Mini-review on current studies of airborne microplastics: Analytical methods, occurrence, sources, fate and potential risk to human beings

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Microplastics (MPs) are emerging pollutants and have potential adverse effects to organisms. Airborne MPs are of great concern, because they are an important contributor to MPs in other environmental compartments such as water and soils and may pose potential risk to human health via inhalation or dust ingestion. Analytical methods, abundance, pollution characteristics, potential sources and risk to human beings of airborne MPs in suspended particulates, atmospheric fallout and deposited dusts were summarized in the present review. Research gaps and suggestions for future works on airborne MPs were also given. Digestion of samples was suggested to avoid the interference of organic materials to airborne MPs. New techniques such as hyperspectral imaging technique, pyrolysis and thermal desorption gas chromatography mass spectrometry were expected to be used for the analysis of airborne MPs. Furthermore, more studies were required to fully understand the pollution status and potential risk of airborne MPs.

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1. Introduction

Microplastics (MPs) are plastic particles with dimension < 5 mm, which originate from primary sources such as synthetic textiles, cosmetics, etc [1], or from secondary sources such as fragmentation and abrasion of large plastic debris [2]. Being considered as emerging pollutants, MPs have been detected in different types of environmental compartments worldwide, such as water [3,4], sediments [5–8], soils [9,10] and atmosphere [11–13]. MPs have also been detected in freshwater and marine organisms due to ingestion of MPs via organisms [3,8,14,15]. Because of the potential negative effects of MPs to aquatic organisms, numerous studies have been carried out in aquatic ecosystems [3,4,16–18], with fiber, granule, pellet, and film being the main shapes of MPs observed [3,4]. With respect to chemical composition, polypropylene (PP), polyethylene (PE), polyethylene terephthalate (PET), polyvinyl chloride (PVC), polystyrene (PS), and polyamide (PA) were polymer types frequently detected in the aquatic environments and organisms [4,19].

Studies on airborne MPs were relatively scarce and have gained increasing concerns recently. Airborne MPs are considered to be an important contributor to MPs in the aquatic environments and the soils, as airborne MPs would enter these environments via dry or wet deposition [20,21]. Moreover, human beings would be exposed to airborne MPs via inhalation and dust ingestion, causing potential adverse effects to human health [22]. Airborne MPs ingested by human beings would cause inflammation and secondary genotoxicity [23]. Furthermore, airborne MPs may contain various harmful chemicals, such as the unreacted monomers, additives of plastics, and other harmful contaminants absorbed from the environments (such as polycyclic aromatic hydrocarbons, persistent organic pollutants, heavy metals and microorganisms) [22,23]. These harmful chemicals may enhance the toxicity of airborne MPs to human beings [22,23].

The purposes of this review are to 1) review recent methods that were used for sampling, pretreatment, and analysis of airborne MPs; 2) summarize the occurrence and characteristics of airborne MPs in suspended particles, atmospheric fallout and deposited...
dusts; 3) discuss the potential sources, dispersion and deposition of airborne MPs; 4) assess the potential risk of airborne MPs to human beings; and 5) identify the research gaps and give suggestions for future works.

2. Techniques used for airborne MP detection

Generally, detection of airborne MPs included sample collection, pretreatment and instrumental analysis.

2.1. Sample collection

Airborne MPs in different types of environment media were collected using different methods. As shown in Table 1, to analyze suspended atmospheric microplastics (SAMPs), particulate matter (PM) in the air were collected on quartz fiber filters (pore size: 1.6 µm, diameter: 47 mm) [11], glass microfiber filters (pore size: 1.6 µm, diameter: 90 mm) [13] or polytetrafluoroethylene (PTFE) filters (pore size: 2 µm, diameter: 46.2 mm) [24] using suspended particulate samplers. Generally, total suspended particulates (TSP) were collected to analyze SAMPs [11,13], whereas, in addition to TSP, PM2.5 and PM10 were also collected in Asaluyeh County, Iran [24]. The air volumes of the samples varied from 2 to 23.93 m³ [11,13,24].

