

Microplastics in the Aquatic Environment

Subjects: **Neurosciences**

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Microplastics, or microbeads, are plastic particles < 5 mm diameter, and they include nano-sized particles (1 nm). Their size has been miniaturized or fragmented enough that there might be a need for the use of microscopy techniques to study them. In many cases, microplastics continue to carry the chemical structure of their parent plastic with minimum alterations due to exposure to varied environments.

contamination

degradation

plastics

water pollution

1. Introduction

Global plastics production surged from 1.5 to 245 megaton in the period 1950 to 2008 with a small decrease to 230 megaton in 2009 [1][2]. Annual plastic production gives an indication of how much plastic waste ends up in the environment as microplastics. About 10–15% of all plastic manufactured each year end up as municipal solid waste, which is cause for concern [3]. For instance, plasticizers constitute 70% of the weight of plastics, while 3% are endocrine chemicals such as bisphenols and flame retardants

The bulk of plastic waste entering the marine environment originates from terrestrial sources. (1) street litter is mobilized into waterways by rain, and wind, (2) improper or illegal dumping of waste, (3) inappropriately covered waste containers and vehicles, (4) badly managed dump sites, About 80% of the production of plastics that wind up in marine environments originates from run-flow water from land waters to wastewater treatment plants (WWTPs) [4]. Numerous studies have shown that plastic debris constitutes a considerable proportion of waste around marine environments, while data on the extent of pollution in freshwater environments is gradually building up [5][6][7][8][9][10].

Microplastics, or microbeads, are plastic particles In many cases, microplastics continue to carry the chemical structure of their parent plastic with minimum alterations due to exposure to varied environments [11]. In general, chemical pollutants are known to bio-magnify up the food chain [12]. Generally, plastics adsorb and hyper-concentrate a wide range of chemicals called persistent bio-accumulative and toxic chemicals including pesticides, flame retardants, and industrial chemicals, and heavy metals like Ni, Cd, Cu, Cd, so that these chemicals can be up to a million times the levels in the surrounding water [13].

Microplastics have been detected in a number of environmental compartments around the world. The majority of clothing fibers are synthetic, and research from the shoreline around the globe showed textile fibers are dominant [14][15][16]. The hypothesis was that fibers are escaping from washing machines, a phenomenon most likely to occur

in developed countries. In fact, in recent research, it has been found that microfibers from synthetic textiles are one of a major sources of microplastics in the environment, irrespective of the country of origin [12].

The risk posed by microplastics varies with shape and size so that with a larger surface area, fibers will be more toxic than spherical beads [18][19]. Water reservoirs such as lakes and dams are particularly susceptible to microplastic pollution, hence there is considerable data on microplastic pollution characteristics in these ecosystems. A study on microplastics pollution in the backwaters of Xiangxi River reported microplastics concentrations in the range 0.55×105 – 342×105 items per square kilometer and 80–864 items per square meter in surface water and sediment, respectively [20]. These results indicate the presence of microplastics in reservoir impacted tributaries and suggest water level controlled hydrodynamic conditions and nonpoint sources as key determinants for the accumulation and distribution of microplastics [21].

While the effects of microplastics as anthropogenic litter on the aquatic ecosystem have been documented [4][22], including the modeling of all plastics ever produced [23], many researchers on microplastics note the dearth of research data both in the oceanic environment and in freshwater sources [24][25][26][27]. An increasing volume of reviews has appeared, ranging from exploring the whole spectrum of microplastics to discussing more specific laboratory methods of analysis and recommendations for quantification, the state of primary microplastics, and microbial degradation approaches [28]. Therefore, standardization and harmonization of the sampling and processing techniques is important for inter-study comparison of the data, monitoring pollution, and safeguarding the ecological integrity of aquatic ecosystems [29].

To abate the ecological impacts of microplastics, all stakeholders have to make concerted efforts. For instance, (1) governments can fund research that can lead to reduced risks of microplastics entering water bodies, (2) the general public can be encouraged to explore ways of managing plastic wastes through reuse, recycling and the recovery of resources locked away in these materials for sustainable community development, and (3) to minimize the plastics and microplastics load entering the aquatic environment, industry can adopt the cost-effective reduce-reuse-recycle (3Rs) circular economy [16][30][31][32]. Overall, these efforts will minimize the number of plastics that end up in the environment and impacting both aquatic and human health.

