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ABSE ANNALS OF BIOMEDICAL SCIENCE AND ENGINEERING
ISSN 2833-518X

Review Article

Emerging Risk of Microplastics on Health, Agriculture and Environment

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Abstract

Exposure to microplastics is unavoidable, and a vast amount of microplastics are traveling around the oceans. Microplastics are considered one of the major potential pollutants due to their exposure and interference with the health of humans, animals, aquatic species, agriculture, etc. Shockingly, the microplastic was also detected in the human placenta (fetal and amniochorial membranes), which could cause long-term effects on human health. The disposal of plastic into the oceans is the most happening process across the globe; thereby, microplastic pollution is evident, leading to a huge risk to marine species. Also, the accumulation of microplastics on soil or land leads to an increase in pH value, thereby affecting the surface water and soil-groundwater medium, eventually affecting plant and human health. At the same time, microplastics and their particles are found in milk, meat, and other edible items, which directly affects human health. The appearance of microplastic particles in insects, birds, animals, and even human blood indicates its adverse effect on the environment. This review has discussed the impact of microplastic on the health of humans, aquatic species, and agriculture.

More Information

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Submitted: April 15, 2024
Approved: April 29, 2024
Published: April 30, 2024

How to cite this article: Parida S, Ashok N, Kurapati R. Emerging Risk of Microplastics on Health, Agriculture and Environment. Ann Biomed Sci Eng. 2024; 8: 004-010.

DOI: 10.29328/journal.abse.1001028

Keywords: Microplastics; Pollutants; Health; Aquatic species; Agriculture; Environment; Agriculture; Crops

Abbreviations

MP: Microplastics; NP: Nanoplastics; ECHA: European Chemicals Agency; PE: Poly(ethylene); PP: Poly(propylene); PVC: Poly(vinyl chloride); PET: Poly(ethylene terephthalate); PC: Poly(carbonate); PTFE: Poly(tetrafluoroethylene); PS: Poly(styrene); PA: Poly(amide); PU: Poly(urethane); PES: Poly(ether-sulfone); LDPE: Low-density Poly(ethylene); SOC: Soil Organic Carbon; IL-6: Interleukin 6; TNFα: Tumor Necrosis Factor α; NLRP3: NLR family, Pyrin domain containing 3; ROS: Reactive Oxygen Species; SOD: Superoxide Dismutase; GSH: Glutathione; IL-1 beta: Interleukin-1 beta; GSDMD: Gasdermin D protein; GSDMD-N: N-Terminal Effector Gasdermin; ASC: Apoptosis-associated Speck-like Protein Containing a Caspase activating and Recruitment Domain; TNF alpha: Tumor Necrosis Factor-alpha; TRADD: TNF Receptor 1 Associated Death Domain Protein; FADD: Fas-associated Death Domain Protein; ATR-MIR: Attenuated Total Reflection Mid-Infrared; LIIS: Laser Infrared Imaging Spectrometer; FTIM: Fourier-Transform Infrared Microscope; IBD: Inflammatory Bowel Disease

Introduction

Plastic waste increased exponentially after the COVID-19 pandemic due to plastic materials used in various products, including personal protection kits. The extensive use of plastics has been headed to be a potentially hazardous pollutant in the environment. Nearly 20 to 42% of the total global plastic production is already stored on land, and their biodegradation is expected to be too sluggish [1]. In general, plastics are mainly derived from petroleum and more than 90% of plastic being used is single-use plastic, and a substantial amount of this single-use plastic is reaching the soil and marine environment. Most of the plastic reaching the environment is non-degradable, which eventually undergoes a reaction with sunlight (UV light), moisture, air (oxygen), etc., leading to the break of the bulk plastic into microplastic (0.1 μm to 100 μm) and nanoplastic (≤ 0.1 μm) [2]. However, according to the European Chemicals Agency (ECHA), microplastics are solid plastic particles (synthetic or nonbiodegradable) having all dimensions in the size range of 0.1 to 5 mm or a length in the range of 0.3 to 15 mm, including a length of diameter ratio greater than 3 [3]. Subsequently, the accumulation of plastics in the environment shows an increment order with a positive slope over time. Microplastic (MP) or nanoplastic (NP) particles are ubiquitous in nature, water, soil, and biosphere [4,5]. Research indicates that the parental polymer types found in microplastics are polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polyethylene terephthalate (PET), polycarbonate (PC), polytetrafluoroethylene (PTFE), and polystyrene (PS). MPs especially exist in several forms, with fibers forming in the environment. The nanoplastic is used in many industries, including 3D printing, paints, adhesive materials, etc., and eventually released into the atmosphere. The resulting micro or nanoscale plastics are being found everywhere on the Earth, including the soil, air, lake waters, marine water, tap water, the deepest point of the ocean, marine species, air, birds, fruits, fresh vegetables, surface animals, and humans [6,7]. Billions of plastic micro/nanoplastic particles were shown to be generated from the plastic tea bags due to the heat treatment of around 100 °C. A single plastic tea bag generated nearly 11 billion microplastic and 3 billion nanoplastic particles [8].

