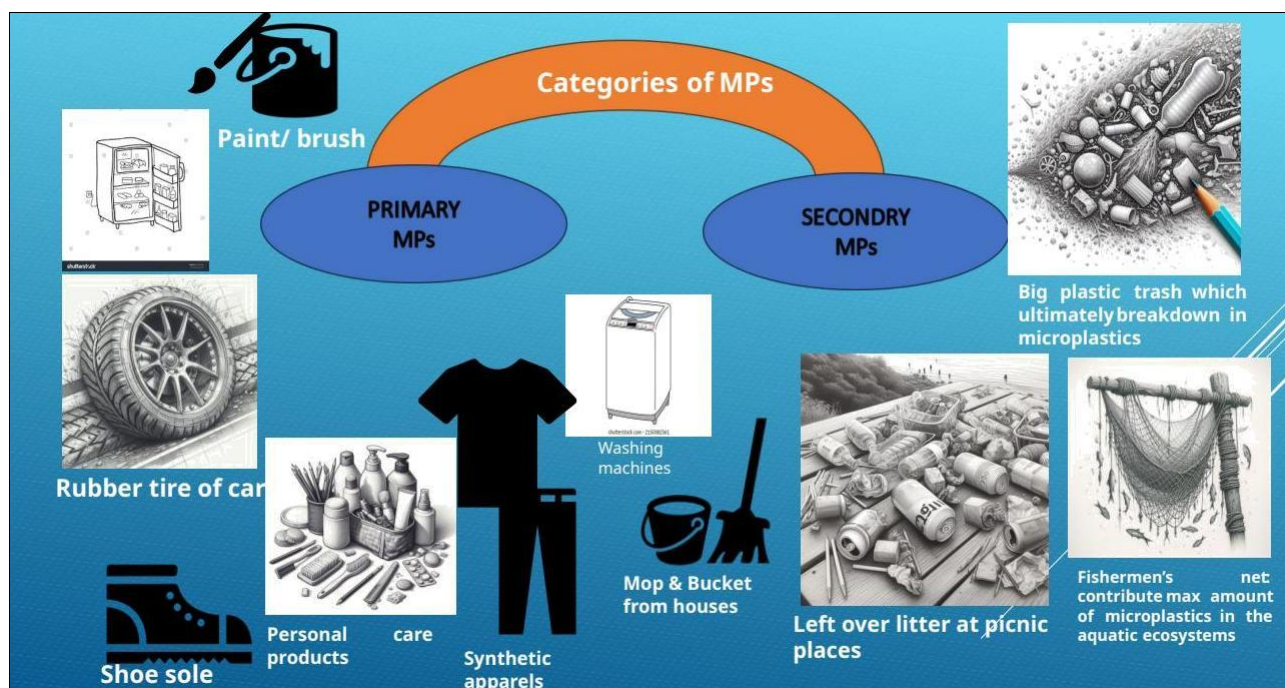


Fig 1: Sources of primary and secondary MPs

The number of plastic products produced annually worldwide was 460 million tons in 2019; just 9 per cent of these were recycled, by 2060, the amount is predicted to rise to 1.2 billion tons (OECD, 2022) ^[13]. Numerous plastics enter the environment as a result of high yield and poor recovery. Polypropylene (PP), polyethylene (PE), polyethylene terephthalate (PET), polystyrene (PS), polyvinyl chloride (PVC), and other common commercial plastics are available in the market (Andrady, 2011) ^[3, 14]. Microplastics have been found all the way to the Mariana Trench (Peng *et al.*, 2018) ^[15], the summit of Mount Everest (Napper *et al.*, 2020) ^[16], the north to the Arctic (Bergmann, *et al.*, 2022) ^[17], and the south to Antarctica (Aves, *et al.*, 2022) ^[18]. The predominant component of marine debris is plastic (Rellán, *et al.*, 2023) ^[19]. The amount of plastics that entered the ocean in 2017 more than eight million tons is more than 33 times the total amount that had accumulated there by 2015 (Peng *et al.*, 2020) ^[20]. One of the most important environmental problems of the twenty-first century is plastic pollution. "End plastic pollution: Towards an international legally binding instrument" is the historic resolution that was accepted by the United Nations Environment Assembly (UNEA) after it was considered (UNEP, 2022) ^[21]. Toxic effects and potential health risks associated with microplastics are difficult to identify in the real world due to their very complicated sources, diverse occurrences, and concealed hazards. One of the primary issues in assessing the potential health risks of microplastics to humans is the dearth of knowledge regarding the microplastics to which people are exposed (Vethaak and Legler, 2021) ^[22]. Research on the origin, prevalence, and toxicity of microplastics in the actual world is constrained by the qualitative and quantitative analysis techniques used (Ye *et al.*, 2022) ^[23].

Accession of microplastics into the biotic ecosystem: Through fresh water ecosystem:

Environmental factors like wind, waves, currents, and water density can affect the spread of microplastics. The main sources of microplastics are polymeric components found in cleaning

and cosmetic products, feedstocks used to make plastic products, and plastic powders used in air blasting (Jiang 2018) ^[24]. Microplastics can infiltrate the freshwater system and are primarily formed after macroplastics are destroyed, according to Morritt *et al.* (2014) ^[25]. The main sources of microplastics in freshwater ecosystems are run-off from land-based sources, air deposition, industrial effluent, drinking water production, distribution, and wastewater effluent (Cesa *et al.* 2017) ^[26]. Drinking water treatment creates a barrier against microplastics. Microplastic particles in drinking water are a result of the depletion of certain plastic materials used in treatment of plants (Mintenig *et al.* 2019) ^[27]. Additional sources of microplastic particles in drinking water include the bottles and their tops (Oßmann *et al.* 2018) ^[28]. Wastewater effluent is a well-known source of microplastics in freshwater and a crucial repository for these freely circulating microplastics (Horton 2017) ^[29]. Microplastics in rivers and coastal areas can be largely sourced from sewage treatment plant effluents. The primary local inputs into sewage systems are synthetic fibers from clothing and microbeads from cosmetics.

A wastewater treatment facility (WWTP) may serve as a microplastics' conduit. The microplastics exit the WWTPs by two routes: direct and indirect. Through the direct channel, a large quantity of microplastics are released into the environment through the wastewater from WWTPs. On the other hand, microplastics are discharged from WWTPs through an indirect pathway into sludge (Gatidou *et al.* 2019) ^[30], and this sludge is then applied to agricultural land as fertilizer (Sun *et al.* 2019) ^[31]. Certain microplastics may escape the filters of wastewater treatment plants and end up in receiving bodies of water. According to Murphy *et al.* (2016) ^[32], WWTP effluent contains 65 million microplastic particles every day. Microplastic contamination is a result of maritime activity through the discharge of paint and fishing equipment particles as well as the ocean's disposal of plastic garbage.

Wet and dry deposition as well as precipitation from atmospheric deposition have been identified as additional potential sources of microplastics in freshwater environments (Wright and Kelly 2017) ^[33, 34]. It transports microplastic

particles to far-off places, including as alpine and arctic regions, where they settle and contaminate the environment. The atmosphere can introduce microplastics into freshwater ecosystems through industrial and urban dust (Abbasi *et al.*, 2019)^[35]. This is an indirect source of microplastics in freshwater. Due to rainfall carrying plastic trash into stormwater drains from roadways, sidewalks, and urban surfaces, urban environments are a major source of microplastic contamination. The burning of waste, buildings, industry emissions, landfills, use of fertilizer, and traffic are the main sources of the microplastics in the air. Heavy metal-rich microplastics found in roadway dust are hazardous to freshwater ecosystems. It is yet unknown how industry effluents contribute to wastewater's microplastic contamination (Kooi *et al.* 2018)^[36]. Industrial microplastics have, nevertheless, been found in freshwater.

Through marine ecosystem

Eighty percent of the plastics identified in marine trash have a terrestrial origin (Andrady, 2011)^[3, 14]. Since about half of the world's population lives within fifty miles of the coast, there is a significant chance that these types of plastic will find their way into rivers, wastewater systems, or the ocean by being blown offshore (Moore, 2008; Thompson, 2006)^[10]. A significant amount of microplastics will pass through filtration systems used in waste-water treatment plants, which trap macroplastics and some small plastic debris in oxidation ponds

or sewage sludge. Microplastics are used in cosmetics as well as air-blasting media, and they can enter waterways through residential or industrial drainage systems (Derraik, 2002)^[37]. Numerous studies (Browne *et al.*, 2010; Moore *et al.*, 2002)^[38, 39] have demonstrated how plastic trash enters the ocean due to the high unidirectional flow of freshwater systems. Moore (2008)^[10] measured the amount of plastic particles smaller than 5 mm in diameter found in water samples taken in 2004-2005 from two rivers in Los Angeles, California, USA. The data that was obtained could be extrapolated to show that, in only two days, these two rivers alone would discharge nearly 2 billion plastic particles into the marine ecosystem. The movement of terrestrial debris from land to sea can be made worse by extreme weather events such hurricanes or flash flooding (Barnes *et al.*, 2009; Thompson *et al.*, 2005)^[9].