The specific aims were to (1) discuss the sources and routes through which microplastics enter the aquatic environment, (2) discuss the occurrence of microplastics in African aquatic systems, and (3) evaluate the pollution characteristics of microplastics in aquatic systems. In addition, the review evaluates and separates natural bio-accumulation of polybutylterephthalates (PBTs) in aquatic organisms from those leaching from microplastics, and offers recommendations for the remediation of microplastics pollution.

2. Mechanisms of Microplastic Formation

Once formed, microplastics are transported via wastewater runoff and enter into municipality effluents, freshwater or marine system [14][33][34][35]. By virtue of their size, these particles are not retained by the conventional water filtration systems, and find their way into water bodies, thus posing a potential threat to aquatic and human life.

Secondary microplastics are produced from larger pieces of plastics breaking down into smaller fragments due to environmental stress, cracking, and degradation associated with weather conditions and biological and UV attacks [15][36]. The plastics are also broken down by the abrasive effect of waves against the coastal sand and rocks (Figure 1).

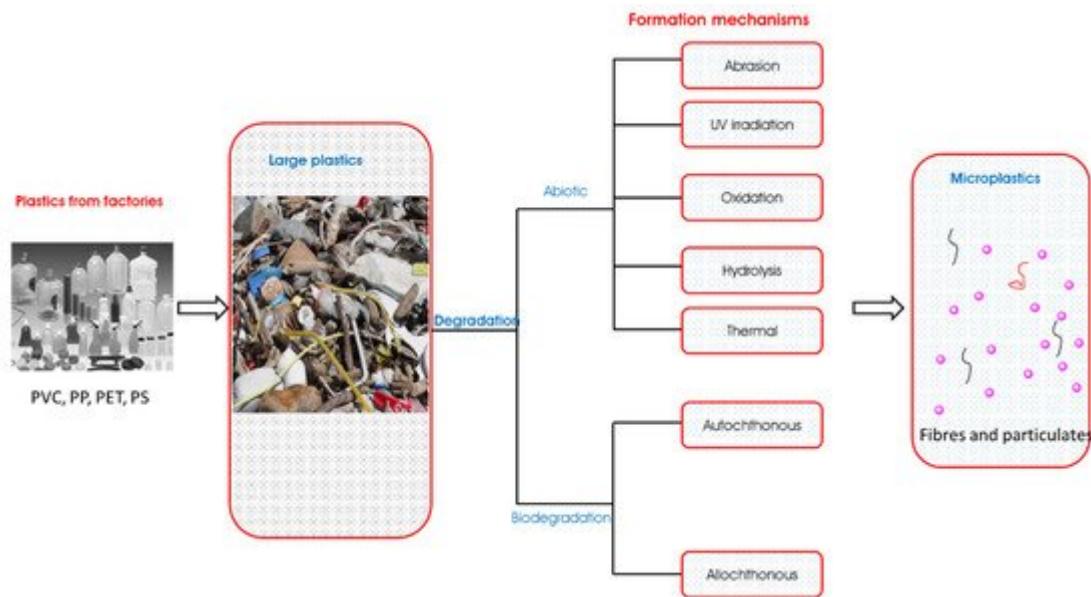


Figure 1. Mechanisms of degradation of plastics into microplastics.

The process of plastics degradation by physical and chemical influences into microplastics is known as abiotic degradation. The major factors contributing to abiotic degradation of plastics are UV-irradiation, oxidation, thermal impacts, hydrolysis, and abrasion due to wave action in the seas and oceans [37].

Most commonly used plastics are non-biodegradable; consequently, they accumulate in the environment [23]. Biodegradation of plastics usually occurs in both the aquatic and terrestrial environments. In shallow waters; however, there are a variety of microbial communities that are crucial in the biodegradation process [37]. Generally, the degradation of plastics through biotic means is a complex process and requires a combination of various types of microorganisms for complete degradation into microplastics.

3. Microplastics in Environmental Compartments

Despite several studies on microplastics, their fate in the environment is poorly understood. Due to the hydrophobic nature of microplastic surfaces, they can significantly adsorb toxic organic contaminants and are considered as vectors for most persistent organic pollutants (POPs) listed under the Stockholm Convention [35]. For instance, studies reported potentially pathogenic *Vibrio parahaemolyticus* on microplastics from North/Baltic Sea [38]. Thus, future studies should not only put emphasis on toxic chemical transportation of microplastics to living organisms, but also on the pathogens they potentially transport.