Total atmospheric fallout (including dry and wet atmospheric fallout) were collected using passive samplers [20,21,25–27]. Glass bottles were the most commonly used collectors [20,21,25,26]. The atmospheric fallout samples were collected monthly [26,27] or quarterly [21]. In some studies, samples were collected at various frequencies depending on cumulative of rainfall [20,25]. To collected MPs in dry atmospheric fallout (dust fall) in indoor environments, quartz fibers [11] or double-sided adhesive plastic pads [28] have been used as passive samplers.

Dust samples were collected using vacuum cleaner [11], hog bristle brush [29], or wooden brush [24,30], and then transferred to low-density polyethylene bags [24] or paper bags [29]. To avoid cross contamination, the brushes used to collect dust should be washed with filtered distilled water [24] or rinsed with ethanol [29].

2.2. Separation and digestion

MPs in environmental matrices usually coexist with organic materials. To obtain accurate characterization and quantification of MPs, it is important to remove the organic materials in the samples. Till now, various methods have been explored to destruct natural organic materials before instrumental analysis of MPs in water, sediment, biota, and soil [3,4,9,18,31]. The most widely used method is to digest samples with 30% (v/v) H₂O₂ solution, and the digestion process was accompanied with heating to speed up the reaction in some cases [3,31]. Solutions such as mixture of 30% H₂O₂ and H₂SO₄ [32], Fenton’s reagent (30% H₂O₂ with an iron catalyst) [31,33], HNO₃ [34], 10% KOH [3], and 10 M NaOH [35] have also been used to digest samples. Furthermore, enzymatic digestion of samples using sodium dodecyl sulfate in combination with an optical microscope [24,30]. Scanning electron microscopy (SEM) was used to confirm the morphological characteristics of representative airborne MPs and illustrate the degradation pattern of airborne MPs [26]. Scanning electron microscopy (SEM) was also used to identify typical airborne MPs selected [30].

After physical characterization, airborne MPs was further identified for their chemical compositions. As shown in Table 1, Fourier transform infrared micro-spectroscopy (µ-FTIR) was the most widely used device for physical characterization of airborne MPs [11,13,20,21,25,27]. Digital microscope [26] and fluorescence microscopy [24,30] has also been used for visual observation of MPs. Nevertheless, fluorescence microscopy was found to be ineffective for the detection and count of MPs, thus it was used in combination with an optical microscope [24,30]. Scanning electron microscopy (SEM) was used to confirm the morphological characteristics of representative airborne MPs and illustrate the degradation pattern of airborne MPs [26]. Furthermore, SEM could be used in combination with an energy dispersive X-ray spectroscopy (EDS) detector to analyze the surface morphology and elemental composition of airborne MPs [24,30]. However, the SEM technique is time-consuming and expensive, and is only suitable for detecting typical airborne MPs selected [30].

Whereas, it was suggested that solution with a density range of 1.6–1.8 g/mL would be optimal for density separation [5].

Atmospheric fallout collected by the passive collectors were first filtered on filters such as glass fibre filters [20,26], quartz fiber filters [25], nitrocellulose filters [21] and PTFE filters [27]. To remove the moss in samples collected in spring from Yantai, China, particles on the filters were rinsed off and digested with 30% H₂O₂ for 6 h at 70 °C before filtration [21]. Allen et al. [27] performed a more complicated procedure of H₂O₂ digestion. In brief, particles rinsed from the filters were first digested with 10 mL of H₂O₂ at 55 °C for 7 days, and on day 8, 5 mL of H₂O₂ was added to digest the samples for another 7 days.

Similar to sediments and soils, dusts are also solid samples with high content of organic matter [30]. Dust samples were usually sieved through stainless steel sieves (mesh: 2 mm, 2.5 mm or 5 mm) to remove large debris [11,24,29,30]. After sieving, MPs were density separated from the dust using ZnCl₂ solution (1.6 g/mL or 1.78 g/mL) [11,29,30] or NaI solution (1.6 g/mL) [24]. To remove organic matter in dust, street dust samples were treated with 30% H₂O₂ for 8 days before separation [24,30].