Over the last decade, numerous cases of microplastic ingestion have been reported in marine animals. However, many recent reports confirmed that microplastics keep accumulating in the critical organs of humans, alarming the risk posed by the microplastic particles [9]. One of the recent studies confirmed the unexpectedly high amount of nine kinds of microplastics in the human body fluids despite the biological barriers, which emphasizes the potential risk these microplastics pose to humans and other organisms as shown in Figure 1 [10]. Not only to humans but the microparticles also pose a hazard to the animal kingdom, plants, and the environment (water) [4]. Recent reports have confirmed that microplastic has reached the deepest part of the world's ocean [11]. MPs were also found to heavily affect aquatic species, their biodiversity, and agriculture or plant growth.

Impact of microplastics on humans: Recent reports say humans consume more than 50,000 microplastic particles annually. Recent studies have confirmed microplastics such as polyethylene terephthalate (PET) and polycarbonate (PC) in human stools and many other key organs [12]. However, microplastics are not found in all the organs of humans [3]. These MPs (e.g., polyethylene terephthalate and polycarbonate) were also detected in the human blood and feces of infants and adults, alarming the possible chronic toxic effects on humans [13]. Another work revealed the presence of MPs (fibers) made of rayon and polyester in the human lower airways, which has been shown to affect the functioning of the lungs. Another seminar work reported that microplastic particles (polyethylene) of the size range 2.1 to 26.0 µm were detected in the human thrombi [14]. Surprisingly, the infants were found with millions of tiny microplastics of polypropylene (PP) resulting from the degradation of infant feeding bottles. This PP is also heavily used in food packaging. Nearly 16 million particles were measured to release from the PP bottles per one liter of milk, where sterilization and exposure to high temperatures were the major factors causing the degradation of the PP bottles [15]. Exposing those resulting microparticles to the intestinal cells activates intestinal inflammation via the production of reactive oxygen species (ROS) and increases lipid peroxidation [16]. Also, MP exposure resulting in the high expression of pro-inflammatory cytokines such as IL-6 and TNFα triggered the inflammatory process, activating the NLRP3 inflammasome, which is crucial in activating the inflammatory chain reactions, as shown in Figure 2. All these works highly indicate the potential health risks posed by microplastics in the human placenta, especially in infants, coming through plastic feeding bottles [17]. Therefore, proper guidelines should be given by the healthcare departments to avoid sterilization of infant feeding bottles at high temperatures, which could minimize the generation of microplastics. A study by Dong and co-workers reported that microplastics (50 to 100 µm) are ubiquitous, especially in placentas and meconium, where mostly polyamide (PA) and polyurethane (PU) are major contributors. Also, they found a correlation between the high concentration of microplastics and microbiota genera and meconium [10].

