Microplastics in Urban Environments: Sources, Pathways, and Distribution

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Abstract Due to high-density anthropic activity, the urban environment is regarded as one of the major sources of microplastics (MPs). MPs can be produced in the process of tire wear, landfill and sewage treatment, construction, industrial activity, household laundry, and so on. According to recent studies, MPs have been widely detected in urban atmosphere, ground surface dust or soil, and municipal rivers. Due to lightweight and low density, MPs can easily float and transform between different environmental matrices in urban ecosystems. Storm-water runoff is regarded as an important pathway of MP from land to urban rivers or coastal waters. By wind transportation, MPs on the municipal ground surface can be transferred to urban rivers or the atmosphere. After treating sewage treatment plants, concentrations of MPs can be extremely reduced in the discharged water but increased in the sludge. MPs have also been found in landfills and may leak into other environmental substrates. It can be concluded that MPs can migrate and transform among multiple urban environments through physical and biochemical drivers. Distribution and

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transformation of MPs are closely related to the urban ecological environment and also pose a potential risk on the health of urban residents. More research work needs to fully reveal the source and fate of MPs in urban environments.

Keywords Characteristics, Microplastics, Occurrence, Source, Urban

1 Introduction

Increasing urbanization is an actual threat to the surrounding environment. The urban environment is characterized by high-density residential and anthropic activity. Since plastic products are increasingly used by urban resident, plastic waste and their decomposition outcome microplastics (MPs) have become an emerging environmental issue of increasing concern. Cities are commonly regarded as one of the major sources of MPs, which mostly include packaging, textile, furniture container, transportation, electronics, and construction materials. These plastic products can be further crushed and fragmented into MPs [1–3]. MPs can be transferred among different environment matrices, such as urban atmosphere, surface grounds (dust), soil, and water body (urban rivers or lakes).

Figure 1 shows the schematic diagram of sources and transference of MPs in urban environments. MPs come from household activity, industrial production, urban runoff, atmospheric activities, sewage treatment plants, etc. [4]. Specifically, MP items largely generate from accidental loss of plastic particles during the factory

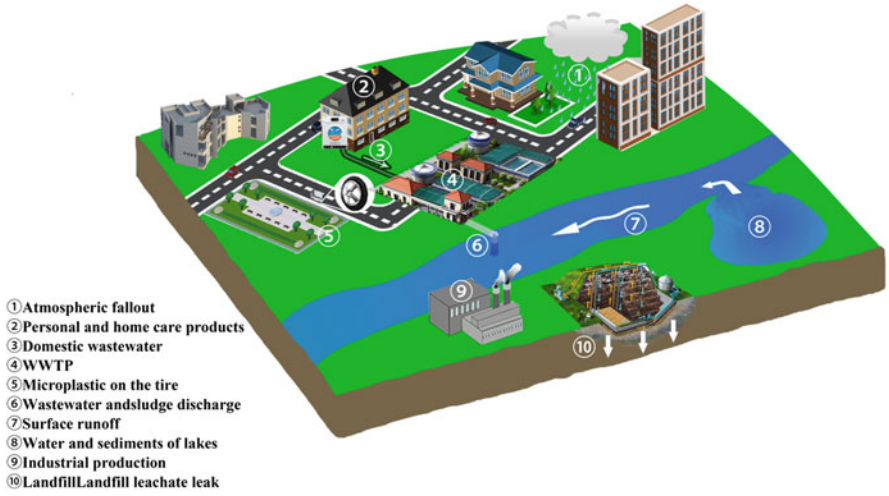

Fig. 1 schematic diagram of sources and transference of MPs in urban environments

and transportation and fiber loss during the washing process of textiles and other daily activities [5]. Browne et al. [6] considered that domestic sewage provided a possible way for the entry of MPs. In addition, there are other ways, including the fragmentation of larger items, the introduction of small particles used as abrasives in cleaning products, and overflow of plastic powder and particles. Recent studies have also shown that the high level of plastic contamination in urban freshwater systems, whose concentration is comparable to that in marine systems [7]. Actually, the presence of MPs in municipal water is considered as important transport carriers for terrestrial MPs to the coastline and the open sea environment [2]. Freshwater systems, especially urban rivers [8], are deemed as an important medium for transferring plastic fragments [9]. MPs were widely detected in multiple urban lakes, rivers, and sewage treatment plants in China [10–13]. Tire wear particles on roads and the polymer of the paint are considered as sources of MPs in urban environments [9]. Tire-derived MPs can further transfer into urban rivers or atmosphere, through surface runoff or wind. In the urban ecosystem, MPs can be randomly distributed into the atmosphere, soil, water column, and sediment, by way of precipitation, surface water erosion, sedimentation, etc. [14]. Horton et al. [9] pointed out that sewage, roads, and surface runoffs were sources of MPs in sediments of the Thames river [9]. Other studies had shown that anthropogenic influences and hydrodynamics have the potential to affect the accumulation and transport of urban MPs [8, 15]. According to the diagram in Fig. 1, MPs show complicated environmental behavior in the urban system. In this chapter, we will review the possible sources, paths, and distribution of MPs in urban environments.