The smaller size of microplastics coupled with their low density makes them to suspend in the air and easily be inhaled and create potential health problems [39]. Among the various microplastics, fibers are an abundant significant source of microplastics in the marine and atmospheric environment, and when ingested, could release different types of pollutants in living organisms [34][40]. However, a thermodynamic method for evaluating the environmental exposure of chemicals adsorbed to microplastics showed a low significance of microplastics as a vector for persistent, bioaccumulative and toxins, relative to other exposure pathways [41]. Nonetheless, as pointed out by the researchers, this study was limited by lack of data on kinetics, chemical interactions (desorption and adsorption), the influence of microbial biofouling, assessment of the fate of the microplastics in a microorganism to improve understanding.

To facilitate the management of microplastics and reduce their environmental impacts, the sources, fate, and environmental behavior of microplastics have to be understood [42]. The following sections provide a brief review of mechanisms of microplastic formation, their behavior, and fate in different environmental compartments.

The position of microplastics in aquatic systems is influenced by various dynamics including fouling and their density, and determines their impacts on marine organisms. After fragmentation, lower density microplastics float on the water surface, while higher density ones sink to accumulate in the sediment [43][44]. Thereafter, there is an interchanging of the microplastics between biota, water, and sediment through bioturbation, ingestion, and excretion (Figure 2). A recent modelling study on the transportation of microplastics confirmed that river hydrodynamics greatly influence microplastics distribution in rivers and their introduction into marine systems [45].

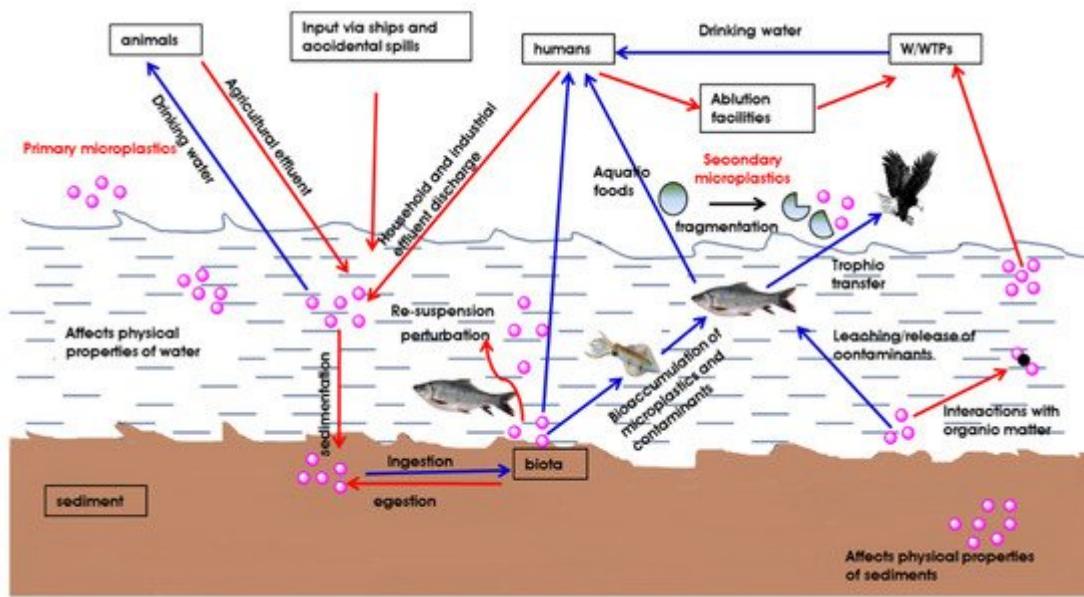


Figure 3. An illustration of the occurrence and fate of microplastics in aquatic systems.

Several studies have highlighted the presence of microplastics in aquatic biota, but the impact of ingestion by various organisms is not adequately researched. Once ingested, they transfer toxic chemicals which are either adsorbed onto the microplastics during emission and transportation or additive toxic chemicals added during the manufacturing process [46]. Large amounts of microplastics are expected in the aquatic biota; however, there is no

experimental evidence that clearly shows whether microplastics transfer greater concentrations of pollutants to tissues than sediments or whether microplastics are capable of transferring high concentrations of pollutants to impair functions of organisms [47]. Furthermore, taking into consideration the high amount of global seafood consumption, for example over 125×10^6 tons in 2009 [22], the contamination of human food by microplastics should get more research attention.

