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Sources, impacts and management of microplastics

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Abstract: *Microplastics are contemporary issues requiring close attention and continuous research. This paper aims to summarize recent studies of sources, impacts, and management of environmental microplastics, find universal strategies from different aspects' research and provide suggestions from a future scope.*

Keywords: *Environment, microplastics, accumulation effects, potential risks*

1. Introduction

Plastic pollution was first noticed in the late 1960s, as Kenyon and Kridler (1969) found plastic pieces in albatrosses' stomachs. In the following forty years, there were a lot of studies associated with this topic but not at the micro-level until the Thompson et al. (2004) defined the term "microplastics" as "granular and fibrous plastic fragments with a dimension of around 20 μm in UK beach and sea collection campaigns" (Chiara, Luca, and Elena, 2021, p.1). In 2008, the Marine Strategy Framework Directive (MSFD) and USA conference about the interaction between microplastics and fauna promoted the research of its impacts and solutions. Consequently, there was an exponential growth of research from 2009 to 2021, focusing on address this issue in different aspects (Chiara, Luca, and Elena, 2021).

For now, there are plenty of definitions about the size of plastics, but no agreements are reached (Chiara, Luca, and Elena, 2021). The latest definition from Hartmann et al. (2019) indicates the size of microplastics as 1 to <1000 μm, while the minor division, nanoplastics, was from 1 to <1000 nm. Due to the small size, the current technique of net sampling has a considerable limitation of mesh size to capture specimens effectively. Huppertsberg and Knepper (2018) and Pan et al. (2019) also suggest a lack of standard, easy, cheap, comparable, and robust analysis methodology. At the management level, the classification and disposal of massive plastics are challenging. According to Kershaw (2015), exposing biodegradable plastics in natural environments like the ocean rather than composting plants prolongs degradation time and increases microplastics release, but establishing these plants cost much. Therefore, a cheap and universal management plan is needed as well. As for the impacts, Kazour et al. (2019) show that microplastics from landfills have more severe influences than from plants. Further studies of excretion and how microplastics affecting human health in biological activities are necessary (Schwabl et al., 2018).

Based on current articles and above limitations, this paper will review the sources, impacts, and management of environmental microplastics from different aspects and then discuss possible future strategies.

2. Methodology

In recent research, Chiara, Luca, and Elena (2021) reviewed 730 articles from Science Direct to orchestrate microplastic stories throughout history. They recorded the number of publications with the keywords of "microplastic" (Table 1) and selected influential documents to support their study. Likewise, I found 7,716 peer-reviewed journal articles from the ANU Library Super Search and 16,500 publications from Google Scholar in the last four years (from 2017 to June 2 2021, the number will change as time goes by). Then I sorted them by the relevance of my topic and chose 25 peer-reviewed journal articles as reviewing references. Other supporting papers without this range were extracted based on their significance and contribution to this study. Overall, I included 30 peer-reviewed journal articles.

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Table 1. Number of publications in databases searched on 2 June 2020

Database	Keyword: Microplastic
ScienceDirect	6,190
Scopus	4,570
SpringerLink	3,606
Wiley	1,212
Scientific.Net	960
ACSPublications	449
Nature	125

Adapted from Chiara, Luca, and Elena's (2021, p.15) Table 5

3. Results

3.1 Sources

Generally, microplastics come from plastic litter breaking down in wastewater treatment plants (WWTPs) and natural degradation. Leads and Weinstein (2019) categorized the collected debris as fibers, fragments, tire wear particles, foams, and spheres, while Zhou et al. (2018) also used the term pellets and flakes. Most of these elements were sampled from the sea as the discharge went. According to Lares et al. (2018) and Leslie et al. (2017), the removal efficiency of WWTPs was ranging from 70% to 99%. As a result, the effluents contained microplastics in size from 0.7μm to 300 μm, including fibers of PES, PET, and PA, and particles of PE, PES, and PP. Chiara, Luca, and Elena (2021) also indicated misunderstandings and overestimations of bio-based plastics, which lead to a lot of direct discharge to the ocean without treatments. These plastics degrade into microplastics naturally and time-consumingly, which could accumulate in marine environments and organisms.