One of the most frequently observed plastic trash objects with a marine origin is fishing gear (Andrady, 2011)^[3, 14]. Since lost or discarded fishing gear, such as nylon netting and plastic monofilament line, is usually neutrally buoyant, it can drift in the water at different depths. Because of its innate potential to entangle marine biota a phenomenon known as "ghost fishing" this is especially troublesome (Lozano and Mouat, 2009)^[40]. According to estimates, the world's commercial fishing fleet poured over 23,000 tons of plastic packing materials into the ocean during the 1970s, making marine boats historically a major source of marine litter (Pruter, 1987)^[41].

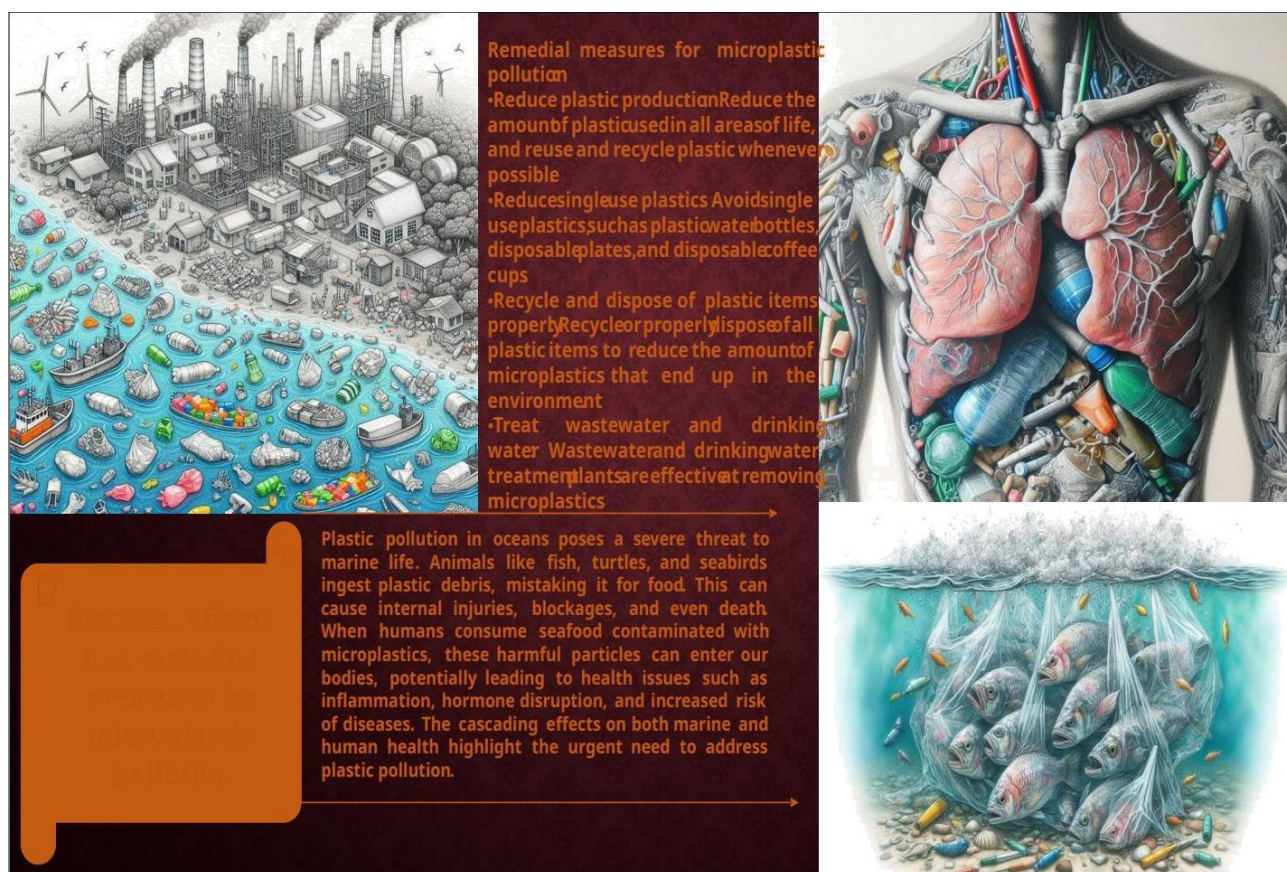


Fig 2: Graphical summary of the sources and effects of microplastics pollution

Humans ultimately depends on this contaminated aquatic ecosystem which leads to the entry of these "tiny particles" into their body that eventually accounts for the different ailments. Under the food chain, microplastics (MPs) from the sea enter marine creatures' diets, accumulate, and eventually affect people. As a matter of fact, there have been multiple reports of

microplastics (MPs) in food and the environment (Hartmann *et al.*, 2019; Barboza *et al.*, 2018; Karami *et al.*, 2017)^[42, 43, 44], mainly in seafood, sea salt, etc. Although the impact of plastics on human health is yet unknown, they frequently contain additives like flame retardants and stabilizers as well as other potentially hazardous chemicals that could affect an organism

if consumed (Groh *et al.*, 2019; Nor *et al.*, 2019) [45]. Human exposure to MPs is inevitable due to their widespread presence in the environment. There are three main ways that MPs can enter the body: food, inhalation, and skin contact. Once internalized, MPs can cross cell membranes. The body perceives them as foreign substances, leading to the production of localized immune responses (Schymanski *et al.*, 2018) [46]. The possible hazards that MPs offer to human health can give rise to discussion because of the uncertainty surrounding the amount, variability, and changes of MP exposure concentrations and the corresponding incorporation kinetics (Zhang *et al.*, 2020) [47].

Since food, water, and air all contain significant amounts of MPs, ingestion and inhalation are the most frequent ways that people become exposed. Bottled water is a common source of exposure, which could originate from the plastic container in which it is packaged as well as the water itself (Wright & Kelly, 2017) [33, 34]. A human consumption research found that each American consumes between 74,000 and 121,000 microplastic

particles annually (Smith *et al.*, 2018) [48]. The discovery of MPs in human feces provides compelling evidence that they were ingested through the food chain and came into contact with the stomach (Ilekis *et al.*, 2016) [49]. After being swallowed or inhaled and eventually entering the bloodstream, MPs can enter the lungs and gastrointestinal tract through procedures such as endocytosis and persorption (Jones *et al.*, 2020) [50].

To date, the human exposures to these MP/NPs have only been evaluated in a few investigations. A study predicted daily MP exposure to 203 particles for girls and 223 particles for males based on food and drinking water consumption in the United States. Moreover, for boys and girls, the sum of their estimated annual exposure to MPs from ingestion and inhalation results in roughly 81,000 and 74,000 particles · year⁻¹, respectively. However, there is no detailed description of the child population, thus it is assumed that all of the individuals are under the age of eighteen (Cox *et al.*, 2019) [51]. These numbers, though, might be "dramatic underestimates."

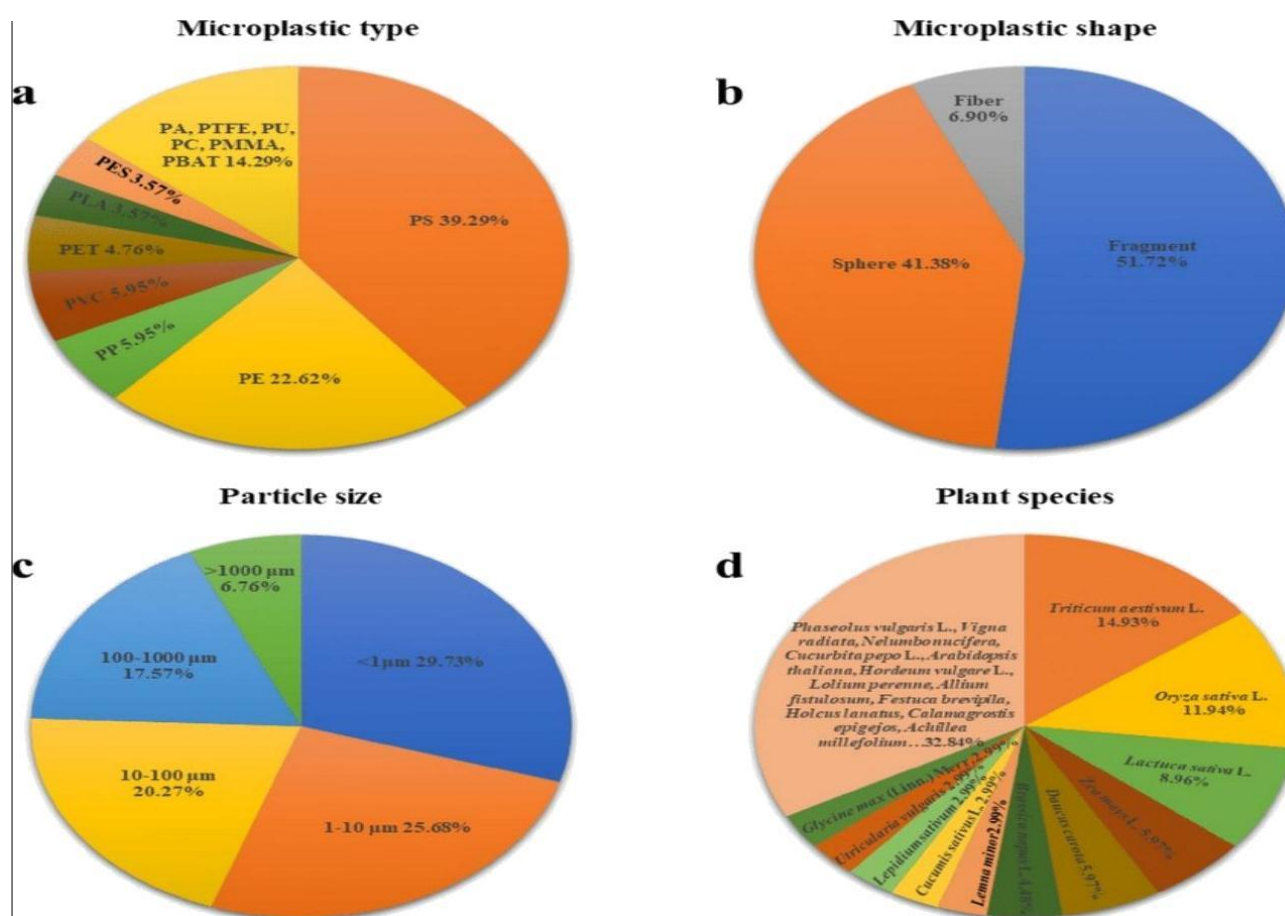


Fig 4: Statistical data of the tested microplastics (a type, b shape, c particle size) and plant species (d) Source: Li *et al.*, 2022

