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Review

Microplastics pollution in different aquatic environments and biota: A review of recent studies

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ABSTRACT

Microplastics (MPs) are generated from plastic and have negative impact to our environment due to high level of fragmentation. They can be originated from various sources in different forms such as fragment, fiber, foam and so on. For detection of MPs, many techniques have been developed with different functions such as microscopic observation, density separation, Raman and FTIR analysis. Besides, due to ingestion of MPs by wide range of marine species, research on the effect of this pollution on biota as well as human is vital. Therefore, we comprehensively reviewed the occurrence and distribution of MPs pollution in both marine and freshwater environments, including rivers, lakes and wastewater treatment plants (WWTPs). For future studies, we propose the development of new techniques for sampling MPs in aquatic environments and biota and recommend more research regarding MPs release by WWTPs.

1. Introduction

Plastic materials are relatively young materials with history about 60 years. Then, they have covered almost all aquatic environments (Van Cauwenberghe et al., 2013; Gündoğdu and Çevik, 2017). Modern concern about MPs has been growing since 2004 as Thompson studied on ocean plastic at Plymouth University in the United Kingdom. They found MPs in most of the samples from 18 British beaches, as well as in plankton samples collected from the North Sea as far back as the 1960s (Thompson et al., 2004).

With the increasing world population, the usage of plastic has increased, meanwhile the waste management of plastics is still concern for researchers. As reported by Plastics*Europe* (2017), about 335 million tonnes of plastics were produced in the year 2016. This increased production is a cause for concern about the ecological consequences of ingested plastic and potential MPs pollution. There is a question to how widely MPs have affected aquatic environments and their biota (Villarrubia-Gómez et al., 2017; Xanthos and Walker, 2017).

There is no significant attention to the MPs pollution terrestrial ecosystems like urban environment in comparison to the marine ecosystem (Dehghani et al., 2017). In fact, the level of MPs pollution is higher in undeveloped areas due to lack of proper waste management which may cause huge amount of plastics to enter from land to oceans by 2025 (Jambeck et al., 2015).

Plastics can be classified in three size classes of large MPs (1 to < 5 mm), mesoplastics (5 to < 25 mm) and macroplastics (≥ 25 mm) (Lee et al., 2013). In terms of type MPs have been fallen into five groups: fragments (hard, jagged-edged particles), micro-pellets (hard, rounded particles), fibers (fibrous or thin uniform plastic strands), films (thin, 2-dimensional plastic films), and foam (i.e., Styrofoam-type material) as reported by Anderson et al. (2017). Although, they can divided in six basic types as polyethylene (PE), polypropylene (PP), polyamide (PA), polyvinyl chloride (PVC), polystyrene (PS), polyurethane (PUR), and polyethylene terephthalate (PET) (Hidalgo-Ruz et al., 2012; Van Cauwenberghe et al., 2015a; Pitt et al., 2018). According to Peters et al. (2017), fragments are the least commonly ingested form of MPs while they are generated from MP degradation. Degraded MPs and weathered polymer-based particles have ranges between 50 and 5000 μm in size and are available in marine, freshwater, and estuarine environments (Peters and Bratton, 2016). Table 1 shows the size, shape and color of different types of MPs in some studies.

Based on this introduction, the objectives of this review were

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Table 1
Comparison of different types of MPs in terms of physical appearance.

Type	Size	Shape	Color	Composed group
Fragment		Chips/swarf	Different colors	Dominant group
Film	< 0.1 mm	Hard and flat	Different colors	Not common
Foam	0.1 mm diameter	Elongated and thin shape, spongy texture	White/yellow	Usually PS and PE
Plastic pellets	0.25–0.5 mm,	Spherical	White/gray	Microbeads
	1–2 mm,	Cylindrical	Colorless/translucent	PE
Fibers	Thickness of 30 μm,	Rounded	White/transparent	All size fractions

Adopted from: (Kunz et al., 2016; Van der Hal et al., 2017).

divided to several parts as follows: (1) MPs pollution in different aqueous environments such as fresh waters (lake and rivers), marine and wastewater treatment plants (2) Evaluation of MPs pollution in biota and (3) Suggestion of strategies and methods to reduce the MPs effect based on existing gaps.