Besides sewage, the sludge from plants also contains plenty of microplastics, which are used as soil fertilizers in European countries. According to Scheurer and Bigalke (2018), up to 55.5mg/kg soil-microplastics were found in the study site, and the primary size was from 125 μm to 500 μm. Some of them come from mulching of plastics besides fertilizers. Microplastics can also enter other environmental elements from the soil and other diffusion sources (Chiara, Luca, and Elena, 2021). For example, Kazour et al. (2019) indicated that landfills have twice collected microplastics in the air than the WWTPs within a distance of 5km. These particles can be transported to any area, including but not restricted to remote Swiss mountains (Scheurer and Bigalke, 2018), puddles (Liu, Vianello and Vollertsen, 2019), glaciers, and alpine snow (Ambrosini et al., 2019). Another study showed the occurrence of microplastics in terrestrial water systems from "surface run-off, atmospheric fallout (Dris et al., 2016) and direct waste disposal" (Li, Liu, and Paul Chen, 2018, p.365). In living areas, microplastics can circulate with atmosphere and water systems (Fig. 1).

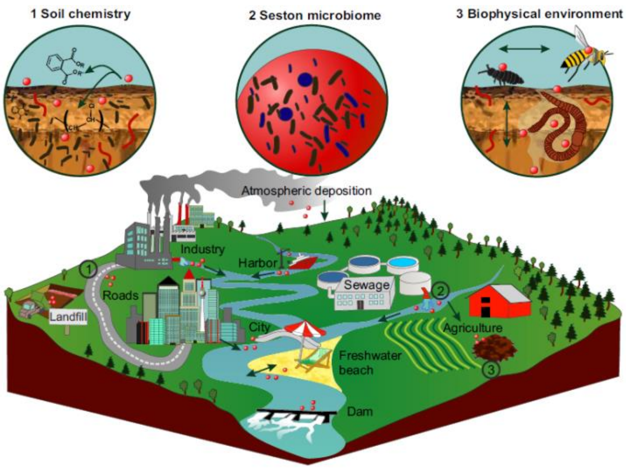

Fig. 1. Microplastics in terrestrial and freshwater systems. Red-filled spheres stand for microplastic concentration, and arrows represent transportation directions. The above circular panels show selected effects on soil, microbiome, and biophysical environments. Adopted from de Souza Machado et al.'s (2018, p.1407) figure 1.

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3.2 Impacts

For now, there is no clear evidence about how microplastics hurt living organisms, while there are facts that plastics cause problems for aquatic fauna and birds (Chiara, Luca, and Elena, 2021). However, a growing concern associated with the potential impacts on human beings by intakes and bioaccumulation effects occurs as microplastics-related studies develop.

At the system level, microplastics ingested by animals is a widely acknowledged problem. They act as carriers of toxic additives and substances (Chiara, Luca, and Elena, 2021) and poison intake bodies. Zuo et al. (2019) highlighted a biodegradable plastic named polybutylene adipate co-terephthalate (PBAT), which has a high absorption ability of environmental pollutants like phenanthrene. Since microplastics in water can transport and be ingested more easily than other media, there is very close academic attention on aquatic systems, especially marine systems. Li, Liu, and Paul Chen (2018) categorized water-based environmental impacts into physical, chemical, and biological. In terms of the physical effects, they highlighted the entanglement and accumulation effects. The former has a severe influence on big animals and may cause death by drowning, suffocating, strangulating, and starving. The latter happens on all animals, especially those in high trophic levels. As for chemical impacts, the accumulated polymeric compounds and additives like copper ions will be toxic when the low pH and high-temperature conditions in creature bodies. Regarding biological effects, microplastics can carry bacteria and pathogens. They can also change microplastics' properties by surface biofilms. However, specific influences of the alternation need more research.