As mentioned above, digesting samples with 30% H₂O₂ was the only method reported for airborne MPs [21,24,27,30], while other methods such as alkaline digestion or enzymatic digestion were not reported for this type of samples. It should be noted that, in some studies, samples were not digested before instrumental analysis of airborne MPs [11,13,20,21,25,26,29], which might lead to over-estimation of MP numbers, as natural materials such as cotton or wool may also been included during enumeration [11,13,25,26,29]. For example, the contribution of natural materials to total fibers was as high as 67% in indoor suspended atmospheric particulate samples from Paris, France, and only 33% of the observed fibers were identified as airborne MPs [11].

2.3. Characterization and quantification

Similar to analysis of MPs in other environment media, instrumental analysis needs to be conducted to obtain physical characteristics and chemical characteristics of airborne MPs [4,38].

To obtain physical characteristics such as shape, size, color and number, airborne MPs were observed and counted under microscopes (Fig. 1). As shown in Table 1, stereomicroscope was the most commonly used device for physical characterization of airborne MPs [11,13,20,21,25,27]. Digital microscope [26] and fluorescence microscopy [24,30] has also been used for visual observation of MPs. Nevertheless, fluorescence microscopy was found to be ineffective for the detection and count of MPs, thus it was used in combination with an optical microscope [24,30].
<table>
<thead>
<tr>
<th>Study area</th>
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<th>Observation size range (μm)</th>
<th>Characterization</th>
<th>Reference</th>
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<td>Paris, France (indoors)</td>
<td>Total suspended particulates</td>
<td>Suspended particulate sampler</td>
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<td>50–5000</td>
<td>Counted by stereomicroscope and identified by μ-FITR</td>
<td>[11]</td>
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<tr>
<td>Paris, France (outdoors)</td>
<td>Total suspended particulates</td>
<td>Suspended particulate sampler</td>
<td>—</td>
<td>50–5000</td>
<td>Counted by stereomicroscope and identified by μ-FITR</td>
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<tr>
<td>Shanghai, China</td>
<td>Total suspended particulates</td>
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<td>—</td>
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<td>Asaluyeh County, Iran-industrial station</td>
<td>Total suspended particulates</td>
<td>Suspended particulate sampler</td>
<td>Digested with 30% H₂O₂ for 8 d and then density separated using NaI solution (1.6 g/mL)</td>
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<td>Visually examined using binocular microscopy, polarized light microscopy and fluorescence microscopy, and determined by SEM/EDS</td>
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<td>Asaluyeh County, Iran-urban station</td>
<td>Total suspended particulates</td>
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<td>Digested with 30% H₂O₂ for 8 d and then density separated using NaI solution (1.6 g/mL)</td>
<td>2–5000</td>
<td>Visually examined using binocular microscopy, polarized light microscopy and fluorescence microscopy, and determined by SEM/EDS</td>
<td>[24]</td>
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<tr>
<td>Paris, France -urban area</td>
<td>Dry and wet atmospheric fallout</td>
<td>Passive sampler</td>
<td>Filtered on glass fibre filters (1.6 μm)</td>
<td>100–5000</td>
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<td>Paris, France -urban area</td>
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<td>Filtered on quartz fiber filters (1.6 μm)</td>
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<td>Observed by stereomicroscope and identified by μ-FITR</td>
<td>[25]</td>
</tr>
<tr>
<td>Paris, France -suburban area</td>
<td>Dry and wet atmospheric fallout</td>
<td>Passive sampler</td>
<td>Filtered on quartz fiber filters (1.6 μm)</td>
<td>50–5000</td>
<td>Observed by stereomicroscope and identified by μ-FITR</td>
<td>[25]</td>
</tr>
<tr>
<td>Dongguan, China</td>
<td>Dry and wet atmospheric fallout</td>
<td>Passive sampler</td>
<td>Filtered on glass microfiber filters (1.0 μm)</td>
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<td>Observed by digital microscope and SEM and identified by μ-FITR</td>
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<td>Yantai, China</td>
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<td>Counted by stereomicroscope and identified by Micro-Raman spectroscopy</td>
<td>[27]</td>
</tr>
<tr>
<td>Tehran, Iran</td>
<td>Street dust</td>
<td>Wooden brush</td>
<td>Digested with 30% H₂O₂ for 8 d and then density separated using ZnCl₂ solution (1.6 g/mL)</td>
<td>2–5000</td>
<td>Visually examined using binocular microscopy and fluorescence microscopy, and determined by SEM/EDS</td>
<td>[30]</td>
</tr>
<tr>
<td>Asaluyeh County, Iran-urban station</td>
<td>Street dust</td>
<td>Wooden brush</td>
<td>Digested with 30% H₂O₂ for 8 d and then density separated using ZnCl₂ solution (1.78 g/mL)</td>
<td>2–5000</td>
<td>Visually examined using binocular microscopy, polarized light microscopy and fluorescence microscopy, and determined by SEM/EDS</td>
<td>[24]</td>
</tr>
<tr>
<td>China</td>
<td>Indoor dust</td>
<td>Hog bristle brush</td>
<td>Density separated twice using ZnCl₂ solution (1.6 g/mL)</td>
<td>50–2000</td>
<td>Counted under a light microscope and chemically identified by μ-FITR; the mass concentrations of specific MPs were analyzed by LC-MS/MS²</td>
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Table 1 (continued)