The estimates of MP consumption in the United States provided by Cox *et al.* (2019) [51] may be underestimated by at least 1×10^5 (Cox *et al.*, 2019) [51]. According to their findings, up to 52,000 MP particles can be taken annually by an average adult male calorie intake of 15 per cent; tragically, the remaining 85 per cent of calories cannot be directly linked to a particular number of MPs consumed. The authors determined the MP concentration in a variety of samples, including seafood, honey, salt, sugar, and water, using a variety of analytical techniques, such as Fourier-transform infrared spectroscopy (FTIR), inductively coupled plasma mass spectrometry (ICP-MS), Raman spectroscopy, and Rose Bengal stain.

The three main materials used to make most MPs that may be dangerous to people are polyvinyl chloride (PVC), polystyrene (PS), and polyethylene terephthalate (PET) (Rodrigus *et al.*, 2019). Through the release of chemicals that cause cancer, these plastics have been shown in laboratory experiments to negatively affect cell viability and activate the activation of inflammatory genes. Phthalates and bisphenol A are examples of endocrine-disrupting chemicals that can be found in plastics, including MPs. Human health problems such as epigenetic modifications, reproductive toxicity, insulin resistance, type II diabetes, obesity, skeletal abnormalities, allergies, asthma, and cancer have all been linked to these chemicals (Benjamin *et al.*,

2017)^[52]. The combination of various polymers and other chemicals that make up MPs/NPs may pose more serious health hazards (O'Neil & Lawler, 2021)^[53].

Routes for MPs in the Human Body

According to the research, there are three primary ways that MPs can be exposed: ingestion, which is the most significant and is estimated to result in annual intakes of 39,000- 52,000 mg per individual, cutaneous contact, and inhalation (Prata, 2018)^[54]. MPs have the ability to become integrated into tissues after being inhaled or eaten. They can avoid the epithelium in the digestive tract by diffusion paracellularly or by endocytosis processes, after which dendritic cells carry them into the

lymphatic and circulatory systems (Cox *et al.*, 2019)^[51]. As per the findings, MPs have the potential to accumulate within the body and inflict localized harm by intensifying or inducing immunological reactions, so impairing the body's resistance against infections (Wright & Kelly, 2017)^[33, 34].

These MPs may go from the respiratory or digestive systems into the placenta by means of paracellular or M-cell-mediated endocytosis pathways. Particle absorption and translocation which has already been defined as internalization from the gastrointestinal tract are the most likely modes of transport for MPs (Wright & Kelly, 2017)^[33, 34]. According to a recent study, MP concentrations in indoor air and dust (from houses and businesses) were higher than those outside (Ageel *et al.*, 2022)^[55].

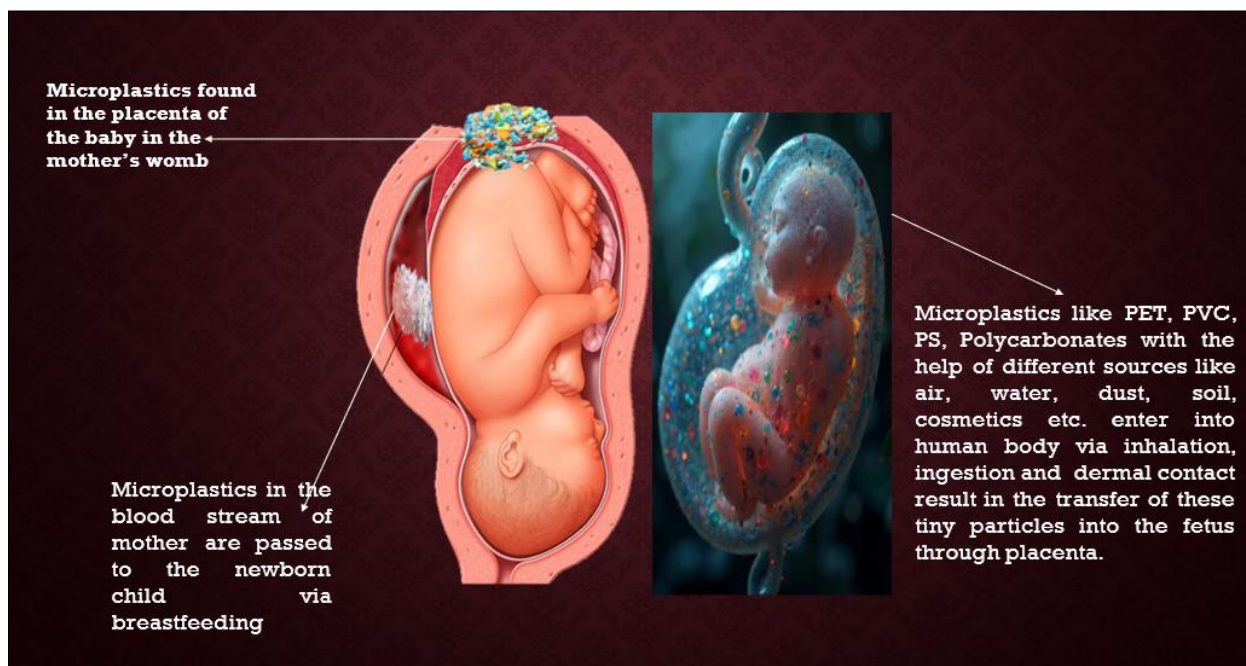


Fig 5: Transfer of microplastics from mother to the fetus through different modes

The following subsections will provide insight into distinct modes of transfer, including placental and breast milking, inhalation, ingestion, cutaneous contact, circulatory system, and brain.

a) Placenta and Breastmilk

Once MPs have reached the maternal side of the placenta, they can infiltrate the tissue deeply by a variety of as-yet-unknown active and passive transport mechanisms, just like other foreign molecules. Different physiological conditions and genetic features can influence the trans-placental transit of MPs, which are sized between 5 and 10 μm . This could provide an explanation for the different locations and characteristics of the particles discovered in the current study, the patients' varying food and lifestyle choices, and the fact that two of the six placentas studied in a previous study by (Ragusa *et al.* 2021)^[56] did not contain MPs. Cellular regulatory pathways that MPs may potentially alter in the placenta include nonconforming chemokine receptors that regulate communication between the fetus and the mother, motioning between the womb and the embryo, and the transfer of uterine immune cells like dendritic, natural killer, T, and macrophage cells during a characteristic gestation. Two adverse pregnancy outcomes that could arise from this are preeclampsia and fetal growth restriction (Smith *et al.*, 2018)^[48]. Breastfeeding should be as clean as possible

because breastmilk is the best nutritional standard for babies, giving them nutrients and bolstering their immune systems.

Braun *et al.* 2021^[57] confirmed the presence of MPs in the placenta, which represents interactions between the mothers exposed to the environment and the fetuses. According to recent studies, the presence of plastic particles in the circulation causes MPs to circulate throughout the entire body (Leslie, *et al.*, 2021)^[57]. Possible paths for foreign particles to travel from circulation to breast milk in the mammary glands include immune cell-dependent pathways and mammary epithelial cell-dependent pathways; the latter is more relevant for inhaled particles (Cai, *et al.*, 2019)^[58].

b) Inhalation

Inhalation has emerged as a key mode of human exposure to MPs due to the fact that MPs are routinely detected in high concentrations in both indoor and outdoor air (Ahmad *et al.*, 2023)^[59]. From a physiological perspective, MPs that are often found in the atmosphere interact with cells and lung fluid (Sethi *et al.*, 2019)^[60]. Chronic obstructive pulmonary disease (COPD), dyspnea, asthma, and other acute and chronic respiratory disorders can be brought on by inhaling MPs, which can set off inflammatory cascade reactions. Since that airway epithelial cells are the first line of defense in the respiratory tract, their loss of epithelial integrity is a crucial step in the development

of COPD (Dong, *et al.*, 2020)^[61]. Research suggests that human alveolar epithelial cells' absorption of polystyrene nanoparticles causes cellular toxicity, increased proinflammatory cytokine release, and disruption of tight junctions, all of which may be factors in the development of COPD (Xu *et al.*, 2019)^[62]. Inflammation and oxidative stress damage the epithelium, resulting in tight junction expression reduction and increased permeability, which ultimately leads to epithelial barrier failure (Dong, *et al.*, 2020)^[61].