Impact of microplastics on aquatic species: Microplastics are ubiquitous, spanning from the equatorial zones to the polar regions and from surface water to the depths of sea sediments. Due to their small size, microparticles rapidly disseminate via water and wind. As a result, these particles are found across different water bodies, in the depths of the oceans, and also in aquatic inhabitants [18]. The morphology of microplastics in aquatic environments has been studied and categorized mainly as debris, film, foam, microbead, and fine lines/fibers. It has also been identified that the primary pathways for these plastics to enter the ocean are road runoff (66%), wastewater treatment systems (25%), and wind transfer (7%) (*Plastics Europe*, 2016). Numerous studies have documented the range of plastic sizes, including diameters of <10 mm, <5 mm, <2 mm, and <1 mm [19]. The presence of microplastics in water bodies has a detrimental effect on aquatic organisms, mainly attributed to ingestion and entanglement. Primarily, ingestion occurs due to misjudgment by predators, as the microplastics resemble food particles or certain organisms in form, smell, or color [20].

The second aspect is that organisms consume microplastics indirectly by consuming prey that previously had them within their bodies or adhered to their surfaces [21,22]. Microplastics that enter organisms may initially remain in the intestinal tract temporarily, with some eventually being excreted. Smaller MPs can migrate into other tissues or organs and be transported through the food chain. Several studies have demonstrated that microplastics' ingestion is influenced by numerous factors, such as species and their feeding habits, characteristics, and bioavailability of MPs. Due to this, the abundance and characteristics of MPs are diverse in different species. According to Su, et al. non-selective feeders had a higher probability of consuming MPs than selective feeders, particularly filter feeders [23]. Filter-feeding fish take vast amounts of water that contains plankton and other particles. They subsequently expel the water through their gills, which causes MPs to be inhaled. Food selectivity and predation strategies of different species also contribute to the differences in MPs ingestion. Since most fish rely primarily on vision to search for prey, characteristics such as the color and shape