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<td>Density separated twice using ZnCl₂ solution (1.6 g/mL)</td>
<td>50–2000 μm</td>
<td>Counted under a light microscope and chemically identified by FTIR; the mass concentrations of specific MPs were analyzed by LC-MS/MS</td>
<td>[29]</td>
</tr>
<tr>
<td>Paris, France</td>
<td>Indoor dust</td>
<td>Vacuum cleaner</td>
<td>Density separated using ZnCl₂ solution (1.6 g/mL)</td>
<td>50–5000 μm</td>
<td>Counted by stereomicroscope and identified by FTIR</td>
<td>[11]</td>
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3.1. Occurrence and characteristics of airborne MPs

Abundance and characteristics of airborne MPs in various environmental media were summarized in Table 2.

SAMPs have been analyzed in three studies as demonstrated in Table 2. Only fibers were detected in suspended particulates collected in Paris, France [11] and Asaluyeh County, Iran [24]. Fibers in indoor suspended particles from Paris, France were 0.4–59.4 fibers/m³, significantly higher than those in outdoor environments (0.3–1.5 fibers/m³), and most fibers fell in the range of 50–250 μm [11]. Similar fiber concentrations were observed in outdoor TSP samples from the industrial (0.76 fibers/m³) and urban station (0.63

fallout [26]. Recently, hyperspectral imaging technique has emerged as a simple and fast method to detect MPs in seawater [43] and soil [44] without digestion. Further studies are suggested to validate whether this method could be used to detect airborne MPs.

In addition to characterization, quantification of specific airborne MP polymers has also been performed. Mass concentrations of two main airborne polymer PET and polycarbonate (PC) were quantified using alkali-assisted thermal depolymerization–liquid chromatography–tandem mass spectrometry (LC-MS/MS) as described by Liu et al. [29]. Techniques such as pyrolysis–gas chromatography mass chromatography (Pyr-GC-MS) [45] and thermal desorption–gas chromatography mass spectrometry (TDG-GC-MS) [46] were also reported to have the ability of quantifying mass concentrations of specific MP polymers in environmental samples and could be explored to quantify airborne MP polymers in future work.

