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Review

The impact of microplastic pollution on ecological environment: a review

Xi Mao[1,2,*], Yuchen Xu[2], Zhong Cheng[2], Yunbo Yang[2], Zetang Guan[2], Lu Jiang[2], Kai Tang[2]

[1]School of Civil Engineering and Architecture, Wuyi University, 354300 Wuyishan, Fujian, China
[2]College of Water Conservancy and Hydropower Engineering, Sichuan Agricultural University, 625014 Yaan, Sichuan, China
*Correspondence: maowhiteknight@163.com (Xi Mao)

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Abstract

Microplastic pollution and its impact on the ecological environment have attracted worldwide attention. The strong adsorption capacity of the microplastic surface plays an important role in the migration of microplastics throughout the environment. Synergistic effects between microplastics and persistent organic pollutants increase the toxicity of pollutants to organisms. In addition, microplastics cause different degrees of harm to aquatic organisms with different nutritional levels. However, the toxic effects of microplastics and organic pollutants on organisms, the distribution of microplastics in higher aquatic organisms, and the nutrient transfer in complex aquatic food webs require further research. Therefore, studying the impact of microplastics on the ecological environment would provide insights into controlling microplastic pollution. This paper in-depth discusses the source, distribution, and transmission of microplastics and summarizes the current situation of the impact of microplastics on the ecological environment, including physical, chemical, and biological effects. This paper also suggests topics for further research on the influence of microplastics on various aspects of the ecological environment.

Keywords: Aquatic organism; Ecological environment; Microplastic; Microplastic pollution; Water environment

1. Introduction

Microplastic pollution has become a global environmental problem, and many scholars have studied the toxicity of microplastics. When microplastics enter organisms, microplastics threaten biological health through oxidative stress, nerve injury, endocrine disruption, immune injury, and other mechanisms. Additionally, when microplastics exist in the environment, under certain conditions, the interaction between microplastics and persistent organic pollutants has uncertain effects on organisms, most of which are harmful. When plastic products manufactured and discarded by human beings enter the ecological environment, the harm to organisms may affect human beings through the food chain.

With the increasing amount of microplastics entering the ecological environment, the control of microplastic pollution has substantial significance for environmental protection and species protection.

Microplastics are plastic particles with a diameter of less than 5 mm. Due to the wide existence of microplastics in the ecological environment and various determined and uncertain hazards to organisms, microplastics have received extensive attention from a wide range of research fields. Microplastics can exist in the environment for hundreds of years because of their stable chemical properties [1]. At present, most plastics are low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polystyrene (PS), polyethylene tetraacetate (PET), and polyvinyl chloride (PVC). Sources of microplastics are divided into primary and secondary sources [2]. Primary sources are mainly plastic particles in personal care products and cosmetics. Secondary sources are microplastics derived from the physical, chemical, and biodegradation of large plastics. Surface runoff, wastewater from sewage treatment plants, aquaculture and fishery, dumping of household and industrial wastes, and atmospheric emissions into the ocean are reasons for microplastics that enter the ecological environment [3].

These widely distributed microplastics threaten marine organisms. Plastics of different colors, volumes, and shapes exist in the water environment [4]. Because their small density, light volume, and particle size are similar to the food of many marine organisms, microplastics are eaten by or adsorbed on marine organisms after entering the water and accumulate in their gastrointestinal organs and tissues, threatening their health [5]. High-nutrient organisms accumulate microplastics by eating low-nutrient organisms whose bodies have accumulated microplastics [6]. After entering organisms, microplastics harm them through different mechanisms. Human consumption of fish containing microplastics may result in microplastics entering the human body, posing an unknown threat to human health and, ultimately, affecting biodiversity.

Persistent organic pollutants are common in the ecological environment. Because of the adsorption characteristics of microplastics, they interact with adsorbed persistent organic pollutants, resulting in compound toxicity, indirectly affecting organisms. The advantages and disadvantages of this interaction for biological effects are unknown, and under certain circumstances, this interaction may benefit organisms. Additionally, microplastics can be used as a carrier of persistent organic pollutants such that they migrate to the ocean and threaten marine organisms.

