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VIEWS

Understanding and addressing the environmental risk of microplastics

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Abstract Over the past decades, the plastic production has been dramatically increased. Indeed, a category of small plastic particles mainly with the shapes of fragments, fibers, or spheres, called microplastics (particles smaller than 5 mm) and nanoplastics (particles smaller than 1 μm) have attracted particular attention. Because of its wide distribution in the environment and potential adverse effects to animal and human, microplastic pollution has been reported as a serious environment problem receiving increased attention in recent years. As one of the commonly detected emerging contaminants in the environment, recent evidence indicates that the concentration of microplastics show an increasing trend, for the reason that up to 12.7 million metric tons of plastic litter is released into aquatic environment from land-based sources each year. Furthermore, microplastic exposure levels of model organisms in laboratory studies are usually several orders of magnitude higher than those found in environment, and the microplastics exposure conditions are also different with those observed in the environment. Additionally, the detection of microplastics in feces indicates that they can be excreted out of the bodies of animal and human. Hence, great uncertainties might exist in microplastics exposure and health risk assessment based on current studies, which might be exaggerated. Policies reduce microplastic emission sources and hence minimize their environmental risks are determined. To promote the above policies, we must first overcome the technical obstacles of detecting microplastics in various samples.

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Over the past decades, the plastic production has been dramatically increased, reaching more than 400 million metric tons in 2020 (SAPEA, 2019). With the widespread plastic application, polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polyurethane (PUR), polyethylene terephthalate (PET), polycarbonate (PC) and polystyrene (PS) constitute more than four fifths of its total production. Indeed, a category of small plastic particles mainly with the shapes of fragments, fibers, or spheres, called microplastics (particles smaller than 5 mm) and nanoplastics (particles smaller than 1 μm) have attracted particular attention (Wright and Kelly, 2017). Because of its wide distribution in the environment and potential adverse effects to animal and human, microplastic pollution has been reported as a serious environment problem receiving increased attention in recent years (Fig. 1). As one of the commonly detected emerging contaminants in the environment, recent evidence indicates that the concentration of microplastics show an increasing trend, for the reason that up to 12.7 million metric tons of plastic litter is released into aquatic environment from land-based sources each year (Besseling et al., 2019). Usually, homoaggregation of microplastics occurs when microplastics clump together without the presence of other solid constituents. Homoaggregation of microplastics is thought to be one of the most important environmental behaviors, particularly in aquatic environments. These behaviors are which determine the mobility, distribution and bioavailability of microplastics, leading to its wide distribution and potential risk (Wang et al., 2020; Wang et al., 2021). Additionally, one of the main routes for microplastics to reach isolated and remote regions is through atmospheric transfer, including tire