For a while, microplastic pollution has been considered a marine problem, but recent work has reported microplastics in freshwater systems [48]. The work by several researchers provides an indication on the prevalence of microplastics in freshwater in Africa, Asia, Europe, and North America [49][48][50][51][52][53][54]. However, differences between freshwater and marine environments include the closeness of microplastics to their original sources in freshwater. This has led to differences in the types of microplastics in freshwater bodies like rivers, which show a predictable trend with regard to shape, size, and relative abundance [55].

Although microplastics have been reported in freshwater [48][56][57], data on the presence and distribution of microplastics in the freshwater environments is sparsely available. Consequently, there is still a lack of detailed studies on the relative load in the two environmental compartments [58]. Considering that humans are highly dependent on freshwater sources for drinking and other uses, limited knowledge on the transfer of microplastics from freshwater to terrestrial environments and their potential impact on human health is cause for concern. In order to develop suitable policy and management instruments to mitigate the impact of microplastics on freshwaters, there is a need to fund research, and promote education and awareness to the wider population, especially in developing countries.

A recent review that assessed the contamination of soil by microplastics deemed that the contamination reached high concentrations identical to those of toxic metals [59]. As to the sources of microplastic to the soil, sewage sludge is a key source of microplastics into the soil. Despite the presence of toxic chemicals in microplastics as well as their high adsorption capacity for harmful pollutants from the surrounding environments, sewage sludge is commonly used as a fertilizer [53][60][61]. A recent study on the transport of surface deposited microplastics into the soil has shown that soil microarthropods are responsible for the accumulation and distribution of microplastics in the soil food web [62].

In most cases, small plastic fragments, and seawater containing microplastic fibers enter the coastal sediments and increase the concentration of microplastics in sediment [63][64][65]. In other studies, high levels of microplastics were reported in the sediments sampled from Edgbaston Pool in the UK [66], and Changjiang Estuary in China [65]. Similarly, high concentrations of microplastics were detected in the Mediterranean Sea north-western Adriatic beach sediments [67], and in beach sediments along the South-eastern coastline of South Africa [68]. However, the reason for microplastics sinking in sediments due to physical or biological processes requires detailed study.

4. Interaction of Microplastics with Pollutants

Microplastics can scavenge most organic pollutants and toxic metals in the environment. Consequently, they are carriers of toxic substances like pesticides, polychlorinated biphenyls, and polycyclic aromatic hydrocarbons [3]. Furthermore, the study investigated on the influence of microplastics on toxic metals adsorption in stormwater demonstrated that microplastics are vector for toxic metal transportation from urban environment to the water resources [69]. The ease of scavenging of toxic chemicals by microplastics is largely owing to their small size and hydrophobic nature [70][35].

In addition, microplastics may also contain toxic chemicals which are embedded during manufacture for the purpose of protecting plastic from fire risk (e.g., polybrominated diphenyl ethers, phthalates, nonylphenols, bisphenol A, polybromobiphenyls, polychlorobiphenyls), antioxidants to protect microbial growth (e.g., triclosan), and UV stabilizers to inhibit degradation on exposure to sunlight [47][71][72][73]. When the additives are not chemically bonded to the polymer molecules, they can be easily released from the plastics and subsequently transferred to water, sediment, and living organisms [3][58][74]. Ingestion of microplastics by marine microorganisms, animals and humans may result in physical and toxicological effects [1][65]. The physico-chemical characteristics of microplastics such as size, density, and chemical composition are key attributes for their bioavailability to the organisms [44][75].