As for impacts on terrestrial systems, agricultural soils might have more microplastic pollution than ocean basins (de Souza Machado et al., 2018). It will affect soil functions, microclimates, and soil-based fauna hence. For example, Zhu et al. (2018) found microplastic negatively affects springtails' gut microbiomes. Consequently, their growth and reproduction are hurt. In addition, Prata (2018) revealed that airborne microplastic from the flock, synthetic textiles, and Polyvinyl chloride (PVC) under low environmental concentrations might cause respiratory and cardiovascular diseases. The reason is that carboxyl (COOH), amino (NH_2), and lecithin terminated microplastics can get through the membrane interface (de Souza Machado et al., 2018).

Regarding other impacts on human health, Vethaak and Legler (2021) highlighted that long-term exposure to abundant microplastics might cause "oxidative stress, secretion of cytokines, cellular damage, inflammatory and immune reactions, and DNA damage, as well as neurotoxic and metabolic effects" (p.673). It also can lead to lung injuries "including inflammation, fibrosis, and allergy, among workers in the plastic and textile industry who are exposed to high amounts of plastic fibrous dust" (p.673). However, more research is required to specify these impacts and whether the consequences are from microplastics or other plastic-based elements. Cox et al. (2019) also expressed the concern of the potential impacts of microplastics on human health when they reach a certain amount level. They suggested that the bioaccumulation effects should be continuously studied as the annual consumption and inhalation of microplastics are remarkable (Fig. 2), especially for more vulnerable groups.

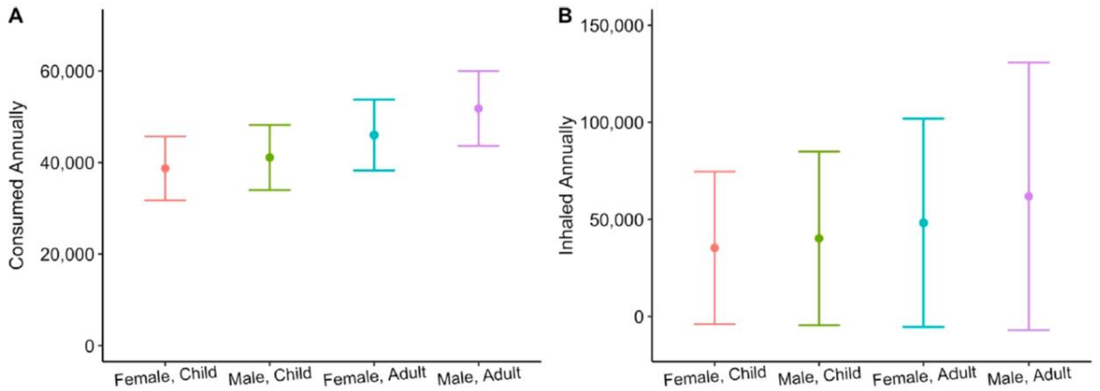

Fig. 2. Annual consumption (left) and inhalation (right) of microplastics particles. Male adults are the most influenced groups, with over 50,000 particles consumed and 60,000 particles inhaled annually. Adopted from Cox et al.'s (2019, p.7070) figure 1.

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3.3 Management

Overall, there is a lack of commonly recognized protocols for microplastics management and data collection. According to Chiara, Luca, and Elena (2021), American and European institutions have already taken actions to regulate marine waste, which can be traced back to a protocol and guidelines on Survey and Monitoring of Marine Litter from UNEP in 2010. In 2011, "the European Commission's Joint Research Centre Institute for Environment and Sustainability (JRC) published the 'Marine Litter - Technical Recommendations for the Implementation of MSFD Requirements' document" (p.2). This document highlighted ecological impacts and human health by providing techniques to monitor beaches, surface water, floating, seabed, biota, and micro-litter. Based on this report, abundant methodologies of identifying, defining, and quantifying microplastics occurred (most of them are associated with seas). In 2016 JRC indicated rivers as vital sources of ocean litter, and they provided standards and methods for monitoring aquatic systems. Correspondingly, the impacts of marine waste on animals (fish, turtles, whales, seabirds, etc.) were identified in later studies. One of these studies (Ribeiro, O'Brien, Galloway, and Thomas, 2019) suggested that intakes of seafood with plastics ingested were not harmful to human health since they are visible and can be easily removed before eating. However, some exceptions like shellfishes may contain plastics in small pieces, which increase the possibilities of accident intakes by human beings. In 2017, IPA Adriatic Cross-border Cooperation Programme DeFishGear (DFG) presented protocols for gathering and analyzing microplastics in detail. Together with Masura protocols (Masura et al., 2015), these recommendations are followed by later studies up to now.