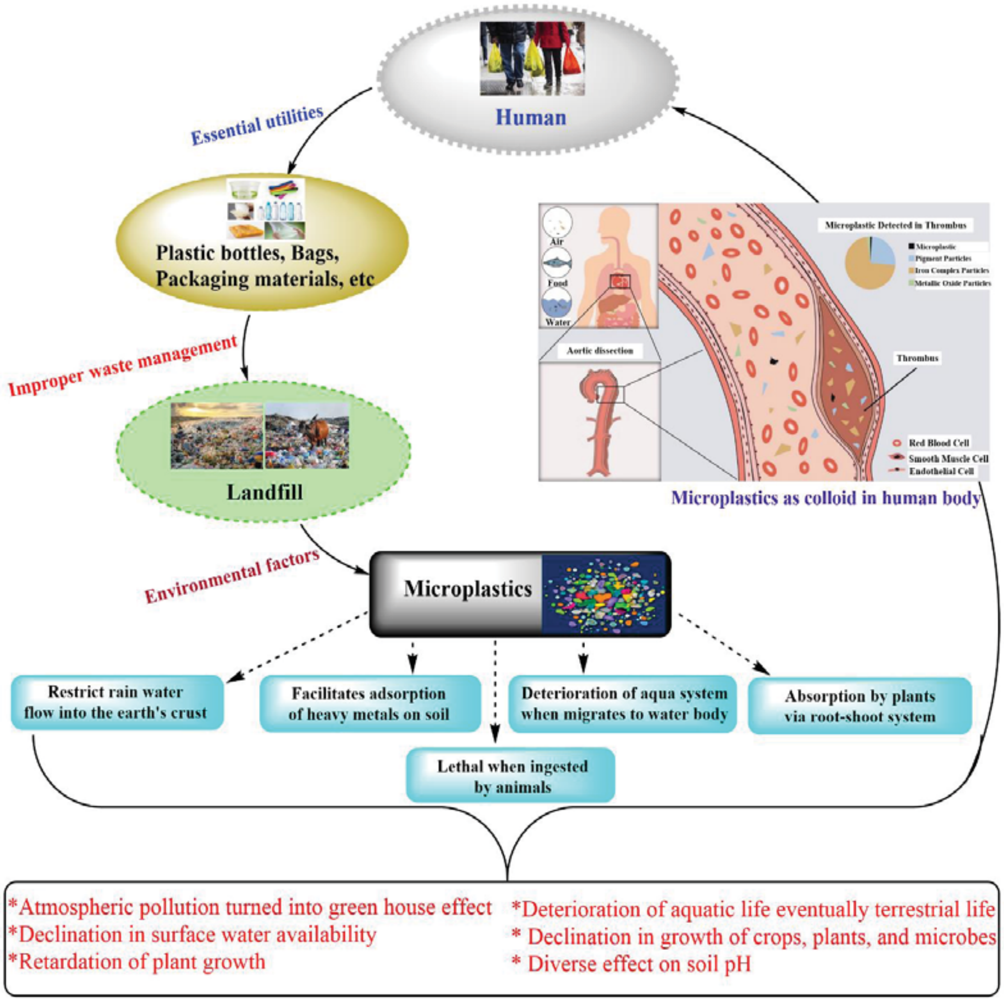

Figure 1: The microplastic generation from the bulk plastic landfills and their exposure to humans.

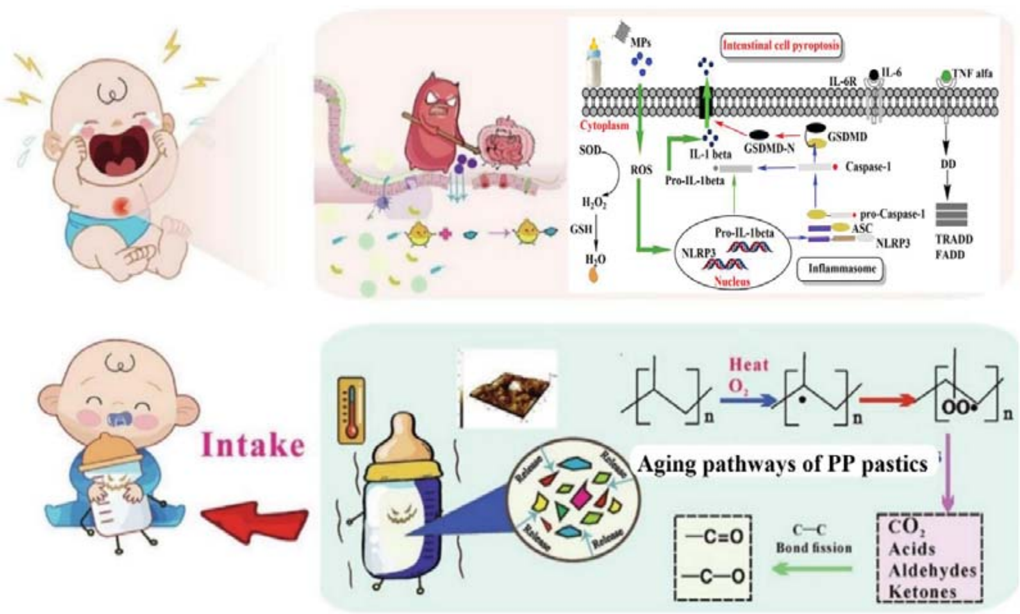

Figure 2: Shows the possible degradation of polypropylene (PP) plastic used in infant feeding bottles, where the exposure (sterilization) of PP plastic to heat and oxygen resulted in forming the microplastic and the exposure of those microplastic to the intestinal cells and activating the NLRP3 inflammasome through reactive oxygen species (ROS) generation. This figure is adapted from the Reference [16].

of MPs influence feeding behavior, resulting in microplastic ingestion. The properties of MPs, such as shape, size, color, and the type of polymer, influence their bioavailability. A research study by Kim, et al. showed that Zebrafishes can recognize MPs as inedible materials, but rarely do they discriminate between microplastics and food when presented together [24].

Ingestion of MPs results in abrasions (internal/external), physical damage, clogging of the digestive tract, and ulcers. When MPs build up over time in an organism, they can cause pathogenic responses such as lipid accumulation and inflammation [25,26]. It has been demonstrated that aquatic species exposed to MPs suffer from malnourishment and eventually die. A report by Xu, et al. highlighted that intake of microplastics led to abnormal breathing and swimming patterns in Asian Green Mussel *Perna viridis* and *Goby Pomatoschistus microps*, eventually leading to impaired growth [27]. It has also been demonstrated that aquatic species exposed to MPs succumb to malnourishment, leading to death. MPs interact with abiotic elements in addition to aquatic creatures, influencing aquatic environments and biota. To sum up, MPs can transport more contaminants into living things. Ecosystems may suffer from various effects from heavy metals in plastic color and additives emitted by deteriorating MPs. Therefore, it is quite essential to alleviate MP pollution, as failure to do so will endanger biodiversity.