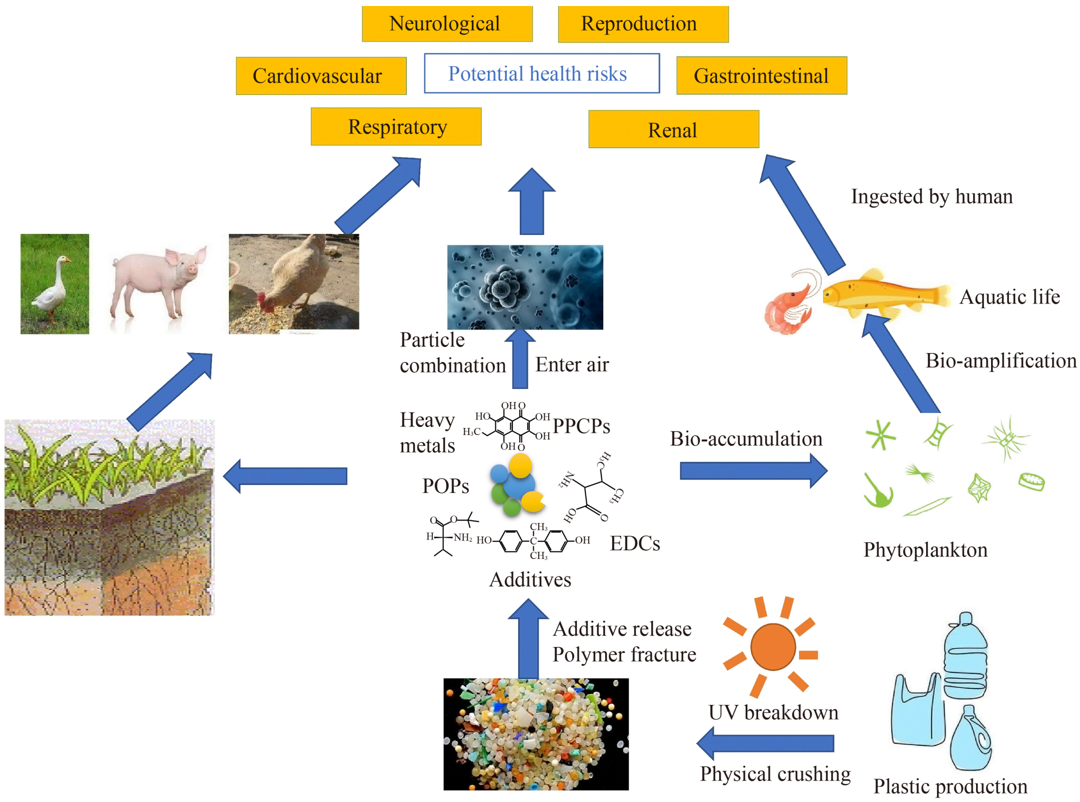

Fig. 1 Potential environmental exposure pathways and effects of microplastics.

wear particles (TWPs) and brake wear particles (BWPs) in road traffic emissions (Evangeliou et al., 2020). Quite a lot of studies have been focused on the microplastic pollution quantification in various environmental matrices. Because of their small size, microplastics can easily enter food web and end up in human food.

With regard to the hazardous effects of microplastics, an important point is that they can enter the body through inhalation and ingestion, potentially causing adverse health effect. Evidence of inhaled microplastics has been observed in animals and plants. Yuan et al. (2019) reported that PS-nanoplastics can be adsorbed and accumulated on the spore surface of *C. pteridoides* and posed a negative effect on spore inhibition. Our previous studies also identified microplastics could affect the aquatic organisms, which increased the pollutant enrichment via the food chain, caused insufficient intake of energy, and thus increased the mortality and disrupted the ecosystem balance (Qu et al., 2018; Qu et al., 2019; Qu et al., 2020). Human can be affected by microplastics through many pathways, including food and drinking ingestion. For example, up to 10^7 particles of microplastics were detected in 1 L of water, and other marine products source such as shrimp, fish, oyster, and salt also contained numerous microplastics (Yang et al., 2015; Akhbarizadeh et al., 2018; Cox et al., 2019). Many types of microplastics were detected in human feces, suggesting a human ingestion evidence. Meanwhile, the adverse effect of microplastics on humans has been forecasted, the smaller the particulate matter is, the deeper it can enter into body, including intestinal, pulmonary alveoli and even brain (Maher et al., 2016; Phuong et al., 2016). Microplastics had a similar effect on the animals as particular air pollutants, which can cross cell membranes and trigger oxidative stress, inflammation and cytotoxic (Wright and Kelly, 2017). Whether dose-dependent relationship between microplastics and human being are existing? Limited literature in human cells (*in vitro*) and mouse (*in vivo*) experiments suggest the microplastics may cause some biological effects, such as cytotoxicity, oxidative stress, inflammatory and DNA damage (Yong et al., 2020). Wright and Kelly also reported that when workers were exposed at high concentration of microplastics, they can lead to lung injuries which conclude inflammation, fibrosis and allergy (Wright and Kelly, 2017). Compared with microplastics, depending on the type of cell, the smaller nanoplastics could be ingested with some ease via endocytosis (Zhang et al., 2015). If this occurs, the nanoplastics may permeabilize endosomal membranes, interact with and alter vital organelles like the nucleus and mitochondria, as well as cellular processes including the creation of the mitotic spindle and chromosomal migration during cell division, which lead to cellular disruption of transporters throughout the exocytic pathway. Additionally, endosomal membrane traffic that is necessary for a number of crucial cellular activities, such as surface protein turnover, signal attenuation, and retrograde signaling from endosomal compartments, may be disturbed by the nanoplasitcs (Treyer et al., 2016).