2.4. Quality control and quality assurance

To obtain reliable data of airborne MPs, it is necessary to prevent plastic pollution throughout the processes of sample collection, pretreatment and instrumental analysis. Cotton laboratory coats were suggested to be worn during all experiments [13,20,24–27,30]. The use of plastic materials should be avoided as much as possible [13,20,25,30], if plastic materials were necessary to use, they should be rinsed with ultrapure water at least three times [13]. Furthermore, all the glassware should be properly cleaned and heated at 500 °C before use [25], and materials such as glass fibre filters and quartz fiber filters should be heated at 500 °C prior to use. After sampling, it would be better to process the samples in a ‘clean room’, where working surfaces were thoroughly wiped and all windows and doors were closed [24]. To verify that the samples were not contaminated during the experiments, laboratory blanks such as MilliQ water samples were treated in the same way as were the field samples [20,21,25–27,30]. Moreover, empty petri dishes or dishes full of filtered water were placed as control samples in the laboratory during the experiments to detect whether MPs were added during the extraction and subsequent analysis of airborne MPs [24,30]. In addition, field blanks were also collected and analyzed by Allen et al. [27] to quantify possible MP contamination caused by sampling of atmospheric fallout samples. To ensure the accuracy of data, duplicate samples were often performed [27,30]. For example, duplicate atmospheric fallout samples were collected for each sampling period [27]. Although, duplicate atmospheric fallout samples were not collected by Dris et al. [25], airborne MPs in the samples were counted by three different observers, with differences less than 5%. In addition, airborne MPs in five randomly selected street dust samples were counted twice by Abbasi et al. [24] for replication purpose, with differences less than 5%. In addition, airborne MPs in the samples were counted by three different observers, with differences less than 5%. In addition, airborne MPs in the samples were counted by three different observers, with differences less than 5%. In addition, airborne MPs in the samples were counted by three different observers, with differences less than 5%.
fibers/m²) of Asaluyeh County, Iran, with white or transparent fibers being the most abundant [24]. Although various shapes of MPs were detected in TSP from Shanghai, China, round and flat fibrous MPs were primarily observed, comprising 67% of the total particles [13]. SAMP concentrations in Shanghai fell in the range of 0–4.18 particles/m³ (average: 1.42 ± 1.42 particles/m³), with blue (37%) and black (33%), MPs being the dominant MPs [13]. In terms of polymer type, PP was most abundant for Asaluyeh County, Iran, where 77% of MPs were less than 100 μm, in particular, 98% of spherical MPs were <100 μm [24]. Colors of MPs were also obtained by μ-FTIR in Dongguan were similar to those observed in Paris, and mainly fell in the range of 200–700 μm, with a proportion of ~30% [26]. The predominant fiber lengths in atmospheric fallout from the remote catchment of Pyrenees mountains were 100–200 μm and 200–300 μm [27], smaller than those in mega cities such as Paris [25] and Dongguan [26]. With respect to fragment and film, the predominant size range was <50 μm and 50–200 μm, respectively [27]. Predominant lengths of MPs in the atmospheric fallout from Yantai were less than 500 μm, accounting more than 50% of total MPs [21]. In addition, PET was the most abundant polymer type for fibers in the Pyrenees mountains [27]. The predominant polymer type for fragments in the Pyrenees Mountains was PS, followed by PE [27]. PE was also dominant for fragments in Yantai [21].

3.2. MPs in the atmospheric fallout

As shown in Table 2, MPs in the total atmospheric fallout samples from Greater Paris fell in the range of 29–280 particles/m²/d, with an average of 18 particles/m²/d [20]. Higher deposition fluxes of MPs were observed in atmospheric fallout samples from Yantai and Dongguan, China, with a range of 130–624 particles/m²/d [21] and 175–313 particles/m²/d, respectively [26]. However, since 77% of fibers and 15.4% of other shapes were identified as non-plastics, the average deposition flux of MPs identified by μ-FTIR in Dongguan was 36 ± 7 particles/m²/d [26]. To discover the extent of the MP atmospheric deposition in remote terrestrial location, MPs in atmospheric fallout from the Pyrenees mountains have been analyzed, and an average deposition flux of 365 ± 69 particles/m²/d was observed [27]. Fibers were dominant in atmospheric fallout collected in Paris [20], Yantai [21] and Dongguan [26], accounting for as much as about 90% of the total MPs. Different from those in cities, fragments were found to be the dominant shape in the atmospheric fallout from the Pyrenees mountains, followed by films and fibers [27]. Foam was observed sometimes in atmospheric fallout, but at very low detection frequencies [21,26]. In terms of size, the predominant fiber length range was 200–600 μm in the atmospheric fallout from Paris [25]. Fibers in atmospheric fallout from Dongguan were similar to those observed in Paris, and mainly fell in the range of 200–700 μm, with a proportion of ~30% [26]. The predominant fiber lengths in atmospheric fallout from the remote catchment of Pyrenees mountains were 100–200 μm and 200–300 μm [27], smaller than those in mega cities such as Paris [25] and Dongguan [26]. With respect to fragment and film, the predominant size range was <50 μm and 50–200 μm, respectively [27]. Predominant lengths of MPs in the atmospheric fallout from Yantai were less than 500 μm, accounting more than 50% of total MPs [21]. In addition, PET was the most abundant polymer type for fibers in Paris [25] and Yantai (40%) [21], whereas, PP was the most abundant polymer type for fibers in the Pyrenees mountains [27]. The predominant polymer type for fragments in the Pyrenees Mountains was PS, followed by PE [27]. PE was also dominant for fragments in Yantai [21].