References

1. Law, K.L.; Thompson, R.C. Oceans. *Microplastics in the seas*. *Science* 2014, 345, 144–145.
2. Plastics—The Facts. An Analysis of European Plastics Production, Demand and Waste Data in 2016. Available online: (accessed on 12 February 2021).
3. Andrade, A.L. Microplastics in the marine environment. *Mar. Pollut. Bull.* 2011, 62, 1596–1605.
4. EIA. Lost at Sea: The Urgent Need to Tackle Marine Litter; EIA: Washington, DC, USA, 2015.
5. Eckert, E.M.; Di Cesare, A.; Kettner, M.T.; Arias-Andres, M.; Fontaneto, D.; Grossart, H.; Corno, G. Microplastics increase the impact of treated wastewater on the freshwater microbial community. *Environ. Pollut.* 2018, 234, 495–502.
6. Murphy, F.; Quinn, B. The effects of microplastic on freshwater *Hydra attenuata* feeding, morphology & reproduction. *Environ. Pollut.* 2018, 234, 487–494.
7. Peng, G.; Xu, P.; Zhu, B.; Bai, M.; Li, D. Microplastics in freshwater river sediments in Shanghai, China: A case study of risk assessment in mega-cities. *Environ. Pollut.* 2018, 234, 448–456.
8. Su, L.; Cai, H.; Kolandhasamy, P.; Wu, C.; Rochman, C.M.; Shi, H. Using the Asian clam as an indicator of microplastic pollution in freshwater ecosystems. *Environ. Pollut.* 2018, 234, 347–355.
9. Derraik, G.B.J. The pollution of the marine environment by plastic debris: A review. *Mar. Pollut. Bull.* 2002, 44, 842–852.

10. Li, C.; Busquets, R.; Campos, L.C. Assessment of microplastics in freshwater systems: A review. *Sci. Total Environ.* 2019, 707, 135578.
11. Arthur, C.; Baker, J.; Bamford, H. Proceedings of the International Research Workshop on the Occurrence, Effects and Fate of Microplastic Marine Debris; NOAA Technical Memorandum NOS-OR&R-30; National Oceanic and Atmospheric Administration, U.S. Department of Commerce: Washington, DC, USA, 2009.
12. Kidd, K.A.; Bootsma, H.A.; Hesslein, A.H. Biomagnification of DDT through the Benthic and Pelagic Food Webs of Lake Malawi, East Africa: Importance of Trophic Level and Carbon Source. *Environ. Sci. Technol.* 2001, 35, 14–20.
13. Rochman, C.M.; Tahir, A.; Williams, S.L.; Baxa, D.V.; Lam, R.; Miller, J.T.; Teh, F.C.; Werorilangi, S.; Teh, S.J. Anthropogenic debris in seafood: Plastic debris and fibers from textiles in fish and bivalves sold for human consumption. *Sci. Rep.* 2015, 5, 14340.
14. Browne, M.A.; Crump, P.; Niven, S.J.; Teuten, E.; Tonkin, A.; Galloway, T.; Thompson, R. Accumulation of Microplastic on Shorelines Worldwide: Sources and Sinks. *Environ. Sci. Technol.* 2011, 45, 9175–9179.
15. Bouwmeester, H.; Hollman, P.C.H.; Peters, R.J.B. Potential Health Impact of Environmentally Released Micro- and Nanoplastics in the Human Food Production Chain: Experiences from Nanotoxicology. *Environ. Sci. Technol.* 2015, 49, 8932–8947.
16. Jiang, J. Occurrence of microplastics and its pollution in the environment: A review. *Sustain. Prod. Consum.* 2018, 13, 16–23.
17. Acharya, S.; Rumi, S.S.; Hu, Y.; Abidi, N. Microfibers from synthetic textiles as a major source of microplastics in the environment: A review. *Text. Res. J.* 2021, 1, 1–21.
18. Kang, J.H.; Kwon, O.Y.; Lee, K.W.; Song, Y.K.; Shim, W.J. Marine neustonic microplastics around the south-eastern coast of Korea. *Mar. Pollut. Bull.* 2015, 96, 304–312.
19. Wagner, M.; Scherer, C.; Alvarez-Muñoz, D.; Brennholt, N.; Bourrain, X.; Buchinger, S.; Fries, E.; Grosbois, C.; Klasmeier, J.; Marti, T.; et al. Microplastics in freshwater ecosystems: What we know and what we need to know. *Environ. Sci. Eur.* 2014, 26, 12.
20. Zhang, K.; Xiong, X.; Hu, H.; Wu, C.; Bi, Y.; Wu, Y.; Zhou, B.; Lam, P.K.; Liu, J. Occurrence and Characteristics of Microplastic Pollution in Xiangxi Bay of Three Gorges Reservoir, China. *Environ. Sci. Technol.* 2017, 51, 3794–3801.
21. Zhang, C.; Chen, X.; Wang, J.; Tan, L. Toxic effects of microplastic on marine microalgae *Skeletonema costatum*: Interactions between microplastic and algae. *Environ. Pollut.* 2017, 220, 1282–1288.