In a meta-analysis of 26 research publications on human exposure to MPs, with a particular focus on the American population, Cox *et al.* (2019)^[51] emphasized the significance of the inhalation route (Cox *et al.* (2019)^[51]). The results showed that the average concentration was 9.8 MPs per m³. It was calculated that whereas children inhaled 110 and 97 MPs daily, adult males and females inhaled 170 and 132 MPs daily, respectively. These estimations indicated that inhalation is the main method that humans are exposed to MPs, accounting for at least 50 per cent of the total daily exposure through all routes. An average annual inhalation intake of 0.2 mg per kg of body weight, or roughly 12,891 MP fibers, was found in another recent study carried out in Australian homes. Younger children (≤ 0.5 years old) had an even higher intake, at 0.31 mg per kg of body weight annually (Soltani *et al.*, 2021)^[63]. While individual inhalation exposure was previously estimated to range from 26 to 132 MPs per day (Prata, 2018)^[54], research conducted by (Vianello *et al.* (2019)^[64] found that adult males participating in light activity inhaled an average of 272 MPs per day. Interestingly, a recent study brought attention to the higher risk of MP inhalation that comes with using different kinds of face masks during the COVID-19 epidemic.

The two forms of MPs that were most frequently found were fibers and spheres; N95 masks showed the lowest levels of MP inhalation, while activated carbon masks showed the greatest (Ageel, *et al.*, 2022)^[55]. Indoor dust has emerged as an important matrix for human exposure to microplastics. Children were more vulnerable to MPs due to higher rates of dust consumption, and high quantities of MPs were identified in indoor dust samples. Indoor dust exposure was shown to be higher than outdoor exposure, with daily intake of MPs ranging from 6500 to 89,700 ng per kg of body weight. It was discovered that because of differences in body weight and rates of dust ingestion, adults had lower exposure levels, while newborns had the highest levels. The importance of taking indoor dust exposure into account, particularly for youngsters, is emphasized by this (Ageel, *et al.*, 2022)^[55].

c) Ingestion

Since MPs are present in the digestive systems of many different creatures, humans are most exposed to them through the digestive tract (Viamello *et al.*, 2019). M cells in the gut aid in MP absorption, guiding them to the lymphoid tissue (Ensign *et al.*, 2012)^[65]. In reaction to MPs, the intestinal epithelium secretes chemokines and cytokines. In a contact with MPs, gut barrier cells, such as colon cells, induce phagocytosis, which damages the intestinal barrier (Stock *et al.*, 2019)^[66]. MPs disrupt the microecology of the gut, affecting energy metabolism and potentially harmfully affecting health. This can happen both directly and indirectly. Larger MPs are removed by

mucus and eliminated with feces instead of being effectively collected (Schwabl *et al.*, 2019)^[67]. Determining the toxicity of MPs and their impacts on human health requires an understanding of how MPs affect the gut microbiota's function (Lu *et al.*, 2019)^[68]. Recent studies have outlined the routes by which individuals are exposed to particulates matter (MPs), highlighting the significance of indoor dust and nutrition as conduits. Dietary factors are important because MPs have been found in a wide range of foods, including milk, beer, sugar, honey, seafood, and shellfish. Various demographic groups' daily MP consumption ranged from 106 to 142 particles per day, according to studies that calculated food exposure (Cox *et al.*, 2019)^[51] details are presented in table 1 and graphically shown in chart 1.

As was previously mentioned, the release of MPs from plastic packaging, such as teabags (Hernandez *et al.*, 2019)^[69] and baby feeding bottles, is another known source of exposure. MPs have also been found in bottled drinks, meat products, and milk containers with labels (Kedzierski *et al.*, 2021)^[162]. These findings emphasize the need for in-depth investigation to fully understand the extent and risks associated with food consumption. Indoor dust has emerged as another important matrix for human exposure to particulates. Children are more sensitive to MPs because they consume more dust than adults do, according to studies that have identified significant quantities of MPs in samples of indoor dust.

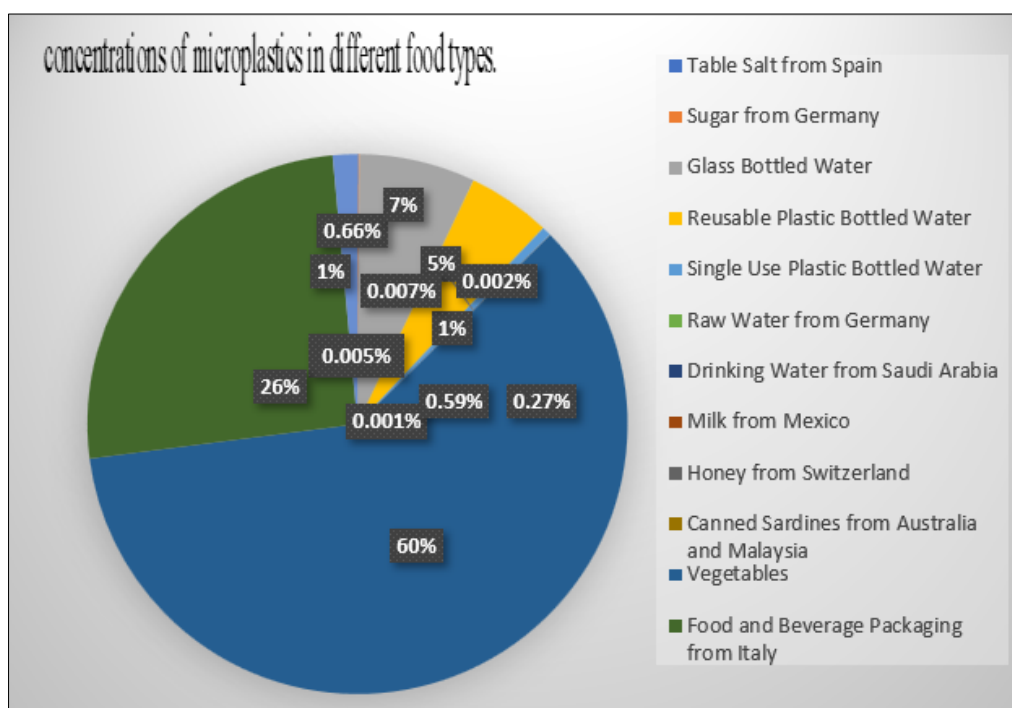
d) Dermal Contact

Synthetic fibers and cosmetic use are examples of cutaneous contact. Research that specifically assess the risks of MP exposure on human skin are hard to come by. Nonetheless, considering the pervasiveness of MPs in indoor dust, atmospheric deposition from both indoor and outdoor air, the use of microbeads in cosmetics, and the continuous degradation of microfibers from textiles, as previously mentioned, it makes sense to consider dermal contact as a possible pathway for human exposure to MPs. Microbeads are typically smaller than 1 mm in diameter and are commonly used in toothpaste, denture fillings, and skin cleaning and exfoliating products. Several studies have attempted to estimate the quantity of microbeads that each individual uses in different personal care products (Gouin *et al.*, 2011)^[70]. As an illustration, studies on face scrubs carried out in the UK found that the MP level varied from 10 to 100 g per liter, or 40.5 to 215 mg *per capita* daily (Mowat, 2003)^[71]. Using liquid soaps, another study determined that the average daily consumption of MPs in the US population is 2.4 mg per person (Gouin *et al.*, 2011)^[70]. Although these few studies do not provide a comprehensive understanding of human cutaneous exposure to MPs, they do highlight the significance of taking this route of exposure into account. Nevertheless, there are alternative routes by which larger particles may enter the epidermis, such as sweat glands, hair follicles, or open wounds. Additionally, cutaneous exposure to MPs has been connected to skin damage caused by oxidative stress and inflammation. Further research is needed to determine how much MPs are exposed to human skin through contact with makeup, settling dust particles, fabric fibers, and other sources.

Table 1: Presence of microplastics in different food products.