3.3. MPs in urban deposited dust

Fiber levels in apartment dusts from Paris ranged from 190.0–670.0 fibers/mg [11]. Similar fiber levels have been observed in indoor samples from major cities of China, with a range of 17–620 fibers/mg (average: 342 fibers/mg) [29]. As shown in Table 2, MP concentrations in outdoor dusts from China were significantly lower than those in indoor dusts [29]. MPs in street dusts varied from 83 ± 10 to 605 ± 10 particles/30 g dust in the central area of Tehran, Iran [30], and from 52 to 7748 particles/15 g in Asaluyeh County, Iran [24]. Fibers were dominant in MPs in indoor (88.0%) and outdoor (73.7%) dusts from China [29], whereas, granules (range: 54.5–82.2%; mean: 65.9%) were more abundant than fibers (range: 16.9–44.3%; mean: 33.5%) in street dusts from Tehran, Iran [30]. Spherical (74%) and film-like (14%) particles were the dominant MPs in street dust, from Asaluyeh County, Iran [24]. Colors of MPs were also obtained for street dusts from Iran. Similar to those in TSP samples, white or
transient MPs were most abundant in street dusts from Asaluyeh County, Iran [24]. Black and yellow particles comprised more than 50% of total MPs in street dusts from Tehran, Iran, with a contribution of 29.9% and 24.6%, respectively, followed by transparent MPs (17.3%), blue MPs (12.6%), and red MPs (10.2%) [30]. Chemical identification was only performed for indoor dusts from China, with PET being the main polymer type [29]. Furthermore, high concentrations of PET have been found in both indoor and outdoor dust from China, with a range of 1550–120,000 mg/kg and 212–9020 mg/kg, respectively [29].

4. Potential sources, dispersion and deposition of airborne MPs

Synthetic textile is an important source for airborne MPs [13,22]. Small fibers used in clothing may be released into the atmosphere during clothing wears or drying [13,23,25]. Fibers used in soft furnishings such as carpets, curtains, etc., may also enter the atmosphere during their usage [24,25]. Furthermore, fibrous MPs may undergo photo-oxidative degradation, wind shear, or abrasion, and eventually be fragmented into fine particles [23]. Coating materials
may also be sources for airborne MPs. For example, epoxy and alkyd resins would gradually turn to fragment MPs in the atmosphere after long-term exposure to UV radiation and physical abrasion [13]. In addition, plastic mulching films, waste incineration, land-filling, sewage sludge used as fertilizer in agriculture, and synthetic particles in horticultural soils would be potential sources of airborne MPs [23,47]. Dust was considered as a sink of airborne MPs, on the other hand, MPs deposited on the ground would also resuspend and enter the air. Thus, dust could be suggested as a secondary source of airborne MPs.

MPs in the atmosphere could transport far away and deposit to the ground as well [20,27]. Source and transport analysis of MPs in the remote area of the Pyrenees Mountains indicated a source area that extended to 95 km from the sampling site [27]. Factors such as pollution concentration gradient, wind speed, wind direction, temperature and humidity would influence the dispersion and deposition of airborne MPs [22,47]. For example, SAMP abundance in Shanghai decreased as the distance to the coastline decreased because of the dilution effect of ocean air and the decreased influence of human activities [13]. Due to the role of dilution, MP levels in outdoor environments were significantly lower than those in indoor environments [11,29]. Precipitation was also indicated to play an important role in the deposition of MPs [22,25]. The lowest MP level was observed in total atmospheric fallout in Paris during a dry-weather period, while the highest MP level was observed during the period when almost daily rainfall occurred [20]. In addition, rain and snow was suggested to be the drivers for MP deposition in the remote mountain catchment of the Pyrenees Mountains [27].