22. Van Cauwenberghe, L.; Janssen, C.R. Microplastics in bivalves cultured for human consumption. *Environ. Pollut.* 2014, 193, 65–70.

23. Geyer, R.; Jambeck, J.R.; Law, K.L. Production, use, and the fate of all plastics ever made. *Sci. Adv.* 2017, 3, 25–29.

24. Free, C.M.; Jensen, O.P.; Mason, S.A.; Eriksen, M.; Williamson, N.J. High-levels of microplastic pollution in a large, remote, mountain lake. *Mar. Pollut. Bull.* 2014, 85, 156–163.

25. Driedger, A.G.J.; Durr, H.H.; Mitchell, K.; Van Cappellen, P. Plastic debris in the Laurentian Great Lakes: A review. *J. Great Lakes Res.* 2015, 41, 9–19.

26. Michielssen, M.R.; Michielssen, E.R.; Ni, J.; Duhaime, M.B. Fate of microplastics and other small anthropogenic litter (SAL) in wastewater treatment plants depends on unit processes employed. *Environ. Sci. Water Res. Technol.* 2016, 2, 1064–1073.

27. Storck, F.; Kools, S.; Rinck-Pfeiffer, S. Microplastics in Fresh Water Resources; GWRC Science Brief September/2015; Global Water Research Coalition: Stirling, Australia, 2015.

28. Pathak, V.M. Review on the current status of polymer degradation: A microbial approach. *Bioresour. Bioprocess.* 2017, 4, 15.

29. Adomat, Y.; Grischek, T. Sampling and processing methods of microplastics in river sediments—A review. *Sci. Total Environ.* 2021, 758, 143691.

30. Auta, H.S.; Emenike, C.U.; Fauziah, S.H. Distribution and importance of microplastics in the marine environment: A review of the sources, fate, effects, and potential solutions. *Environ. Int.* 2017, 102, 165–176.

31. Napper, I.E.; Thompson, R.C. Release of synthetic microplastic plastic fibres from domestic washing machines: Effects of fabric type and washing conditions. *Mar. Pollut. Bull.* 2016, 112, 39–45.

32. GESAMP. Sources, Fate, and Effects of Microplastics in the Marine Environment: Part Two of a Global Assessment; Kershaw, P.J., Rochman, C.M., Eds.; Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP): London, UK, 2016.

33. Fendall, L.S.; Sewell, M.A. Contributing to marine pollution by washing your face: Microplastics in facial cleansers. *Mar. Pollut. Bull.* 2009, 58, 1225–1228.

34. Napper, I.E.; Bakir, A.; Rowland, S.J.; Thompson, R.C. Characterisation, quantity and sorptive properties of microplastics extracted from cosmetics. *Mar. Pollut. Bull.* 2015, 99, 178–185.

35. Wright, S.L.; Kelly, F.J. Plastic and human health: A micro issue? *Environ. Sci. Technol.* 2017, 51, 6634–6647.

36. Wu, W.; Yang, J.; Criddle, C.S. Microplastics pollution and reduction strategies. *Front. Environ. Sci. Eng.* 2017, 11, 6.

37. da Costa, J.P.; Duarte, A.C.; Rocha-Santos, T.A.P. Microplastics—Occurrence, Fate and Behaviour in the Environment. *Compr. Anal. Chem.* 2017, 75, 1–24.

38. Kirstein, I.V.; Kirmizi, S.; Wichels, A.; Garin-fernandez, A.; Erler, R.; Martin, L. Dangerous hitchhikers? Evidence for potentially pathogenic *Vibrio* spp. on microplastic particles. *Mar. Environ. Res.* 2016, 120, 1–8.

39. Akanyange, S.N.; Lyu, X.; Zhao, X.; Li, X.; Zhang, Y.; Crittenden, J.C.; Anning, C.; Chen, T.; Jiang, T.; Zhao, H. Does microplastic really represent a threat? A review of the atmospheric contamination sources and potential impact. *Sci. Total Environ.* 2021, 777, 146020.