It is not sufficient to just take into consideration the size of the particles and their quantity. Microplastics fate and toxicological effects would be affected by their polymeric composition, particle shape, surface area, density, persistence, sorbed contaminants, and the additive content (Hale, 2018). At least, we can not ignore the combined effects of coexistent microplastics and harmful pollutants in the environment. Actually, many types of chemicals (e.g., persistent organic pollutants (POPs), pharmaceuticals and personal care products (PPCPs), endocrine disrupting chemicals (EDCs), heavy metal and so on) are widely distributed in natural environment (Khan et al., 2022). Microplastics usually act as vectors to transfer and enrich the hazardous chemicals and their metabolites into the plants and animals in environment (Qu et al., 2018; Qu et al., 2020). A knowledge gap outlined above is that scarce information is available on co-effect of microplastics, chemical additives and adsorbed contaminants to organisms. Microplastics will weather once entering into the aquatic and terrestrial environment. The sorption and aggregation that occur between weathered microplastics and their co-existing constituents are affected by the increase in oxygen-containing functional groups and the specific surface area of microplastics that results from these processes. Other behavior like aging and aggregation may have an impact on the fate, transformation, and toxicity of microplastics in environment (Yuan et al., 2020; Duan et al., 2021). More adverse effect may be caused when microplastics and other chemicals cross biological membranes together (Huang et al., 2022). Large surface area of microplastics can increase the concentration of chemicals from outside to inside of the membrane. More serious liver injury and more contaminants accumulated in the liver were observed with the co-exposure of microplastics and venlafaxine against *Misgurnus anguillicaudatus* (Qu et al., 2019). Meanwhile, co-exposure with microplastics and methamphetamine will change the enantioselectivity, bioconcentration factors (BCFs), biomagnification factors (BMFs) and distribution of methamphetamine in the aquatic food chain and increase the chemical burden on aquatic organisms (Qu et al., 2020). For humans, microplastics may even "load" bacterial pathogens or antibiotic resistance gene, and then interact with gut microbiota (Lu et al., 2019). This "Trojan horse" effect of microplastics combining with other potential pathogens to human body deserves attention in further study. Although the above studies show various potential harms of microplastics, some scientists believe that microplastics are inert and there is not enough approved evidence of their own harm. Fortunately, there is an increasing number of microplastics studies against potential toxic effect in aquatic organisms, but adverse health effect on human being are still unconspicuous. According to the study of Zhang et al., the daily intake of microplastics (PC and PET) of human adult (0.2–5.8 μg/kg·bw/d) was several orders of magnitude lower than in pet (4.3×10^7–6.5×10^7 μg/kg·bw/d) (Zhang et al., 2021). Also, the daily microplastics intake is less than 0.004% of the other particles intake for general population (Mohamed Nor et al., 2021). Futhermore, microplastic exposure levels of model organisms in laboratory studies (4.2×10^7–1.1×10^{12} particles/m^3) are usually several orders of magnitude higher than those found in environment (0.004–9200 particles/m^3), and the microplastics exposure conditions are also different with those observed in the environment (Phuong et al., 2016; Rist et al., 2018). Additionally, detection of microplastics in feces indicates that they can be excreted out of the bodies of animal and human. Hence, great uncertainties might exist in microplastics exposure and health risk assessment based on current studies, which might be exaggerated (Fig. 2).

Although microplastic has become a hot research issue in the academic circle, their ecological and health risks are still not well understood. However, this does not hinder our ongoing efforts to eliminate their potential environmental risks. In January 2018, the "EU Plastics Strategy" proposed to increase the current plastic recovery rate from 30 % to 55 % by 2030. In January 2019, ECHA (European Chemicals Agency) proposed limiting the intentional use of microplastics in products put on the EU/EEA market in order to avoid or reduce the environmental pollution. In January 2020, the National Development and Reform Commission and the Ministry of Ecology and Environment of China jointly issued the "Opinions on Further Strengthening the Control of Plastic Pollution", commonly known as the "Plastic Ban Order", which requires that the management system for the production, circulation, consumption, recycling and disposal of plastic products should be improved in 2025, and the use of non-degradable plastics should be gradually banned and restricted. The successful implementation of these policies will surely reduce microplastic emission sources and hence minimize their environmental risks. However, a most important issue in understanding and addressing the environmental pollution risk of microplastics is the lack of sound analytical methods. The most common methods for detecting microplastics samples in the environment are transformed infrared spectroscopy (FTIR) and raman spectroscopy. Gas chromatography-mass spectrometer (GC-MS) and other hyphenated techniques, such as sequential pyrolysis (Pyr-GC/MS) and thermal desorption pyrolysis (TD-Pyr-GC/MS), together with other techniques, can be used to identify organic fragments and structural data of polymers, as well as chemical additives. Other mass spectrometry methods, such as ion mobility spectrometry (IMS), matrix-assisted laser desorption/ionization time-