2. Microplastic distribution

Plastic waste enters the natural environment after its degradation into smaller particles due to photooxidation, weathering, and mechanical and biological degradation, resulting in microplastics [7]. Microplastics are difficult for organisms to digest and decompose, which allows them to spread throughout the global food chain. The closer an organism is to the top of the food chain, the higher its content of microplastics; thus, this phenomenon seriously endangers human health. Studies have demonstrated the existence of microplastics in plankton, fish, and seabirds [8,9].

With the wide use of plastics and the transfer of food chains, microplastic pollution has become a global environmental problem. For example, Wang *et al*. [10] demonstrated that the Wuliangsu Sea in northwest China contained microplastics with an abundance ranging from (1.76 ± 0.71) to (10.12 ± 4.09) nL^{-1}. After sampling and analyzing the sediments from 72 sedimentary sites in the Bohai Sea and the Yellow Sea in eastern China, the researchers found that the sediments contained a small amount of microplastics, and the particle size was between 66.25 and 4982.59 μm [11]. In the Caspian coastal environment, the pollution of microplastics varies in the number of microplastics [12]. Microplastic pollution is common in various environments of the Bristol Strait beach, United Kingdom [13].

The influence of the ocean current and atmospheric circulation causes dynamic changes in the abundance and distribution characteristics of microplastics in the marine environment. Studies have not found microplastics in the surface waters of Antarctic coastal waters less affected by human activities [14]. However, in a subsequent study, the researchers investigated and analyzed the average abundance of microplastics in lateral Antarctic fish near the South Shetland Islands, which is (0.36 ± 0.51) n/n and has been slightly polluted [15]. These research conclusions show that the distribution of microplastics has spread to various world regions and has gradually become a serious global pollution problem. Research on the distribution characteristics of microplastics has focused on the spatial and temporal variation characteristics of surface sediments, not vertical distribution characteristics. Microplastics are buried in the deep sea due to wind, tides, waves, and other external forces. The complex environment in water and the activities of aquatic organisms also make the vertical distribution of microplastics complex and dynamic. Fibers and microplastics are easily attached by organisms and settled to the seabed. Studies have shown that the vertical movement of microplastics substantially influences the size and abundance distribution of microplastics [16]. Cheng *et al*. [17] conducted a continuous seasonal survey in the coastal zone of Yantai and found that the microplastics in the water migrated between the surface water, the water, and seabed sediments through diffusion, suspension and resuspension, settlement, and burial; in their research area, the content of microplastics in the surface water was significantly higher than that in the bottom water.

3. The mechanism of microplastics affecting biology

3.1 Oxidative stress

Microplastics can break the dynamic balance of normal redox by affecting the activity of antioxidant enzymes *in vivo*, resulting in the oxidative damage of biological macromolecules and interfering with normal life activities.

Microplastics cause oxidative stress in organisms, which can lead to cell damage and cell membrane structure damage, resulting in a decrease in cell membrane permeability, affecting the normal physiological process of cells (e.g., reducing cell growth rate and fecundity). Isocitrate dehydrogenase (IDH) is essential to maintain the redox balance of cells. Microplastics can inhibit the activity of IDH, leading to oxidative stress and muscle injury in organisms [18]. Photoautotrophic organisms (e.g., algae and cyanobacteria) are the basis of aquatic food networks, which are crucial to aquatic ecosystems. Algae exposed to nanoparticles has been observed to inhibit the photosynthesis of algae and begin to produce reactive oxygen species (ROS). The intake and accumulation of microplastics increase the ROS content in algae cells, leading to oxidative stress in algae cells [19].

3.2 Neurological damage

Inhibition of acetylcholinesterase (AchE) was found in various organisms exposed to microplastics. It can also be thought of as hindering neuronal function and may decrease neuronal network function [20]. AchE dissolves acetylcholine (ACH) into choline and acetic acid, which are crucial to the normal function of the nervous system [21]. AchE is often used as a biomarker in experiments to determine whether the experimental target causes neurotoxicity. For example, after black crucian carp larvae ate polystyrene microplastics [(24.7 ± 0.2) nm], their brain tissue showed swelling and low activity [22]. Oliveira *et al*. [23] studied the impact of polyethylene (PE) microplastic particles on marine organisms, the larvae of Pomatoschistus microps were exposed to a solution of 184 μg/L PE microplastics (1–5 μm), the results indicate that the particles inhibited the activity of AchE, leading to the blocking of neurotransmitter transfer in fish and ultimately affecting nerve function.