Impact of microplastic on agriculture or crops: Plastic films are widely used to regulate the soil's temperature and increase water use efficiency, thereby improving crop growth and the quality of raw material production. More than 128,652 km^2 of agricultural land in the world is covered with plastic films [1]. Micro Plastics can alter soil physicochemical properties, enzyme activities, microbial communities, soil animals, and plant growth, and these effects can be positive, negative, or negligible, which can be attributed to variations in microplastics (e.g., polymer type, content, size, and shape), soil properties, exposure time, etc. Low-density microplastics migrate via soil erosion and into soil via soil pores. Earthworms' life activities play a significant role in the transportation of microplastics in the soil environment. Microplastics can be eaten and eventually excreted by earthworms. Soil organic carbon (SOC) and clay significantly affect the adsorption and movement of polystyrene microplastics [28]. Hence, the migration of microplastics unfortunately increases the potential risks to microplastic pollution and humans and our ecosystems. It has been studied that an increment in concentrations of microplastics in the soil can affect soil quality and fertility by changing its structure, bulk density, and water-holding capacity. It was found that low-density polyethylene (LDPE) and polypropylene (PP), which are used for mulching purposes, are profiled as essential sources of microplastics in agricultural soil [29]. Immense use of single-use plastics and lacuna in managing these in suburban areas, along with improperly managed landfills and gaps in waste separation procedures, are the primary and secondary sources of MP in agricultural soil in the region [30]. Low-density polyethylene agricultural mulch decomposition has been named "white pollution" because of its lack of color and abundance in surface and subsurface soils [31].

Impact of microplastic on soil: Microplastics and microfibers alter the process of soil formation, stabilization, and disintegration of soil aggregates [32] Plastic mulching, widely used in crop fields, is a crucial parameter of soil degradation. Nevertheless, this mulching type has become a worldwide agricultural practice because of its benefits. At the same time, plastic mulch reduces soil nutrients and carbon stocks [33]. Several mulches contain plastic waste with harmful additives [34]. Microplastic contaminates terrestrial soils, which is probably more severe than that in the aquatic environment because of the massive use of agricultural plastic films and particles in industrial production [35]. Introducing microplastic to agroecosystems reduces food yield and negatively impacts food chain components, food security, and human health [36]. Heavy metal pollution is another crucial parameter related to farmland microplastics, mainly caused by pesticides, wastewater, sludge, and atmospheric deposition. Heavy metal assembles on the polar sites on the microplastic surface through the nonspecific interaction between neutral organometallic complexes and hydrophobic surfaces [37].

It has been observed that microplastics and cadmium (Cd) may facilitate root symbiosis and, thereby, plant performance changes, resulting in soil biodiversity and agricultural ecosystems. Microplastics helped immensely change root length, root mean diameter, total root area, root tissue density, germination, and simultaneously, the ground biomass. Different food crops have various sensitivities to microplastics in these aspects. It has been speculated that the decrease in crop germination may be because of the blockage of pores in the seed capsule by microplastic particles, resulting in less yield in crop production [38]. MP particles affect the changes in soil properties significantly affect soil organisms, especially earthworms, which may affect the biophysical properties of the soil based considerably on the sizes and shapes of MP [39]. De Souza Machado, et al. reported that when polyamide microplastic was present in the soil the increase in nitrogen content of onion leaves was observed. At the same time, polyester fiber decreased the nitrogen content in onion leaves as it does not have nitrogen content. Rather, oxygen exists, which provides substantial proof of microplastic adulteration in fruits and vegetables. Hence, nitrogen-containing microplastics can increase plant leaf nitrogen content, thereby changing leaf tissue's carbon-nitrogen ratio [40]. Zhang and Liu reported that they had found MPs in the abundance of 0.54 mg/kg in agricultural land at the Loess Plateau in China [41]. The exposure of microplastics may cause structural changes in the burrows of the earthworms, which may reflect dysfunction of soil aggregation and operation. In addition to this, various fruit and vegetable plants may uptake microplastics from the soil and move in the food chain, which leads to human consumption, and it has been observed that approximately 80 mg of MPs per day [42]. Hence, above all, this evidence has introduced that microplastics threaten the terrestrial ecosystem. Microplastics can provide new microbial niches, which promote the proliferation of specific microorganisms, which may have unpredictable consequences on ecosystem functions [43]. However, many plastics are in direct contact with food (e.g., meat, cheese, fruit and vegetables, fish) either by packaging with plastic containers or by manufacturing with plastic derivatives similar to food adulteration. Brooks, et al. reported that 120 food packages showed the presence of more than 100 chemical compounds [44]. Edo, et al. reported on the impact of microplastics on insects, which is also related to the agro-ecosystem [45]. Microplastics were found in bees, especially on the edge of the wings and head, which was a surprising result. Bees fly many miles and come into contact with all elements of the environment (from the nectar of flowers to the air) to bring pollutants into their hive, where microplastics eventually accumulate, resulting in honey and other beehive products. This way, microplastics harm vegetation plants, insects, and humans, comprehensively the whole ecosystem. In addition to honey samples, polyethylene, polypropylene, and polyacrylamide polymers were also found in other food products like beer, milk, and soft drinks collected in Ecuador, ultimately relating to the deterioration of the agricultural ecosystem [46].