Nowadays, there are no unified protocols about universal techniques to collect and treat microplastics in any environmental elements, so there is no sound management of plastics at the micro-level. The current appearance-based classification needs to be unified and developed to chemical levels as well (Chiara, Luca, and Elena, 2021).

4. Discussion

The priority in the future is to define the plastic litter appropriately and reach a consensus by all parties, which is a significant precondition of managing microplastics better. Besides microplastic and nanoplastics (see introduction), Hartmann et al. (2019) categorized plastic particles as macroplastics (> 1cm) and mesoplastics (from 1 to 10mm). However, more specified categories are needed based on shapes and chemical compositions rather than only on sizes. For example, Chiara, Luca, and Elena (2021) indicated a controversy of fiber classification. Although "the vast majority of the works call microplastics fragments smaller than 5 mm in size" (p.3), there are disputes about the descriptions like "long" and "thin". Hence, they suggested dividing them by shapes rather than sizes in microplastic categories. This classification will contribute to collecting and analyzing different plastic particles. At the chemical level, since there are various additives and molecular structures, categorizing based on these features will help explore microplastics' impacts on organisms and extract them from environments by. Chemical categories can be established from shape categories. For instance, classifying based on fiber types is a good start (see sources). More classifications of fragments, tire wear particles, foams, spheres, pellets, and flakes are expected from this perspective.

Secondly, reducing the microplastics' discharge into environments is vital. Castro-Jiménez et al. (2019) highlighted that most plastic waste in the ocean was from beaches and coasts rubbish, recreation activities (like using pots, ropes, nets in fishing), and river flow. The first two origins can be restricted by relevant natural and tourism management. Regular monitoring and cleaning will contribute much to reducing marine plastic pollution. However, the latter origin, river flows, is difficult to limit, and it also harms terrestrial systems. According to Chiara, Luca, and Elena (2021), the best solution is continuously improving the WWTPs. A two-stage WWTP has an average removal efficiency of 67%. If it is changed to three-stage, the efficiency can reach 87%. With an additional reverse osmosis stage, the final efficiency can be up to 99%. Besides, the technologies of filtration are essential. Some plants can only remove plastics over 0.5mm (Mintenig et al., 2017), while others can deal with the size between 1 to 5μm (Pivokonsky et al., 2018). The removal efficiency negatively correlates with the plastic size: the former has percentages from 93% to 98%, but the latter only has 70% to 83%. Therefore, currently, there is a trade-off between disc filters and plant efficiency. According to Talvitie, Mikola, Koistinen, and Setälä (2017), 10μm disc filters correspond with 40% efficiency in a plant, but 20μm disc filters can reach 98.5%. As the development goes, advanced technologies with higher efficiency and smaller mech size are expected.