3.3 Endocrine disruption

In modern industrial production, plastic synthesis and processing add organic and inorganic components to plastic to expand the efficiency of the final plastic product. Chemicals such as phthalates, polybrominated diphenyl ethers, and bisphenol A are added to plastics as plasticizers, flame retardants, stabilizers, and fungicides. These substances can thus be used as endocrine disruptors, causing serious endocrine-disrupting effects in development and reproduction [24]. Phthalates and bisphenol A can destroy the thyroid function of amphibians and affect larval development [25]. Moreover, phthalates can cause endocrine disruption in fish by affecting the signaling pathway that targets the nuclear hormone receptorand possibly destroying their endocrine regulation [26,27].

3.4 Immune injury

After biological intake, microplastics can enter the immune system through their accumulation and transfer in tissues and organs and interfere with immune response. Microplastics can interfere with the natural defense mechanism of fish and can be a stress source. Therefore, the entry of microplastics into fish can lead to reduced phagocytic activity of immune cells, reduced cell viability, and destruction of the lysosome membrane [28]. Microplastic exposure may also cause inflammation and affects the activation of pro-inflammatory cytokines. Microplastics can affect the release of cytokines or changes in inflammatory response genes in *in vitro* cell line models [29].

4. Interaction between microplastics and organic pollutants

Microplastics are a primary source of pollutants in the ocean, are toxic, and have a surface with a strong adsorption capacity. Mato *et al*. [30] found that the main source of toxic chemicals in the ocean is the adsorption of organic pollutants by plastic additives or their degradation products. Therefore, microplastics can be used as a carrier of persistent organic pollutants and transmitted to oceans worldwide, harming marine organisms.

4.1 Adsorption of organic pollutants by microplastics

Adsorption of organic pollutants by microplastics is a notable interaction. Xu *et al*. [31] found that microplastics could be used as the carrier of sulfate in a water environment. Li *et al*. [32] found that polyamide particles, which are frequently observed in water environments, can be used as carriers of antibiotics. Rochman *et al*. [33] found complex metal mixtures on plastic fragments composed of various plastic types. These studies show that microplastics have an adsorption effect on organic pollutants in the environment. Moreover, the type, particle size, and aging degree of microplastics affect the adsorption of organic pollutants. Different types of microplastics have different adsorption capacities for organic pollutants. Wang *et al*. [34] studied the adsorption effect of PE and nylon fiber on hydrophobic (phenylpropene) and hydrophilic (phenol) organic pollutants; the results showed that the adsorption capacity of PE was approximately 1–2 orders of magnitude higher than that of nylon fiber, indicating the importance of surface functional groups (with or without hydrophilic groups) for plastics. The adsorption process of a polymer is closely related to its particle size. Zhang *et al*. [35] studied the adsorption of 3,6-dibromocarbazole and 1,3,5,6,8-tetrabromocarbazole on polypropylene microplastics with different particle sizes in simulated seawater; they found that the adsorption capacity of microplastics increased with the decrease in particle size. Napper *et al*. [4] found that rough particles of pollutants were easier to adsorb than smooth particles; they used adsorption experiments of PE on binary mixtures of organochlorine pesticide bis-p-chlorophenyltrichloroethane (C-DDT) and H-phenylpropene. The aging degree of microplastics influences their adsorption capacity. Alimi *et al*. [36] found that aged microplastics adsorb more PCBs than unaged microplastics. In addition, there are a variety of adsorption mechanisms in the process of microplastic adsorption of organic pollutants, and the degree of influence of various adsorption mechanisms is jointly determined by the properties of plastic, water environment and organic pollutants.