2. Source of micro-plastics

Source identification of MPs sources is crucial to reducing the social, environmental and economic impacts (Pettipas et al., 2016). The source of MPs can be categorized as primary such as pellets and secondary which resulting from the fragmentation of larger plastics. Besides, the classification of sources can be as land-based e.g. litter, microbeads and sea-based e.g. fishing nets, buoys (Browne, 2015). They also can be made from the fragmentation of larger objects that causes ever smaller pieces of plastic into the environment. MP amounts and classification of potential sources vary considerably among studies (Collignon et al., 2012). The MPs can be originated from overseas harbors, industrial production sites, human activities such as tourist and urban runoff, textile industries and sewage treatment plants (Dubaish and Liebezeit, 2013; Cesa et al., 2017). In addition, different types of particles made from different sources like road surface markings made of thermoplastic composite paints, fibers derived from synthetic textiles and fragments of large litter items such as plastic bottles and packaging materials (Horton et al., 2017). Even, the variety of MPs colors confirms the multiple sources of MPs (Yu et al., 2016).

The presence of colored MPs confirmed that they originate from synthetic and may be enriched with trace organic substances. Then, MPs are classified as primary (manufactured in small size) or secondary (derived from larger plastics) based on morphology. In the other term, they can be classified as primary or secondary based on shape and surface texture (i.e., smooth edges/texture, symmetrical shape classified as primary) (Estahbanadi and Fahrenfeld, 2016).

Primary MPs originate from spillage during plastic production or recycling and micro-cleansing particles in personal care products (Anderson et al., 2017). These products, such as facial scrubs, have been identified as potentially important primary sources of MPs to the environment especially marine (Conkle et al., 2018). As studied by Estahbanadi and Fahrenfeld (2016), the size distribution of MP in four personal care products were 63–125 μm, 125–250 μm, 250–500 μm, and 500–2000 μm (Browne, 2015).

Secondary MPs made from broken fragments of larger plastic pieces, including, marine litter, synthetic fibers from laundry discharge litter from landfills and industrial or agricultural sources. They are deriving from the fragmentation of larger plastic debris through mechanical forces, by thermo-degradation, photolysis, thermo-oxidation and biodegradation processes (Zhao et al., 2015). Therefore, identification of secondary MPs are difficult due to the large diversity of sources and pathways (Stolte et al., 2015). In addition, Due to their chemical composition and large surface-to-volume ratio, study on composition of MPs is necessary (Wagner et al., 2014).

For example, around 93% of MPs in cosmetics are PE and some made of PP, PE PET and nylon (Eriksen et al., 2013). It can be noted that some significant differences between adsorption by microbeads and adsorption by PE particles can be observed. Although, direction of these effects as microbeads from cosmetics tended to adsorb lower concentrations of persistent organic pollutants (POPs) then PE particles (Napper et al., 2015).

More work has been done to use MPs as physical abrasives in domestic products. For instance, even the vessels can be source of MPs that can be originated from paint flakes off the vessel as reported by Anderson et al. (2017) and vessel traffic as reported by Tamminga et al. (2018). In fact, the understanding about the sources and pathways of MPs is needed to prevent the pollution of our environment (Browne, 2015).

3. Detection techniques

To evaluate the MPs pollution, selection of suitable identification method is crucial. The reliable method should achieve consistency in sampling techniques and taking into account the importance of analyzing the shape and chemical composition of MPs (Alomar et al., 2016). As described quantification methods in literature are limited, there is an urgent need to harmonize procedures for sampling, extraction, identification, assessment and quality assurance (Vandermeersch et al., 2015; Qiu et al., 2016). As discussed by Wesch et al. (2016), the most recent developments of methods for the identification of microfibers such as adoption of spectroscopic techniques should be standardized to monitor MPs more effectively. The detection techniques of MPs are summarized as follows:

1) **Visual Identification:** This method is necessary for separation of MPs from other organic or inorganic material in the sample residues. A visual assessment can help to distinguish MPs originating from field samples to MPs originating from laboratory contamination (Mathalon and Hill, 2014). Large MPs can be detected by this method while smaller particles should be observed using dissection microscope (Doyle et al., 2011). As reported by Lee et al. (2013), particles smaller than 1 mm cannot be identified and counted without microscopic observation and subsequent spectroscopic confirmation. By the way, for detection of polymer types of particles < 500 μm, this method is not suggested due to low level of identification. It also stated that this method can be applied for small transparent particles with 20 μm (Mintenig et al., 2017).
2) **Density Separation with Subsequent C:H:N analysis**: In this method, the polymers separated by difference in their density precisely while for the extraction of high density polymers, this method is not applicable. By weighing a certain volume of the solution, the density of the particle can be obtained. Density separation is useful for marine sediments due to their high density as MPs tend to sink more easily than lighter plastics. This method can be followed by C:H:N Analysis to identify the origin of plastic particles (Claessens et al., 2013).
3) **Pyrolysis-GC/MS:** After above-mentioned methods, it can be used to identify polymer types. It can be obtained by comparing the pyrograms results and selected standard polymers which obtained from the pyrolysis. Hence, this method is not recommended for processing large sample quantities due to the analysis of one particle