In the next place, there is a lack of formal identification, collection, and analysis methodologies towards microplastics at the management level. According to Chiara, Luca, and Elena (2021), current Europe and the US regulations mainly focus on macroplastics (> 1cm) instead of small particles. For now, the most effective way to manage microplastic is to build treatment plants and degrade plastics centrally. There is a misunderstanding that biodegradable plastics can be disposed of by burring in the land or the ocean. Recent studies showed that landfills would release many microplastics into the air, soils, and ground, which is challenging to deal with and has a high potential for intakes in organisms. Another misunderstanding is that all bio-based polymers are biodegradable. Chiara, Luca, and Elena (2021, p.13) provided an example that "If we consider for example a bio-PE derived from sugar cane, the CO_2 footprint will be smaller than a 'fossil' PE, but chemically it is still PE, with a degradation time around 500 years." In this case, the bio-PE will generate a lot of microplastics, which may negatively impact nearby environments for an extended period. Likewise, degradation in the seabed is slowly and detrimental to marine organisms (e.g., Chiara, Luca, and Elena also showed certified biodegradable plastic of Mater-Bi would alter algae's life). Hence, disposing of biodegradable plastics in the composting plants and other plastics in appropriate plants with proper chemical-physical agents, mechanical stress, and heating is the best solution for now, although building them will increase costs.

Regarding health impacts on humans, it is complicated to reveal specific influences on body parts since there is no evidence of damage from the tiny amount of microplastics. However, it is necessary to keep exploring the potential risks. Currently, there are cases that significant plastic-based substances may cause human diseases (see impacts), but how microplastics function in these impacts is unclear. Hence, the research at the micro-level about how these particles affect cell functions needs to be specified. Considering that the plastic-related disease has occupational trends, I recommend the public pay more attention to plastic-based works' physical changes. On the one hand, these workers can receive treatments in time. On the other hand, the clinical experience will contribute to clarifying: the plastics' impacts, how they are degrading in human bodies, the quantity and process of releasing microplastics, and their effects. Moreover, continuously monitoring microplastic content in the environments is critical, especially in high-risk areas (e.g., 5km surrounding landfills and plastic factories). Vulnerable groups (see figure 2) living in these areas can be ideals samples for microplastics health impacts research because of the high exposure rate. Their health conditions need long-term attention as well.

In the contemporary era, climate change is a great challenge. Unexpected climate events (like storms, smog, and floods) will exacerbate the spread of microplastics in earth cycles. As a result, the difficulties of tracing and treating microplastics will increase accordingly. Rapid development is another adverse factor. As urbanization and economic activities grow, there will be massive plastic emissions in plenty of forms, including gas, sewage, and industrial waste. These emissions will increase the burden of current pollution treating facilities and affect regional ecologies without countermeasures. Based on this, corresponding plastic plants and surveillance should be established with future developments. Nevertheless, an opportunity is that high technologies and solid collaboration may occur under globalization. The situations of lacking standards and applicable methods can be altered by various parties working together. For now, Europe and the US have led the managing of marine plastic waste. Further management protocols can be formed by global conferences and environmental cooperation with abundant studies. Another opportunity is that many countries popularize reusable and recyclable materials instead of traditional plastics. Based on this, the direct action is reducing the supply of plastic bags in many industries and encourage cloth bags. As the stress of processing environmental and recycled plastics decreases, potential microplastics generation is mitigated accordingly.

5. Conclusion

As microplastic studies rapidly increase, high-quality literature reviews that summarize knowledge and indicate gaps contribute to guiding future research directions. Chiara, Luca, and Elena's (2021) "Microplastic's story" is an excellent example. Based on their work, this paper provided suggestions of current research lacks as a complimentary. I found most protocols concentrating on severe environmental issues like extreme climate events rather than long-term risks in the reviewing process. Although these tiny plastics have not shown direct correlations with health impacts, it is essential to monitoring their accumulation from a prophetic vision to prepare for potential adverse effects.

Most current studies focus on analyzing sampling and identifying methods or specific impacts on ecosystems and species. However, few papers offered systematical frameworks to manage microplastics as a source of potential pollution. Besides difficulties of administering at the micro-level, lacks of unified definition and standard methodologies are also reasons. Plenty of studies place importance on marine systems since plastics pollution is the most severe. Nevertheless, other environmental elements are also worth investigating, especially terrestrial systems that directly affect human health. Therefore, I expect more research to fulfill these gaps, and the first study at the management level will appear soon.

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