4.2 Transport of organic pollutants by microplastics

Microplastics in the environment easily migrate, diffuse, and redistribute globally because of their small particle size, stable chemical properties, and hydrophobicity. Microplastics play a notable role in the transportation of pollutants, especially hydrophobic microplastics [37]. JAVIER *et al*. [38] studied the adsorption of polychlorinated biphenyls (PCBs) by microplastics; the results showed that the adsorption process was reliable and repeatable for the samples of double distilled water and treated urban sewage, indicating that there were different interactions between organic pollutants and plastics. Wang *et al*. [34] demonstrated that a high abundance of plastic fibers can lead to a higher pollutant transfer effect than marine sediments. In the study of the interaction between microplastics and freshwater microalgae by Lagarde *et al*. [39], microplastics colonized and aggregated rapidly by microalgae, which may lead to changes in the buoyancy of polymers. Therefore, the amount of sedimentation of polymers and microplastics differs due to the chemical properties of microplastics, resulting in different transport routes and uneven distribution. The transport routes of microplastics to the water environment include surface runoff, river inflow, sewage discharge, and shipping et cetera. In recent years, the amount of microplastics in rivers has increased year by year, and the prevention and control of microplastics have also been extended from the ocean to the inland. Surface runoff and river inflow are the main ways for the migration of inland pollutants. Meanwhile, rainfall is the most direct factor to form surface runoff. Therefore, rainfall is a major environmental factor for microplastic pollution in inland waters. Xia *et al*. [40] proved the close relationship between rainfall and microplastic abundance in the rainfall on East Lake: the abundance of microplastics changed significantly and was significantly affected by rainfall.

4.3 Joint toxicity of microplastics and persistent organic pollutants

Microplastics contain toxic substances. Lambert *et al.* [41] found that the ecological toxicity of microplastics may be related to their physical and chemical properties, including particle size, particle shape, crystal, polymer, and additive components. Microplastics can cause disorders of the intestinal flora, destroying the ratio of probiotics and pathogenic bacteria [42]. Fish intake of microplastic debris at a certain concentration of organic pollutants may damage the endocrine system function of adult fish [43]. Studies have shown that microplastic organic pollutants can be deoxygenated in the intestine of fish [44]. Obviously, microplastics do have toxic effects on organisms.

After microplastics adsorb organic pollutants, the two interact. Studies, for example, Giacomo *et al.* [45] have shown that microplastics can adsorb polycyclic aromatic hydrocarbons, highlighting the high bioavailability of these chemicals after intake and the toxicological effects of multiple molecular and cellular pathways on microplastics. Studies have also found that when microplastics are exposed to low concentrations (e.g., 2 ug/L) of 17α-ethylenediethylene glycol (EE2), the inhibitory effect of EE2 on zebrafish movement is reduced because of the decrease in free dissolved EE2 concentration. However, when the concentration of EE2 is increased to 20 ug/L, EE2 and microplastics show a strong destructive effect on zebrafish [46]. The findings of these studies show that synergistic or antagonistic effects occur when microplastics adsorb persistent organic pollutants.

5. Potential effects of microplastic pollution

5.1 Potential effects of microplastics on organisms

Data show that microplastics exist in air, drinking water, and food, which are essential for human survival. Microplastics floating in the air enter the human respiratory system through breathing. The intake of food and drinking water containing microplastics transports microplastics into the human digestive system [47–49]. Results showed that the number of microplastics entering the human body through salt, drinking water, and breathing was (0–7.3) $\times$ 10^4, (0–4.7) $\times$ 10^3, and (0–3.0) $\times$ 10^7 per person per year, respectively [50]. Although the impact of microplastics on human health remains unclear, researchers have generally posited that microplastics have a potential negative impact on human health [51]; for example, microplastics can penetrate the lungs. Furthermore, frequent contact may cause adverse symptoms in the respiratory system and increase the carcinogenic rate [52].

In agriculture, the extensive use of chemical fertilizers and plastic films containing microplastics has caused the microplastic content in agricultural soil to exceed that in the marine environment [53]. However, the study of plant ecotoxicological effects of microplastics remains in the preliminary stage [54]. Only a few investigations have demonstrated the effects of microplastics on plants such as mung bean [55], wheat [56,57], and soybean [58]. Studies have shown that di (2 – ethyl hexyl) phthalate (DEHP) in PVC agricultural film can be precipitated in large quantities under weak acidic conditions [59], resulting in potential toxicological effects on plants. Liu *et al.* [60] found that plasticizers in plastics (phthalate esters) can inhibit the germination of wheat seeds and cause programmed cell death of wheat seeds at high concentrations (1500–1800 mg$\cdot$L^{-1}). In addition, the surface of weathered microplastics in the environment is rough and has a large specific surface area and negative charge [61,62], which can adsorb heavy metals and organic pollutants, becoming the environmental carrier of pollutants and having a certain impact on plants. Therefore, the combined effect of microplastics and heavy metals or pesticides in agricultural systems requires further research. In addition, Giorgetti *et al.* [63] reported that 50 nm polystyrene nanoplastics could be internalized in onion root division cells, causing oxidative stress, cytotoxicity (e.g., mitotic abnormality), and gene toxicity. Therefore, studying the types and particle sizes of microplastics is essential to revealing the plant toxicity of microplastics.