Food type	Average particles	Size range of the particles	Type of polymer	references
Salts from Taiwan market	9.77 MP/ Kg	1-1500µm	Polyethylene terephthalate (PET), Polypropylene (PP), Polyethylene (PE)	Lee <i>et al</i> , 2019 ^[72]
Sea salts from Bangladesh	2676MP/Kg	0.1-5mm	Polystyrene (PS), Ethylene-vinyl acetate (EVA), High-density polyethylene (HDPE) Nylon (polyamide 6), Polyethylene terephthalate (PET)	Parvin <i>et al</i> , 2022 ^[73]
Salt from India				
Gujrat	46-115 particles / 200 g	100-1000µm	PE, PVC (Polyvinyl chloride), PS PE PVC, PS	Vidyasakar <i>et al</i> , 2021
Tamil Nadu	23-101 particles/ 205-21 particles/10g	100-1000µm	LDPE (Low-density polyethylene) PP, PET, Nylon	Nithin <i>et al</i> , 2021 ^[74, 75]
Table salt from Spain	50-280 particles/kg	10-3500µm	PET, PP, PE	Iñiguez <i>et al</i> , 2017 ^[159]
Sugar from Germany	249±130 partials /kg	<0.8 µm	PET, PE, PP	Liebezeit <i>et al</i> , 2018 ^[164]
Glass bottled water	35,436MP/L			
Reusable plastic bottled water	23,594 25,518MP/L	90%	PET, PE, PP	Oßmann <i>et al</i> , 2018 ^[28]
Single use plastic bottled water from Germany	2649 2857MP/L			
Raw water from Germany	0-7MP/m ³	50-150 m	PE, PA(Polyamide)PS, PVC	Mintenig <i>et al</i> , 2019 ^[27]
Drinking water from Saudi Arabia	1.9 4.7particles/L	25-500 m	PE, PS, PET	Almaiman <i>et al</i> , 2021 ^[76]
23 milk samples (22 for adult and 1 for child) from Mexico	6.5 2.3 particles/L	0.1-5 mm	PES, PSU (Polysulfide)	Kutralam-Muniasamy <i>et al</i> , 2020 ^[77]
Honey from Switzerland	32-108 Fibers/kg	30 and 1 m	PET	Mühlschlegel <i>et al</i> , 2017
Canned sardines from Australia and Malaysia	1-3 fragments per individual	149 and 8 m	PP, PET	Karami <i>et al</i> , 2018 ^[78]
Vegetables (lettuce, broccoli, carrot)	52,600-307,750 MP/kg	1.81-2.29 m		Oliveri <i>et al</i> , 2020 ^[79]
Food and beverage packaging from Italy	72,175-130,500 MP/kg	1.51-2.52 m		
Fish (<i>Siganus rivulatus</i> , <i>Diplodus sargus</i> , <i>Sardinella aurita</i> , <i>Sphyræna viridensis</i> , <i>Atherina boyer</i>) from Egypt	28-7527 particles/fish	≤25-2000 m	PVA (Polyvinyl alcohol), LDPE, HDPE, PET, PP, Nylon	Shabaka <i>et al</i> , 2020 ^[80]
Teabags from Canada	11.6 billion MP per cup of tea beverage	10nm-150 m including nanoparticles	PET, Nylon	Hernandez <i>et al</i> , 2019 ^[69]

Source: Ziani *et al*, 2023 ^[81]

**Chart 1:** representation of concentrations of microplastics in different food types

e) Circulatory System and Brain

In terms of the circulatory system, inhaled MPs are more likely to diffuse into the circulation by both cellular absorption and

paracellular distribution after passing through the lower respiratory region, which has a thin covering of secretion (Mowat, 2003) ^[71]. The existence of MPs in people is being

supported by increasing scientific evidence. Ibrahim *et al.* (2021)^[82] reported that MPs were predominant in colectomy specimens, but Schwabl *et al.* reported that MPs were present in human feces, indicating that they are only partially able to pierce the intestinal membrane (Ibrahim *et al.* (2021)^[82]. Research conducted on humans and rats has demonstrated that PVC and PS particles with a size less than 150 µm can go from the gut to the lymphatic and circulatory systems. We looked into MP ingestion, transport, and accumulation using the mussel *Mytilus edulis*. Following intake, MPs gathered in the stomach, moved in 3 days to the circulatory system, and remained there for more than 48 days. The extended durability of MP particles in *M. edulis hemolymph* has further consequences for raptors, including humans, birds, crabs, and starfish (Browne *et al.*, 2008)^[83]. Another study demonstrates that NPs can cause thrombosis; in this instance, hamsters were given injections of 60 nm polystyrene particles, which subsequently appeared in the blood (Nemmar *et al.*, 2003)^[84].

Thus, MPs in the circulatory system may limit blood flow, harming vascular tissues and altering heart function (Persiani *et al.* (2023)^[85]. Different MP types have been shown to accumulate in the heart, as reported by Persiani *et al.* (2023)^[85]. This accumulation is explained by a trophic transfer via the circulation. Mammals have demonstrated that MP presence reduces the activation of fibrotic processes, newborn cardiomyocyte apoptosis, and cardiac contractility. When MPs and NPs interact negatively with developing hearts, they can cause cardiac morphogenesis to fail, loss of function, arrhythmia, or reduced contractility in developing and probably adult hearts, among other cardiac function impairments.

Due to their tiny size, MP particles can readily cross biological barriers and become deposited in the digestive system. They can then travel to different parts of the body, such as the brain, kidneys, liver, and blood (Zhu *et al.*, 2023)^[86]. One new area of toxicity study that has developed is the transgenerational neurotoxicology of MPs. Recent studies have focused on the transgenerational neurotoxicology of microplastics (MPs), or nanoparticles (NPs) derived from the food chain. The function of neurotransmitters and genes related to neurodevelopment is impacted by these particles, which are inherited and traverse the embryonic blood-brain barrier (Nie *et al.*, 2021)^[87]. MPs/NPs can cause neurotoxic effects in a range of species and are able to cross the blood-brain barrier (Prust *et al.*, 2020)^[88]. When NPs are supplied to a fetus by the trachea or breast milk, they breach the placental barrier, which impacts neurodevelopment and causes cognitive impairments (Prust *et al.*, 2020)^[88].

Additionally, there is a higher concentration of NPs in the blood-brain barrier in the early embryonic stage, which may be due to the fetal blood-brain barrier not developing and allowing NPs to cause neurological dysfunction (Fournier *et al.*, 2020)^[89]. Even though these results emphasize the potential for transgenerational neurotoxicity from MPs/NP exposure, more research is required to fully comprehend the mechanisms underlying the interaction between MPs/NPs and the blood-brain barrier during transfer or transgenerational transport. Similarly, a number of investigations were conducted to determine the neurotoxic effects of polystyrene and polyethylene micro- and nanoplastics on various aquatic creatures (Lei *et al.*, 2018)^[90]. In *Caenorhabditis elegans* (nematodes), spherical polystyrene MP exposure led in excitatory toxicity, which lowered survival rates, shortened average lifespans, and hindered locomotor activity.

Furthermore, this exposure led to oxidative stress, downregulated neuronal genes, and damaged GABAergic and cholinergic neurons (Lei *et al.*, 2018)^[90]. *Eisenia fetida* (earthworms) exposed to low-density polyethylene particles in artificial soil had epidermal injury, altered acetylcholinesterase activity, and increased oxidative stress indicators (Chen *et al.*, 2020)^[91]. It was discovered that the tissues of freshwater zebra mussels, *Dreissena polymorpha*, contained polystyrene microbeads. The stomach exhibited the largest concentration of these beads, indicating no genotoxicity but rather cellular stress and higher dopamine levels (Magni *et al.*, 2018)^[92]. Similarly, the bivalves *Scrobicularia plana* displayed oxidative stress in their gills, increased activity of glutathione-S-transferase and superoxide dismutase, and decreased levels of acetylcholinesterase and lipid peroxidation in their digestive glands and gills after being exposed to polystyrene microplastics. The exposure of Mediterranean mussels, or *Mytilus galloprovincialis*, resulted in increased DNA damage, altered gene expression in the digestive gland and gills, and decreased cholinesterase activity, all of which may have neurotoxic consequences (Avio, 2015)^[93].

Conversely, *Corbicula fluminea*, or Asian freshwater clams, were exposed to polymer microspheres and suffered oxidative damage, suppression of cholinesterase activity, and irreversible consequences. These effects were exacerbated in the presence of florfenicol (Guilhermino *et al.*, 2018)^[94]. On the other hand, shrimp and striped barnacle larvae of *Amphibalanus ampitrite* and *Artemia franciscana* exposed to microplastics had altered enzyme activity and swimming behaviors, including dose-independent effects on cholinesterase and increased catalase (Gambardella *et al.*, 2017)^[95]. Lastly, *Artemia franciscana* larvae subjected to amino-modified polystyrene nanoparticles displayed increased amounts of inhibition for cholinesterase and carboxylesterase as well as decreased oxidative stress indicators including GST and catalase activity.

Microplastics Crossing the Blood-Brain Barrier

The study by Kopatz *et al.* (2023)^[96] has addressed the role of the biomolecular corona in MPs and NPs' blood-brain barrier (BBB) breaching. The BBB, an essential defense mechanism, prevents harmful substances from penetrating the brain. Within the mice were administered oral dosages of various sized polystyrene micro/nanoparticles in this investigation. For short-term uptake tests, the values are 9.55, 1.14, and 0.293 µm. The results showed that Particles larger than a nanometer could pass through the BBB, while larger particles could not within two hours after consumption. Shan *et al.* (2022)^[97] investigated into the impacts of PS-NPs, or polystyrene nanoparticles, in another investigation. PS-NPs were given to mice, and they accumulated in the brain and enhanced the permeability of the blood-brain barrier (BBB) in a systematic manner. Damage and activation of microglia were observed by PS-NPs. to brain cells. Using human brain endothelial cells *in vitro* experiments, PS-NPs were taken in by the cells, resulting in the generation of reactive oxygen species, swelling cell death and a breakdown of tight connections. Additionally, PS-NPs stimulated mouse microglia cells. and the neurons in their culture media were harmed. In general, these results imply that PS-NPs have the ability to activate microglia, cause neurotoxicity, and pass the blood-brain barrier.



Source: BBC Wildlife Magazine

Fig 7: microplastics and animals

Rats and humans are commonly used as study models because of the many genetic and biological similarities between them. These studies have shown that MPs/NPs bioaccumulate in a number of organs following oral or intravenous administration, including the liver, spleen, kidney, placenta, stomach, and brain shown in an abstract form in fig:6. The particles were between 40 nm and 50 μm in size; However, little is known about the connection because there haven't been many studies done on it between the outcomes and particle size (O'Neil & Lawler,

2021) [53]. However, future research needs to take field conditions and assess a broad range of plastic compositions, shapes, and sizes.