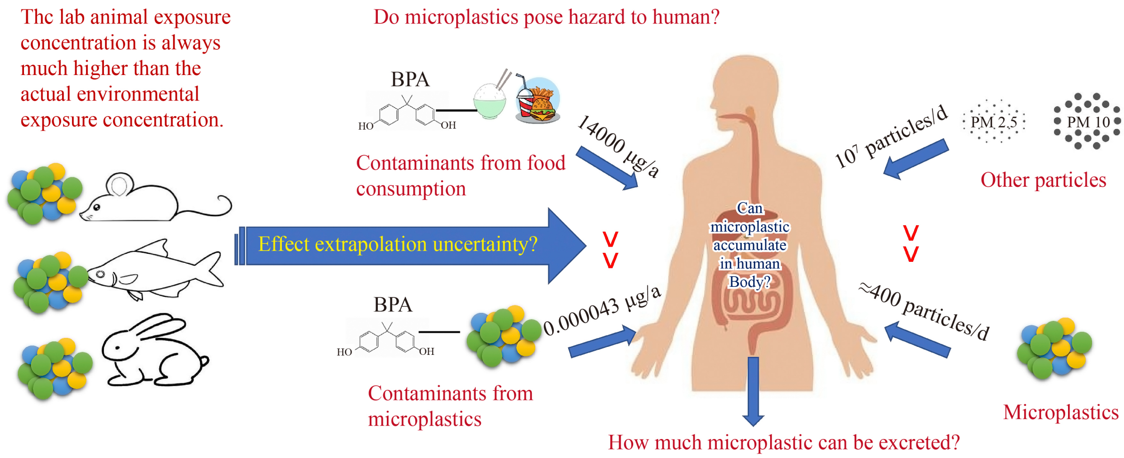

Fig. 2 Do microplastics cause serious human health?

of-flight mass spectrometry (MALDI-TOF-MS), and thermal desorption proton transfer reaction mass spectrometry (TD-PTR-MS), have been reported for the investigation of nanoplastics. However, currently, microplastic characterization and quantification capabilities of all aforementioned methodologies are constrained (Liu et al., 2022; Zhang et al., 2022). To promote the above policies, we must first overcome the technical obstacles of detecting microplastics in various samples. The standardization and quality control of microplastic detection method should be urgently developed.

References

Akhbarizadeh R, Moore F, Keshavarzi B (2018). Investigating a probable relationship between microplastics and potentially toxic elements in fish muscles from northeast of Persian Gulf. Environmental Pollution, 232: 154–163

Besseling E, Redondo-Hasselerharm P, Foekema E M, Koelmans A A (2019). Quantifying ecological risks of aquatic micro- and nanoplastic. Critical Reviews in Environmental Science and Technology, 49(1): 32–80

Cox K D, Covernton G A, Davies H L, Dower J F, Juanes F, Dudas S E (2019). Human consumption of microplastics. Environmental Science & Technology, 53(12): 7068–7074

Duan J, Bolan N, Li Y, Ding S, Atugoda T, Vithanage M, Sarkar B, Tsang D C W, Kirkham M B (2021). Weathering of microplastics and interaction with other coexisting constituents in terrestrial and aquatic environments. Water Research, 196: 117011

Evangeliou N, Grythe H, Klimont Z, Heyes C, Eckhardt S, Lopez-Aparicio S, Stohl A (2020). Atmospheric transport is a major pathway of microplastics to remote regions. Nature Communications, 11(1): 3381

Hale R C (2018). Are the risks from microplastics truly trivial? Environmental Science & Technology, 52(3): 931

Huang D, Chen H, Shen M, Tao J, Chen S, Yin L, Zhou W, Wang X, Xiao R, Li R (2022). Recent advances on the transport of microplastics/nanoplastics in abiotic and biotic compartments. Journal of Hazardous Materials, 438: 129515

Khan S, Naushad M, Govarthanan M, Iqbal J, Alfadul S M (2022). Emerging contaminants of high concern for the environment: current trends and future research. Environmental Research, 207: 112609

Liu S, Shang E, Liu J, Wang Y, Bolan N, Kirklam M B, Li Y (2022). What have we known so far for fluorescence staining and quantification of microplastics: a tutorial review. Frontiers of Environmental Science & Engineering, 16(1): 8

Lu L, Luo T, Zhao Y, Cai C, Fu Z, Jin Y (2019). Interaction between microplastics and microorganism as well as gut microbiota: a consideration on environmental animal and human health. Science of the Total Environment, 667: 94–100