5.2 Potential effects of microplastics on the ecological environment

The amount of plastic fibers found deposited in the air of France is 2–355 / (d$\cdot$m^2), with an average of 0.9 plastic fibers per m^3 outdoor air [64,65]. Microplastics in the above air can enter the marine environment. At present, although indoor toxicological experiments have demonstrated that microplastics can produce various toxic effects on organisms, the concentration of microplastics used in those experiments is much higher than that in the real environment. Therefore, whether microplastics harm the ecosystem in low concentrations in the real environment remains unknown. Notably, many studies have shown that microplastics can be enriched along the food chain through aquatic products and salt.

Plastic degradation in soils is slow because of the lack of sun exposure and mechanical wear [66]. These microplastics can continue to accumulate in the soil and form a sink of microplastics in the soil. Because microplastics are surrounded by soil particles or combined with soil aggregates, they may affect soil bulk density, permeability, water holding capacity, and water stability agglomeration in soil [67]. Anderson *et al.* [68] studied the effects of four types of microplastics (e.g., PP and PET) on bulk density, water holding capacity, and water stability agglomeration of sandy soil and found that only PET had a negative correlation between soil bulk density and water stability agglomeration, and other types of microplastics had no effect. However, Zhang *et al.* [69] demonstrated a different result:

PET had a negative impact on soil water holding capacity and had no effect on soil bulk density [70]. This difference may be due to the use of different soil physicochemical properties in the experiment. In addition, microplastics may change soil porosity through permeability or affect soil permeability and further affect water evaporation in soil. Due to the lack of research on this aspect, further exploration is needed to fully verify the above theories.

6. Conclusions

The study of microplastic pollution has attracted worldwide attention. Despite the progress made in some aspects, many problems require further research.

(1) Establishing a standard method for measuring microplastics is necessary. Because, on the one hand, in the distribution of microplastics, different sampling methods affect the vertical and horizontal distribution results of microplastics in the ocean. Uniform standards should therefore be adopted for sampling. On the other hand, because of the diversity of plastic types, shapes, and diameters, and their wide distribution in different environments, the methods used in the literature differ from the sampling and analysis methods; this difference in methods has profoundly affected the comparability between studies.

(2) The joint pollution effects of microplastics and other environmental pollutants deserve further study. Because, for example, plastic synthesis and processing are added to plastic organic and inorganic components to expand the effectiveness of the final plastic products, and microplastics usually contain additives or monomers. Furthermore, microplastics can adsorb heavy metals, organic pollutants, and other pollutants. Therefore, in all environmental compartments, plastic debris is highly likely to be associated with the exchange of other pollutants. Hence, the toxicity of microplastics is mostly compound toxicity that requires comprehensive study by combining its components.

(3) The separation and removal technology of microplastics in the wastewater discharge system deserve further study. Because, at present, the main treatment methods of microplastics are incineration and landfill, but many microplastics enter the water environment through the urban sewage discharge system, and there is no specific removal process for microplastics in the water environment. According to the existing law of microplastics in the wastewater discharge system, the related technologies can be reasonably enhanced to improve the removal rate of microplastics under the premise of ensuring the standard of wastewater treatment.

(4) Microplastics in soil are mostly caused by large quantities of waste packaging (e.g., agricultural films, plastic films, pesticides, and fertilizers used in agricultural production) and easily decompose into microplastics due to natural or human behavior (e.g., improper recycling). Because of the soil pollution caused by such behaviors, governments should pass relevant laws and advocate that individuals care for the environment and not discard plastic products. Additionally, enterprises can be subsidized to encourage the development of environmentally friendly plastic products.

Author contributions

XM is responsible for writing, editing, and reviewing the whole paper; YX and ZC participated in the 2nd, 3rd, and 6th parts; YY and ZG participated in the 4th part; LJ and KT participated in the 5th part.

Ethics approval and consent to participate

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Conflict of interest

The authors declare no conflict of interest.

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