40. Remy, F.; Collard, F.; Gilbert, B.; Compère, P.; Eppe, G.; Lepoint, G. When Microplastic Is Not Plastic: The Ingestion of Artificial Cellulose Fibers by Macrofauna Living in Seagrass Macrophyto detritus. *Environ. Sci. Technol.* 2015, 49, 11158–11166.

41. Gouin, T.; Roche, N.; Lohmann, R.; Hodges, G. A Thermodynamic Approach for Assessing the Environmental Exposure of Chemicals Absorbed to Microplastic. *Environ. Sci. Technol.* 2011, 45, 1466–1472.

42. Carr, S.A.; Liu, J.; Tesoro, A.G. Transport and fate of microplastic particles in wastewater treatment plants. *Water Res.* 2016, 91, 174–182.

43. Wright, S.L.; Thompson, R.C.; Galloway, T.S. The physical impacts of microplastics on marine organisms: A review. *Environ. Pollut.* 2013, 178, 483–492.

44. Kane, I.A.; Clare, M.A. Dispersion, Accumulation, and the Ultimate Fate of Microplastics in Deep-Marine Environments: A Review and Future Directions. *Front. Earth Sci.* 2019, 7, 1–27.

45. Besseling, E.; Quik, J.T.K.; Sun, M.; Koelmans, A.A. Fate of nano- and microplastic in freshwater systems: A modeling study. *Environ. Pollut.* 2017, 220, 540–548.

46. Song, Y.K.; Hong, S.H.; Jang, M.; Han, G.M. Occurrence and Distribution of Microplastics in the Sea Surface Microlayer in Jinhae Bay, South Korea. *Arch. Environ. Contam. Toxicol.* 2015, 69, 279–287.

47. Browne, M.A.; Niven, S.J.; Galloway, T.S.; Rowland, S.J.; Thompson, R.C. Microplastic Moves Pollutants and Additives to Worms, Reducing Functions Linked to Health and Biodiversity. *Curr. Biol.* 2013, 23, 2388–2392.

48. Khan, F.R.; Mayoma, B.S.; Biginagwa, F.J.; Syberg, K. Microplastics in Inland African Waters: Presence, Sources, and Fate. In *Freshwater Microplastics: Emerging Environmental Contaminants?* Wagner, M., Lambert, S., Eds.; Springer International Publishing: Cham, Switzerland, 2018; pp. 101–124.

49. Eerkes-Medrano, D.; Thompson, R.C.; Aldridge, D.C. Microplastics in freshwater systems: A review of the emerging threats, identification of knowledge gaps and prioritization of research needs. *Water Res.* 2015, 75, 63–82.

50. Faure, F.; Corbaz, M.; Baecher, H.; de Alencastro, L. Pollution due to plastics and microplastics in Lake Geneva and in the Mediterranean Sea. *Arch. Sci.* 2012, 65, 157–164.

51. Imhof, H.K.; Ivleva, N.P.; Schmid, J.; Niessner, R.; Laforsch, C. Contamination of beach sediments of a subalpine lake with microplastic particles. *Curr. Biol.* 2013, 23, R867–R868.

52. Morritt, D.; Stefanoudis, P.V.; Pearce, D.; Crimmen, O.A.; Clark, P.F. Plastic in the Thames: A river runs through it. *Mar. Pollut. Bull.* 2014, 78, 196–200.

53. Dris, R.; Gasperi, J.; Rocher, V.; Saad, M.; Renault, N.; Tassin, B. Microplastic contamination in an urban area: A case study in Greater Paris. *Environ. Chem.* 2015, 12, 592–599.

54. Lechner, A.; Ramler, D. The discharge of certain amounts of industrial microplastic from a production plant into the River Danube is permitted by the Austrian legislation. *Environ. Pollut.* 2015, 200, 159–160.

55. Blettler, M.C.M.; Ulla, M.A.; Rabuffetti, A.P.; Garello, N. Plastic pollution in freshwater ecosystems: Macro-, meso-, and microplastic debris in floodplain lake. *Environ. Monit. Ass.* 2017, 189, 581.

56. Dubaish, F.; Liebezeit, G. Suspended microplastics and black carbon particles in the Jade system, Southern North Sea. *Water Air Soil Pollut.* 2013, 224, 1352.

57. Klein, S.; Worch, E.; Knepper, T.P. Occurrence and spatial distribution of microplastics in river shore sediments of the Rhine-Main area in Germany. *Environ. Sci. Technol.* 2015, 49, 6070–6076.