Toxic Effect of Microplastics on Animals:

Apart from humans, animals are no exception to this threat mostly aquatic animals show more affinity of damage due to their habitat is highly contaminated. The diverse impact of MP on animal health are shown in table 2.

Table 2: The diverse impacts of microplastics on animal health.

Animals	Microplastics	Effects	References
Blue mussels (<i>Mytilus edulis</i> L.)	HDPE (>0-80 μm)	Histological changes, robust inflammatory response including the formation of granulocytomas and lysosomal membrane destabilization	Moos <i>et al.</i> (2012)
Damselfish	PS (200-300 μm)	Bolder and more active behaviors that lead to moving further from shelter and resulting higher mortality rates	McCormick <i>et al.</i> (2020) [166]
Earthworms	PS (100 nm, 1-100 μm)	Oxidative stress, severe DNA damage in coelomocytes	Xu <i>et al.</i> (2021) [121]
Female Wistar rats	PS (500 nm)	Ovarian fibrosis and granulosa cells apoptosis due to activation of Wnt/ β -Catenin signaling pathway and oxidative stress	An <i>et al.</i> (2021)
Flesh-footed Shearwaters		Significant tissue damage, including inflammation, fibrosis, and loss of organ structure in the kidney and spleen, along with reduced tubular glands and rugae in the proventriculus.	Rivers-Auty <i>et al.</i> (2023)
Flesh-footed Shearwaters (<i>Ardenna carneipes</i>)		Scar tissue formation, fibrosis	Charlton-Howard <i>et al.</i> (2021) [158]
Freshwater benthic mollusc (<i>Pomacea paludosa</i>)	PP (11.86-44.62 μm)	Increased reactive oxygen species levels, disruption of hemostasis, fluctuations in digestive enzyme activities in hepatopancreas, severe damage to the digestive gland cells	Jeyavani <i>et al.</i> (2023) [160]
Goldfish (<i>Carassius auratus</i>)	PS (500 nm and 30 μm)	Impairing of olfactory neural signal transduction and olfactory information processing	Shi <i>et al.</i> (2022)

Goldfish (<i>Carassius auratus</i>) juveniles	PVC microbeads (0.100-1000 μm)	Oxidative damage in the brain and liver, downregulated growth hormone expression receptor and binding protein genes and upregulated cortisol receptors	Romano <i>et al.</i> (2021) ^[171]
<i>Lumbricus terrestris</i> (Oligochaeta, Lumbricidae)	PE (<150 μm)	Increased uptake and mortality rate, weight loss, and lower growth rates.	Huerta Lwanga <i>et al.</i> (2020) ^[153]
Male Wistar rats	PS (average 38.92 nm)	Histological lesions in testis tissue, DNA damage, sperm abnormalities, alterations in productive hormones and gene expression patterns	Amereh <i>et al.</i> (2020) ^[98]

Source: Eunju *et al.*, 2024^[99]

Metabolic Disorder: It has been demonstrated by earlier animal studies that microplastics cause intestinal and liver malfunction. For example, Kang *et al.* discover that fish intestine injury is caused by microplastics through two distinct pathways. When PS is 50 nm in size, it shows more oxidative stress, and when PS is 45 μm in size, it significantly upsets the equilibrium of intestinal flora. According to (Kim *et al.*, 2022)^[100] fish digestive enzyme activity is inhibited by microplastics as a result of a microalgae-crustacean-small yellow croaker food chain. Additionally, intestinal barrier and metabolic function are compromised in PS-exposed animals, according to (Jin *et al.* 2019)^[101] According to Tan *et al.*, PS exhibits the greatest inhibition of lipid digestion when microplastics are present in the simulated human gastrointestinal system (Tan *et al.*, 2020)^[102]. The reduction in lipid digestion occurs regardless of PS size. According to Lu *et al.*, fish liver lipid buildup and disruption of energy metabolism are caused by PS exposure (Lu *et al.*, 2016)^[103]. Factors that influence MP uptake by fish is shown in fig: 8. Furthermore, (Deng *et al.* 2018)^[104] observe that mice's metabolites change dramatically following exposure to microplastics and organophosphorus flame retardants (OPFRs) (Deng *et al.* 2018)^[104]. Furthermore, it is evident that microplastics increase the toxicity of OPFRs, underscoring the dangers to one's health associated with exposure to microplastics and other pollutant.

Immune Response: Microplastics have the ability to trigger the body's immune system. According to (Yuan *et al.*, 2023)^[105]

exposure to PE causes zebrafish to manufacture mucosal immunoglobulin and activates their intestinal immune network route (Yuan *et al.*, 2023)^[105]. According to (Li *et al.*, 2020)^[106] rats exposed to PE had higher serum levels of *IL-1 α* , while CD4+ 91cell Th17 and Treg cells secreted less of the cytokine (Li *et al.*, 2020)^[106]. According to Lim *et al.*, rats' lung tissue exhibits elevated expression of *TGF- β* and *TNF- α* , two inflammatory proteins, upon inhaling PS. According to Liu *et al.*, intestinal immunological dysbiosis will greatly accelerate the build-up of microplastics, resulting in additional harmful effects. Additionally, PS exposure dramatically raises the expression of inflammatory markers (*TNF- α* , *IL-1 β* , and *IFN- γ*) in mice (Liu *et al.* 2022)^[107, 108, 106].

Neurotoxicity: Additionally detrimental to cerebral development are microplastics. Following exposure to microplastics, the most often documented neurotoxic consequence is inhibition of acetylcholinesterase (AChE) activity (prust *et al.*, 2020)^[88]. In a study involving young fish, the microplastics altered the activities of energy-related enzymes, increased brain lipid oxidation, and inhibited AChE activity, ultimately leading to neurotoxicity (Barboza *et al.*, 2018)^[43, 109]. According to Prust *et al.*, fish, crabs, and worms exhibit aberrant behavior as a result of microplastic contamination (Yang *et al.*, 2020)^[110]. PS (70 nm) can penetrate larval epidermis and reach muscle tissue, as found by Yang *et al.* It has the ability to kill nerve fibers, reduce AChE activity, and significantly impair larval motility.



Fig 6: Fish suffocating in water

Reproductive and Developmental Toxicity: The quality of embryos and the growth of germ cells are indicators of the impact of microplastics on reproduction. The toxicity mechanism of MPs is shown in fig: 4. For instance, (Liu *et al.* 2022) [107, 108, 106] discover that the PS exposure lowers the quality of oocytes by influencing the maturation of oocytes and the growth of female mice follicles (Liu *et al.*, 2022) [107, 108]. Furthermore, immunological diseases linked to microplastics

may have a negative impact on pregnancy outcomes, according to (Hu *et al.* 2021) [111]. According to Deng *et al.*, sperm quality dramatically declines following prolonged exposure to environmentally relevant PS levels, which has an impact on male mice's fertility (Deng *et al.*, 2022) [151]. Furthermore, (Park *et al.* 2020) [112] demonstrate that there are notable changes in the number of live births per mother, sex ratio, and body weight of pups in groups treated with PE.



Fig 7: Toxicity cycle of microplastics.

Microplastics and Agriculture

Approximately 25 per cent of the more than 800 million urban farmers practicing agriculture worldwide engage in market-oriented farming (Qadir *et al.*, 2010) [115]. In low- and middle-income countries (LMICs), urban and peri-urban farmers can increase household income by growing perishable crops like leafy vegetables for local markets (Zezza and Tasciotti, 2010) [113]. This is important because it ensures that the community has a steady supply of vitamin-rich vegetables. Significantly, in metropolitan and peri-urban areas, the production of fresh vegetables and leafy greens is essential for mitigating hidden hunger, which is defined as a diet deficient in micronutrients, vitamins, and minerals (Chagomoka *et al.*, 2017) [114]. Farmers in low- and middle-income countries (LMICs) frequently use wastewater defined in this paper as the use of raw, partially treated, or diluted wastewater, primarily from domestic sources for irrigation because it can be more dependable or less expensive than other surface water sources and offers a free source of phosphorus and nitrogen, saving money on fertilizers. By reusing water and nutrients, the use of wastewater in urban vegetable farms reduces the demand on water resources while simultaneously increasing water productivity (Qadir *et al.*, 2020; Minhas *et al.*, 2022) [115, 116]. A sizable amount of irrigation utilized in agricultural systems in the USA, Australia, and many other nations with dry and semi-arid regions, such as Saudi Arabia, Tunisia, and Pakistan, is made up of wastewater, either untreated or secondary/tertiary treated. Nevertheless, enteric infections and, more recently,

microplastics, which have proliferated in the environment over the past few decades (Partyka and Bond, 2022; Uddin *et al.*, 2020; Pérez-Reverón *et al.*, 2022) [117, 118] are frequently linked to wastewater irrigation.