Maher B A, Ahmed I A M, Karloukovski V, MacLaren D A, Foulds P G, Allsop D, Mann D M, Torres-Jardón R, Calderon-Garciduenas L (2016). Magnetite pollution nanoparticles in the human brain. Proceedings of the National Academy of Sciences of the United States of America, 113(39): 10797–10801

Mohamed Nor N H, Kooi M, Diepens N J, Koelmans A A (2021). Lifetime accumulation of microplastic in children and adults. Environmental Science & Technology, 55(8): 5084–5096

Phuong N N, Zalouk-Vergnoux A, Poirier L, Kamari A, Châtel A, Mouneyrac C, Lagarde F (2016). Is there any consistency between the microplastics found in the field and those used in laboratory experiments? Environmental Pollution, 211: 111–123

Qu H, Ma R, Barrett H, Wang B, Han J, Wang F, Chen P, Wang W, Peng G, Yu G (2020). How microplastics affect chiral illicit drug methamphetamine in aquatic food chain? From green alga (*Chlorella pyrenoidosa*) to freshwater snail (*Cipangopaludian cathayensis*) Environment International, 136: 105480

Qu H, Ma R, Wang B, Yang J, Duan L, Yu G (2019). Enantiospecific toxicity, distribution and bioaccumulation of chiral antidepressant venlafaxine and its metabolite in loach (*Misgurnus anguillicaudatus*) co-exposed to microplastic and the drugs. Journal of Hazardous Materials, 370: 203–211

Qu H, Ma R, Wang B, Zhang Y, Yin L, Yu G, Deng S, Huang J, Wang Y (2018). Effects of microplastics on the uptake, distribution and biotransformation of chiral antidepressant venlafaxine in aquatic ecosystem. Journal of Hazardous Materials, 359: 104–112

Rist S, Carney Almroth B, Hartmann N B, Karlsson T M (2018). A critical perspective on early communications concerning human health aspects of microplastics. Science of the Total Environment, 626: 720–726

SAPEA (2019). A scientific Perspective on Microplastics in Nature and Society. Science Advice for Policy by European Academies. Berlin: Oceanrep Geomar

Treyer A, Pujato M, Pechuan X, Müsch A (2016). Iterative sorting of apical and basolateral cargo in Madin-Darby canine kidney cells. Molecular Biology of the Cell, 27(14): 2259–2271

Wang X, Bolan N, Tsang D C W, Sarkar B, Bradney L, Li Y (2021). A review of microplastics aggregation in aquatic environment: influence factors, analytical methods, and environmental implications. Journal of Hazardous Materials, 402: 123496

Wang X, Li Y, Zhao J, Xia X, Shi X, Duan J, Zhang W (2020). UV-induced aggregation of polystyrene nanoplastics: effects of radicals, surface functional groups and electrolyte. Environmental Science. Nano, 7(12): 3914–3926

Wright S L, Kelly F J (2017). Plastic and human health: a micro issue? Environmental Science & Technology, 51(12): 6634–6647

Yang D, Shi H, Li L, Li J, Jabeen K, Kolandhasamy P (2015). Microplastic pollution in table salts from China. Environmental Science & Technology, 49(22): 13622–13627

Yong C Q Y, Valiyaveettil S, Tang B L (2020). Toxicity of microplastics and nanoplastics in mammalian systems. International Journal of Environmental Research and Public Health, 17(5): 1509

Yuan J, Ma J, Sun Y, Zhou T, Zhao Y, Yu F (2020). Microbial degradation and other environmental aspects of microplastics/plastics. Science of the Total Environment, 715: 136968

Yuan W, Zhou Y, Liu X, Wang J (2019). New perspective on the nanoplastics disrupting the reproduction of an endangered fern in artificial freshwater. Environmental Science & Technology, 53(21): 12715–12724

Zhang J, Wang L, Leonardo T, Kurunthachalam K (2021). Occurrence of polyethylene terephthalate and polycarbonate microplastics in infant and adult feces. Environmental Science & Technology Letters, 8(11): 989–994

Zhang S, Gao H, Bao G (2015). Physical principles of nanoparticle cellular endocytosis. ACS Nano, 9(9): 8655–8671

Zhang W, Wang Q, Chen H (2022). Challenges in characterization of nanoplastics in the environment. Frontiers of Environmental Science & Engineering, 16(1): 11