Effect of microplastics on Human Health through Agro-Packaging Materials: The existence of microplastics in edible vegetables like carrots, lettuce, broccoli, and potatoes and edible fruits like apples and pears depict that microplastics may flow into the market and reach our kitchen, exhibiting a potential threat to human health [47]. Peihl, et al. reported that cattle, waterfowl, ducks, poultry, and other livestock are also exposed to microplastic pollution [48]. It was reported that there are microplastics in livestock and feces in 19 farms raising pigs, poultry, and cows in southern China. Other researchers used ATR-MIR to determine that chicken contains microplastic polystyrene (100 μm) and polyvinyl chloride (3 μm, 100 μm, and 2 to 4 mm). The food chain maintains the hierarchy via which energy or nutrients are transferred from primary producers through the elementary consumers to the decomposers in an ecosystem. The nitrogen cycle is a crucial predictor of terrestrial ecosystems' ecological stability and management [49]. The presence of microplastics in soil can promote the emission of N_2O during soil nitrification and inhibit oxygen emission during soil denitrification [50]. Several studies found that MPs can accumulate in the intestines after entering the human body, which may result in local inflammation, disrupt endocrine regulation, and affect normal gastrointestinal functions [51]. Teles, et al. explained that this may also destroy the community composition and diversity of intestinal microbes and cause disorders in the intestinal microbial community, thereby affecting human health [52]. Teles, et al. also showed that MPs can pass through the intestinal barrier and enter the circulatory system, including the liver and spleen. In addition, MP contents, such as bisphenols and phthalates, are also related to endocrine disorders and many health problems; major noticed diseases were diabetes, cancer, and obesity [53].

Conclusion and perspectives

Exposure to micro or nanoplastic in humans, including plants, is inevitable, and understanding the interference and the effect of microplastic and nanoplastic particles on various organisms is still at the infant stage. The critical information available to date is limited regarding the exposure of microplastics to enclosed organs like the heart, which is essential to understanding the long-term effect of microplastics. There is also a lack of suitable techniques to analyze the presence of MPs in human tissues. A laser infrared imaging spectrometer (LIIS) and Fourier-transform infrared microscope (FTIM) were used to analyze such MPs in the respiratory tract and sputum and obtained results confirmed that PU, PES (polyether sulfone), and chlorinated polyethylenes are the most commonly detected plastic materials [54]. Such advanced techniques need to be developed to detect microplastics in humans quickly. One more critical work confirmed the positive correlation between the amount of microplastic particles and the severity of inflammatory bowel disease (IBD), which depicts the potential to understand the long-term effect of microplastics on the human digestive system [55]. One of the central rising concerns has been MP toxicity to ecosystems. The entire basin needs extensive long-term monitoring to fully comprehend MPs' distribution properties in the aquatic environment.

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