Comprehensive reviews have been conducted on the origins and migration routes of microplastics in more intensive agricultural systems, such as those in China (Jin *et al.*, 2022; Yu *et al.*, 2022) [119]. The primary soil inputs are irrigation (Zhou *et al.*, 2021; Pérez-Reverón *et al.*, 2022) [118], mulching with plastic sheeting, and seed coatings that contain plastic carriers. Significantly, plastics (and microplastics) can offer a novel hydrophobic ecological habitat that can support a variety of microbial communities. Microbial biofilms are formed on the plastic surface by the extracellular polymeric substances secreted by the microorganisms. Known as the "plastisphere" (Zettler *et al.*, 2013) [120], this type of biofilm is thought to create a shield that allows microorganisms to flourish in harsh environments and aids in their spread (Amaral-Zettler *et al.*, 2020). (Represented in fig: below). It is located at the interface between the plastic surface and the environment. Microplastics have the potential to be an important pathogen vector because the plastisphere can also harbor bacterial and viral human pathogens that are able to maintain their virulence and infectivity (Moresco *et al.*, 2021; Metcalf *et al.*, 2022; Ormsby *et al.*, 2023) [121, 122, 123]. This is especially true if the microplastics have come into contact with a source of faecal contamination.

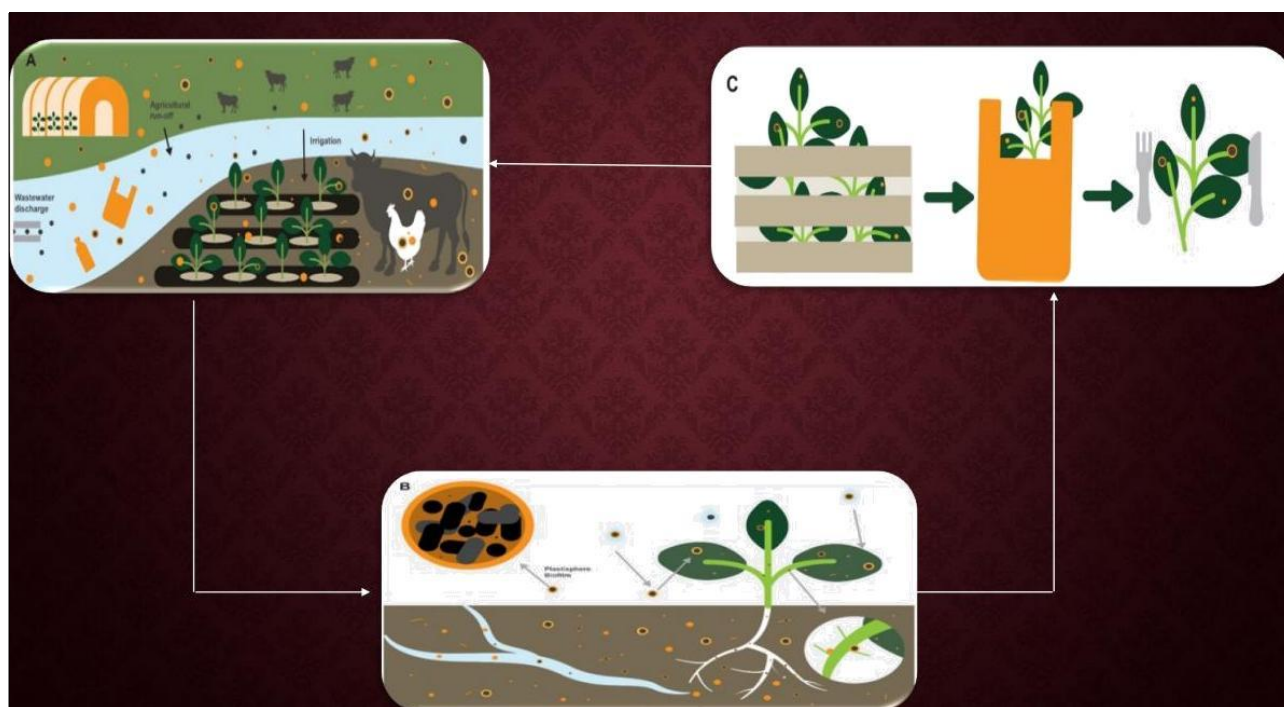


Fig: (A) Plastics and microplastics, or orange circles and fibres, can find their way into agricultural systems through tainted irrigation water, animal excrement, organic fertilizers, or the decomposition of bigger plastic fragments from polytunnels or mulching film. Once in the environment, microbial biofilm known as the "plastisphere" which frequently carries human pathogens quickly colonizes plastic, resulting in orange rings with black dots; (B) Human diseases can be made more resilient and more likely to spread by the plastisphere, which can also help them reach the rhizosphere, growing roots, the surface of leaves and fruit, or both directly through irrigation and indirectly through splashing from the soil; (C) It is unknown whether human pathogens in the plastisphere could subsequently be transferred to the plant once microplastics have adhered to plant tissue. Nevertheless, microplastics can be challenging to remove from plant leaves, even after washing, so they may stay attached during the harvesting and retail processes, increasing the risk that human pathogens will enter the food chain. Source: Quilliam *et al*, 2023^[124]

According to Chen *et al.* (2020)^[91], plastic pollution is significantly contaminating a growing percentage of soil utilized for agricultural production. The amount of plastic in soils is expected to rise globally as a result of practices like plastic mulching and seed treatments (Li *et al.*, 2022)^[107] as well as the effects of fast urbanization and, in LMICs in particular, inadequate waste management infrastructure (Feronato and Torretta, 2019)^[125]. Zhang *et al.*'s meta-analysis from 2022 has recently shown that plastic residues in soil can change the cycling of nutrients and impede plant growth. This is most likely due to plastics changing the diversity and functioning of soil microbial communities, for example by possibly promoting enhanced carbon and nutrient cycling (Bandopadhyay *et al.*, 2018; Xiao *et al.*, 2022)^[126]. However, a variety of other parameters, such as size, shape, concentration, and polymer type, influence the effects of plastics in soil in addition to soil type and environmental circumstances (Iqbal *et al.*, 2023)^[127]. Degradable "bio-plastics" have recently been proposed as a substitute for plastic mulching; however, observations from the field reveal that the effects on crop production, soil health, and nutrient cycling may vary (Brown *et al.*, 2023; Chu *et al.*, 2023; Reay *et al.*, 2023)^[128].

It has recently been shown that plants can absorb and retain both nanoplastics and microplastics, seemingly having little impact on plant physiology (Azeem *et al.*, 2021)^[129]. While microplastics are more likely to aggregate and become adsorbed onto the plant surface because of their bigger size, nanoplastics can penetrate plants through stomata or fractures (Mateos-Cárdenas *et al.*, 2021)^[130]. The degree of the interaction with microplastic particles will depend on the morphology and topology of the plant, as microplastics have the ability to stick to mucilage and exudates and get caught by trichomes (Bi *et al.*,

2020)^[131]. The charge on the plastic surface and the chemical bonds that form between the microplastic and the leaf surface make some microplastics very difficult to remove from crops like lettuce, even after washing with water (He *et al.*, 2023)^[132]. The plastic polymer will also affect how strongly microplastics bind to leaves. Rice seedlings have the ability to absorb plastic particles up to 1 μm in size, which are then drawn to the shoot by transpiration (Liu *et al.*, 2022)^[107, 108, 106]. Microplastics of this size have the ability to bind human viruses, even though they are not able to colonize bacteria.

"A Plastic-Free Future: Strategies to Combat Microplastics"

Globe is in hidden threat! From water to air to food to land everything has been covered by these tiny monsters which is also represented in fig:8, hence we should take it seriously and find ways to combat it. Sustainable choices today lead to a cleaner planet tomorrow. We can put into practice a number of crucial tactics to stop the creation of microplastics and lessen their negative effects on the environment. First and foremost, we must push for stronger laws governing the manufacture of plastics, such as prohibitions on single-use plastics and microbeads in makeup and personal hygiene items. Plastic waste can be greatly decreased by encouraging producers to adopt sustainable practices and by promoting the use of biodegradable materials. Furthermore, improving recycling initiatives and offering incentives to companies that recycle can aid in preventing plastic waste from ending up in landfills and the ocean. Campaigns to raise public knowledge of the negative impacts of microplastics are essential because they can increase demand for environmentally friendly goods. It will also be crucial to support innovation and research in alternative

materials, such plant-based plastics. Lastly, supporting proper disposal methods and organizing community clean-up events can contribute to the reduction of microplastics already present in the environment. We are able to effectively stop the manufacture and spread of microplastics by implementing a comprehensive strategy that includes policy, education, innovation, and community action.

Like any other persistent environmental pollution problem, MP contamination needs to be addressed using both preventive and remediation strategies. Preventive actions aim to reduce future pollution, whereas remediation helps repair the harm that pollution has already done to the environment. Since one cannot fully replace the other in addressing a pollution problem, both prevention and remediation are crucial components of the battle against pollution. Although it is imperative to remediate MP-infested terrestrial or aquatic habitats, there are numerous obstacles preventing its prompt implementation. MPs can range in size from a few millimeters to fragments that are imperceptible to the human eye, as was previously mentioned. It is understandable that progress in managing partially invisible municipal solid waste (MPs) is sluggish as managing visible MPs is already difficult. Most of the time, such as when MP pollution occurs in the soil or ocean, there are no proven methods for cleaning it up. The technology required for identifying MP-polluted settings, isolating/removing MPs, and treating MP pollution is still scarce because this is a young scientific field. Not all of the few techniques that have been found or suggested are economical.