58. Horton, A.A.; Walton, A.; Spurgeon, D.J.; Lahive, E.; Svendsen, C. Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities. *Sci. Total Environ.* 2017, 586, 127–141.

59. Costa, P.J.D.; Paco, A.; Santos, P.S.M.; Duarte, A.C.; Rocha-Santos, T. Micro-plastics in soils: Assessment, analytics and risks. *Environ. Chem.* 2019, 16, 18–30.

60. Bayo, J.; Olmos, S.; López-Castellanos, J.; Alcolea, A. Microplastics And Microfibers In The Sludge Of A Municipal Wastewater Treatment Plant. *Int. J. Sustain. Dev. Plan.* 2016, 11, 812–821.

61. Ziajahromi, S.; Neale, P.; Rintoul, L.; Leusch, F.D.L. Wastewater treatment plants as a pathway 2 for microplastics: Development of a new approach to sample wastewater-based microplastics. *Water Res.* 2017, 112, 93–99.

62. Maas, S.; Daphi, D.; Lehmann, A.; Rillig, M.C. Transport of microplastics by two collembolan species. *Environ. Pollut.* 2017, 225, 456–459.

63. Van Cauwenberghe, L.; Vanreusel, A.; Mees, J.; Janssen, C.R. Microplastic pollution in deep-sea sediments. *Environ. Pollut.* 2013, 182, 495–499.

64. Cesa, F.S.; Turra, A.; Baruque-ramos, J. Synthetic fibers as microplastics in the marine environment: A review from textile perspective with a focus on domestic washings. *Sci. Total Environ.* 2017, 598, 1116–1129.

65. Peng, G.; Zhu, B.; Yang, D.; Su, L.; Shi, H.; Li, D. Microplastics in sediments of the Changjiang Estuary, China. *Environ. Pollut.* 2017, 225, 283–290.

66. Vaughan, R.; Turner, S.D.; Rose, N.L. Microplastics in the sediments of a UK urban lake. *Environ. Pollut.* 2017, 229, 10–18.

67. Munari, C.; Scoponi, M.; Mistri, M. Plastic debris in the Mediterranean Sea: Types, occurrence and distribution along Adriatic shorelines. *Waste Manag.* 2017, 67, 385–391.

68. Nel, H.A.; Froneman, P.W. A quantitative analysis of microplastic pollution along the south-eastern coastline of South Africa. *Mar. Pollut. Bull.* 2015, 101, 274–279.

69. Aghilinasrollahabadi, K.; Salehi, M.; Fujiwara, T. Investigate the influence of microplastics weathering on their heavy metals uptake in stormwater. *J. Hazard. Mater.* 2021, 408, 124439.

70. Cole, M.; Lindeque, P.; Halsband, C.; Galloway, T.S. Microplastics as contaminants in the marine environment: A review. *Mar. Pollut. Bull.* 2011, 62, 2588–2597.

71. Andrade, A.L.; Neal, M.A. Applications and societal benefits of plastics. *Philos. Trans. R. Soc. B* 2009, 364, 1977–1984.

72. Teuten, E.L.; Saquing, J.M.; Knappe, D.R.U.; Barlaz, M.A.; Jonsson, S.; Bjorn, A.; Rowland, S.J.; Thompson, R.C.; Galloway, T.S.; Yamashita, R.; et al. Transport and release of chemicals from plastics to the environment and to wildlife. *Philos. Trans. R. Soc. B Biol. Sci.* 2009, 364, 2027–2045.

73. Kefeni, K.K.; Okonkwo, J.O.; Olukunle, O.I.; Botha, B.M. Brominated flame retardants: Sources, distribution, exposure pathways, and toxicity. *Environ. Rev.* 2011, 19, 238–254.

74. Hermabessiere, L.; Dehaut, A.; Paul-pont, I.; Lacroix, C.; Jezequel, R.; Soudant, P.; Du, G. Occurrence and effects of plastic additives on marine environments and organisms: A review. *Chemosphere* 2017, 182, 781–793.

75. Rocha-santos, T.; Duarte, A.C. A critical overview of the analytical approaches to the occurrence, the fate and the behaviour of microplastics in the environment. *Trends Anal. Chem.* 2015, 65, 47–53.

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