5. Risk on human exposure to airborne MPs

Suspended airborne MPs may enter the respiratory system via inhalation. Assuming that the average air volume consumed by an adult was 15 m$^3$/d, adult exposure to airborne MPs via inhalation by Shanghai residents would be 21 particles/d [13]. However, it should be noted that not all the suspended airborne MPs could reach and finally deposit in the deep lung. For example, fibrous MPs with length-to-diameter ratio greater than 3:1 may stay in the upper airways due to mucociliary clearance [23]. Furthermore, ecological risk from suspended airborne MPs in Shanghai was estimated by calculating the potential ecological hazardous single indices, with values ranging from 0.23 to 6.54, indicating a minor threat to the study area [13].

Dust ingestion is also a significant pathway for human exposure to harmful pollutants, especially for the sensitive population such as infants and toddlers. Previous studies indicated that human beings might be exposed to toxic pollutants such as heavy metals and persistent organic pollutants through dust ingestion [48–50]. Human intake of fibers via ingesting dust fall incidentally during a meal ranged from 13,731 to 68,415 particles/year/person in Scotland, which were much higher than the values via mussel consumption [28]. Based on the MP concentrations in dusts from the main cities of China, estimated daily intake (EDIs) of fibrous and granule MPs via dust ingestion for different age groups of Chinese were estimated to be in the range of 64.1–889 fibers/kg/bw/d and 8.44–119 particles/kg/bw/d, respectively [29]. Furthermore, human uptake of PET and PC MPs by dust ingestion for the different age groups fell in the range of 6500–89,700 ng/kg/bw/d and 0.53–7.37 ng/kg/bw/d, respectively [29]. Highest EDI values were obtained for infants due to their lowest body weight, and higher dust ingestion rate. Human beings may also be exposed to MPs in street dust. The EDI values of MPs via street dust ingestion of Tehran, Iran ranged from 0.6 to 4.0 for children and from 0.3 to 2.0 particles/d for adults in normal exposure scenario (dust ingestion rate: 200 mg/d for children; 100 mg/d for adults), and the ranges would increase to 3–20 particles/d and 1.0–6.7 particles/d, respectively, in acute exposure scenario (dust ingestion rate: 1000 mg/d for children; 330 mg/d for adults) [30]. Higher EDI values of MPs via street dust ingestion were obtained for children and adults in Asaluyeh County, Iran, with a range of 0.7–103.3 and 0.3–517 particles/d, respectively, in normal scenario, and the values were 3.5–516.5 particles/d and 1.1–170.5 particles/d, respectively, in acute scenario [24].

6. Conclusions

This review summarizes analytical methods, occurrence, potential sources, fate and potential risk of airborne MPs from available literatures. MPs could be detected not only in urban areas but also in remote mountains. Inhalation and dust ingestion were both important pathways for human exposure to airborne MPs. However, there are still some issues to be addressed in future studies on airborne MPs:

(1) Standardization of analytical methods for airborne MPs lacked. As indicated by the overview, samples have not been digested in some studies, which would lead to overestimation of airborne MPs due to the interference of organic materials such as cotton or wool. To remove as much of organic materials as possible, digestion of samples is suggested before visual observation.

(2) It is important to identify the chemical characteristics of airborne MPs, whereas, in many studies, only physical characteristics were obtained. In addition, besides μ-FTIR and μ-Raman, hyperspectral imaging technique is also expected to identify the chemical composition of airborne MPs.

(3) Mass concentrations of specific polymer types would provide more information for understanding the potential sources and risk of airborne MPs. However, data on mass concentrations of airborne MP polymers is limited. Therefore, quantification of specific MP polymers should be reinforced in future studies of airborne MPs. Furthermore, techniques such as Pys-GC-MS and TDS-GC-MS could be explored to quantify airborne MPs in future work.

(4) In most studies, the observation size limit of airborne MPs was defined to 50 μm. Nevertheless, microplastics with size less than 50 μm are more prone to be inhaled by human beings and may cause greater health risk. Thus, more advanced analytical techniques should be explored to observe airborne MPs of small size.

(5) Current data on the occurrence of airborne MPs are too limited and are insufficient to assess the pollution status and potential risk of airborne MPs in the global or regional range. More studies of airborne MPs in suspended particulates, atmospheric fallout and dust are required.

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