It has been suggested that bioremediation might lessen surroundings, especially soil, that are contaminated with microplastics. The process of bioremediation involves using microorganisms to hydrolyze and degrade MPs. Numerous microorganisms, including bacteria and fungi, can degrade plastics by secreting enzymes that hydrolyze MPs, and soil provides a haven for these microbes (O'Kelly *et al.*, 2021) ^[133]. Eventually, these become monomers, which the microbes may break down into water and carbon dioxide. It has been suggested that bioretention cells, a kind of runoff water treatment, are a useful tool for eliminating MPs from urban stormwater (Smyth *et al.*, 2021) ^[134]. The MPs discovered in urban stormwater are probably secondary MPs that are the result of bigger MPs being abraded. Stormwater runoff is collected and treated in bioretention cells droughts in the ground. Research indicates that bioretention can lead to a median 84 per cent reduction in MPs (106- 5000 μm) (Smyth *et al.*, 2021) ^[134]. Conversely, initiatives to increase awareness have helped preventive measures to reduce MP pollution gain popularity. The most effective way to stop MP contamination from spreading further is probably source reduction. To put it simply, this calls for more work to be done in the areas of recycling more, cutting back on plastic use, and educating the public to stop littering. Countries are actively enacting rules on the majority of frequently used single-use plastic goods in an effort to reduce the amount of plastic used; however, the use of plastics in packaging materials has not yet been curtailed in the same way (UNEP, 2018) ^[135]. Reducing excessive use of fertilizer and compost could also aid in lowering MP contamination of the soil. It has been suggested and used to use biodegradable plastics, maybe ones derived from cellulose, starch, or other related polymers. However, because the majority of these polymers cannot be recycled after their initial use and the production process requires a lot of water and land, biodegradable plastics raise additional sustainability issues.



Fig 8: Abstract representation of “globe- under a hidden threat”

In response to MP concerns, numerous nations and international organizations have implemented new laws, policies, and regulations in a variety of ways. Improving MP preventative measures can be greatly aided by policy actions. The Microbead-Free Waters Act was sponsored by the US Congress in 2015 with the aim of outlawing the production, packaging, and sale of rinse-off cosmetics that incorporate plastic microbeads (UNEP, 2018) ^[135]. Any cosmetic product meant to be rinsed off after use, like toothpaste, shaving cream, and shampoo, is referred to as a rinse-off cosmetic. In line with the present definition, the Microbead-Free Waters Act of 2015 defines a "plastic microbead" as any plastic particle less than 5 mm. This law's major goal is to stop rinse-off cosmetics that have any primary MPs added on purpose (US, gov. 2015) ^[136]. Furthermore, MP contamination has drawn the interest of the United States Environmental Protection Agency (USEPA) in its Draft National Strategy to Prevent Plastic contamination, which was released in April 2023 (USEPA, 2023) ^[137]. Preventing MPs and nanoplastics from entering waterways is particularly one of the three goals of this draft policy. In 2020, Canada suggested a new approach for managing plastic garbage. It is a thorough management system whose ultimate objective is to lower the quantity of MP discharge into the environment as well as macroplastics (Environment and climate change, Canada, 2023) ^[138]. One of the primary goals of this law was to address the sources of MPs, such as microbeads in personal care products (Environment and climate change, Canada, 2023). 2020 witnessed the start of Australia's phase-out of microbeads in rinse-off cosmetics and personal hygiene products. The Australian government wants to phase out PVC (polyvinyl chloride) plastic labels and enact legislation about plastic trash. Launched in 2021, the Australian National Plastics Plan lays out a strategy to eventually phase plastics out of the Australian economy (DAWE, 2021) ^[139]. It means getting rid of dangerous plastics, cleaning up plastic waste from the seas and beaches, enacting legislation that holds people accountable for their trash, providing funding for recycling facilities, financing research, and sustaining recycling support. Though not yet on a large enough scale, the possibility for wastewater systems to catch particles before they reach surface waterways has already started to get interest (Freeman *et al.*, 2020) ^[140]. For instance, intervention control for the wastewater sector was recently

advocated by United Kingdom Water Sector Research (UKWIR) (UKWIR, 2021) ^[141]. This covers modifications to labeling, increased producer accountability, prohibitions, grants and subsidies for reusable items, and adjustments to public infrastructure like the provision of disposal containers for garbage.

The seventeen Sustainable Development Goals (SDGs) established in 2015 did not, at least not immediately, address MP pollution in the 2030 Agenda, which was proposed by the UN and approved by 193 member states. One SDG that mentions the significance of addressing MP pollution is Indicator 14.1.1 in SDG 14 (life below water), which speaks briefly of floating plastic waste in the oceans (Walker, 2021) ^[142]. Nonetheless, the main UN environmental organization, the United Nations Environment organization (abbreviated UNEP or UN Environment), has started a few initiatives to address MP contamination, particularly in recent years. The United Nations Environment Assembly (UNEA), which has passed four resolutions on marine litter since 2014 (UNEA, 2023) ^[143], is recognized by the UN as the highest-level environmental decision-making body in the world. One of the few international bodies to acknowledge the MP problem is the UNEA, which noted it as an environmental danger as early as 2014. They have also acknowledged that there is currently no global governing structure that can adequately address the problems of marine litter and microplastics. An expert panel was formed to search for solutions during the UNEA's third assembly in 2017. The UNEA unanimously decided at its fifth assembly in 2022 that it would be a good idea to create a legally enforceable agreement to address plastic pollution (UNEP, 2022) ^[141]. This is possibly the most significant and ambitious worldwide environmental

initiative since the 1989 Montreal Protocol, and it is without a doubt the most significant development pertaining to MP pollution in its entire existence. With the goal of finishing this work by the end of 2024, the UNEA has called a meeting of the intergovernmental negotiating committee (UN, 2022) ^[144]. During its fourth congress in 2019, the UNEA took another significant step by establishing the UN Alliance for Sustainable Fashion. According to UNEP reports (UNEP, 2022) ^[121], they have joined forces with the other UN agencies in this coalition to aggressively advocate for government action to shift the textile industry to a sustainable one while minimizing the amount of MPs released into the environment. Given that polyester, acrylic, and nylon make up over 60% of garment material and that these materials account for 9% of MPs that end up in the ocean annually, this initiative is very crucial (European Commission, 2023) ^[145]. While there is an ongoing awareness effort, it's unclear if the government has made any significant progress to date. A comprehensive Circular Economy Action Plan was adopted in 2020 by the European Commission (EC), the executive branch of the 27-member European Union (EU), with the goal of addressing the presence of MPs in the environment (Ritchie & Roser, 2018) ^[146]. This comprehensive plan calls for the development of labelling, standardization, certification, and regulatory measures on the unintentional release of microplastics (MP), in addition to limiting purposely added microplastics like microbeads. One of the main objectives of the EU's Zero Pollution Action Plan for air, water, and soil to be accomplished by 2030 is the reduction of MPs emitted into the environment by thirty percent, which was set by the EU for the following year, 2021. The gist is represented below in table 3.

Table 3: various nations and organizations' actions against microplastic (MP) pollution:

Country/Organization	Action/policy	Description	Year
United States	Microbead-Free Waters Act	Out laws production, packaging, and sale of rinse-off cosmetics with plastic microbeads.	2015
United States	Draft National Strategy to Prevent Plastic Pollution	Aims to prevent MPs and nanoplastics from entering waterways.	2023
Canada	New Approach for Managing Plastic Waste	Comprehensive management system to reduce MP discharge and address sources like microbeads.	2020
Australia	Phasing out Microbeads	Gradual elimination of microbeads in rinse-off cosmetics and personal hygiene products.	2020
Australia	National Plastics Plan	Strategy to phase out harmful plastics and improve recycling infrastructure.	2021
United Kingdom	Intervention control for waste water sector	Advocates for wastewater systems to capture microplastics before they reach waterways.	Recent
United Nations (UN)	Sustainable Development Goals (SDGs)	Addresses MP pollution indirectly through Indicator 14.1.1 in SDG 14 (life below water).	2015
UNEA	Resolutions on Marine Litter	Four resolutions since 2014 addressing marine litter and microplastics.	2014-present
UNEA	Expert Panel Formation	Created to find solutions to microplastic pollution.	2017
UNEA	Legally Enforceable Agreement	Decision to create a global agreement to address plastic pollution.	2022
European Commission	Circular Economy Action Plan	Comprehensive plan to limit unintentional and intentional release of microplastics.	2020
European Union	Zero Pollution Action Plan	Aims to reduce MPs emitted into the environment by 30% by 2030.	2021

Conclusion

The microscopic byproducts of a plastic-fuelled society, microplastics are now found everywhere on Earth, from the huge oceans to our bodies' tiniest cells. Given their tenacity in the environment and capacity to enter the food chain, immediate global action is required. The effects of microplastic pollution are severe and alarming, especially for vulnerable groups like newborns. Even while these contaminants are present in frightening amounts, it is still unclear how much of an impact

they will have on human health, which emphasizes the need for further investigation. The deficiency of established techniques to evaluate microplastic exposure and toxicity is a noteworthy obstacle to comprehending the hazards associated with microplastics for the environment and human health. As we struggle with these issues, it becomes obvious how important preventative actions are. The key to mitigating the issue is to reduce plastic usage, increase recycling activities, and develop technology for removing microplastics from the environment.

Simultaneously, increasing consumer behaviour and public knowledge can lead to significant change. In addition to tackling a specific problem, the conflict against microplastic contamination aims to promote a larger dedication to environmental stewardship and human welfare. We can preserve our ecosystems and shield future generations from the hidden risks associated with plastic pollution by adopting creative solutions and legislative measures. Understanding and action are the first steps on the path to a cleaner, healthier planet; let's support these initiatives with tenacity and drive.

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