2 Microplastics in Urban Atmosphere

MP appearance in the urban atmosphere is generally closely linked to intensive anthropogenic activities [15]. Nevertheless, to date, a few researchers have investigated the emerging pollutants in the atmosphere. Dris is the first scholar who pays attention to MPs in urban atmosphere [16]. He pointed out MPs were easily transported by wind and could exist in the atmosphere for a long time. Due to their small size and relatively low density, atmospheric MPs thereby can have impacts on the urban ecosystem [17]. MPs can also be potentially inhaled by animals and humans and thus pose a threat to human health [18]. According to a recent study [16], wind and atmospheric deposition can transfer MPs to remote places, eventually entering marine environments.

2.1 Source and Characteristics of Microplastics in Urban Atmosphere

A number of recent studies showed the presence of MPs in urban atmospheres (Table 1). According to the shape of MPs, fiber is the dominated type, but small percentages in other shapes include foam, fragment, and film [17, 19–22, 24]. So the fiber-dominated is one of the pivotal characteristics of MP pollution in urban air. MP fibers (MFs) present in the atmosphere can originate from a variety of sources on the ground. Due to wind and air flow, MFs can float and enter into the human respiratory system like other pollutants [17]. It is presumable that synthetic textiles, erosion of synthetic rubber tires, and city dust are the main sources of these MFs [18]. It was reported that more than 90 million metric tons of textile fibers were globally produced in 2011. Two thirds of the production is synthetic and plastic fibers, mostly including polyethylene terephthalate (PET), nylon (rope and woven products), and rayon [20, 21, 24]. The fibrous plastic has grown by about 6.6% per year over the past decades [25]. It is predictable that the degradation and fragmentation of these fibers produce the prevalence of fibrous MPs. It is noted that fiber-dominated MPs have also been observed in indoor space as well as in atmospheric fallout of outdoor environments [19]. In addition, the commercial use of fine diameter (1–5 mm) plastic fibers was considered to produce MFs in certain ways, such as in the sportswear industry [26]. Significant developments in the synthetic fiber industry and the widespread use of inexpensive non-woven fabrics may be helpful to explain the prevalence of microfiber in the atmospheric environment [27].

In daily life, plastic fibers are commonly produced from textiles. These microfibers may be shed and released directly or indirectly when the clothing is worn or during washing and drying [28, 29]. In addition, the physical breakdown of compounds also results in microfibers in daily activities including walking and strenuous exercising, through wearing and tearing of pants. In addition, MP fibers can be produced because of mechanical wear or damage of textile clothing and bedding including pillows, blankets, and curtains. In the sun, photooxidation and thermal effects of drying clothes can easily promote decomposition and degradation of these textiles, which causes the release of microfibers [30]. Afterward, these fibrous MPs can be broken into smaller-sized fine items through wind shear or wear and other environmental drivers [26].

In urban atmosphere, multiple shape MPs can come from waste disposal, road traffic, and so on. Actually, the majority of plastic waste is disposed by dumping into open soil landfills, which gives plastic plenty of exposure to the atmosphere. The continuous exposure can increase the chance of coarse plastic fragments breaking up, which results in the release of MPs [31, 32]. In addition, human activities on the ground, such as industrial cutting or grinding synthetic materials, mowing grass, and automobile tire wear, can produce a significant amount of MPs, which are further transferred into the atmosphere [27, 33].

A recent study showed that atmospheric MPs appear at different rates and sizes for several months [24]. It was because meteorological factors, such as weather,

Table 1 Microplastics in urban atmosphere

Survey site	Survey date	Analytical methods	Collect result			References
			Polymer type	Shape	Concentration	
Urban in France	2015	Collected through a steel funnel	PET; polyamide; the mixture of PET and polyurethane; the mixture of cotton and RY	Fibers (67%, 200–400 μm and 400–600 μm are predominant size ranges) Fragment (30%) Granules (3%)	110 ± 96 particles m^{-2} day^{-1}	[17]
Paris indoor (air and dust), France	2015	Through a pump and a filter (1.6 μm, 47 mm)	The mixture of cotton and polyamide; polypropylene; polyamide fibers and copolymers of polypropylene and polyethylene	Fiber smaller than 3,250 mm	2,070 and 7,300 fibers m^{-2} day^{-1}	[19]
Paris (outdoor), France	2015	Same as above	–	Fibers smaller than 1,650 mm	0.3–1.5 fibers m^{-3}	[19]
Dongguan, China	2016	Using a sampling device equipped with a glass bottle	PE (14%), PP (9%), PS (4%), RY	Fiber (mostly) foams, fragment, film	Average 36 ± 7 particles m^{-2} day^{-1}	[20]
Yantai, China	2014–2015	Pre-filtered through a set of stainless steel sieves (mesh sizes of 5 and 1 mm)	PET, PE, PVC, PS	Fiber (mostly) foams, fragment, film	1.30×10^2–6.24×10^2 particles m^{-2} day^{-1}	[21]
Sakarya province, Turkey	December 2016–May 2017	Through an air vacuum filter (50 and 500 μm) device	–	Average fragments (50%) and fibers (50%)	Average eight items 30 min^{-1}	[22]
Shanghai, China	March and April in 2018	An intelligent flow collected suspended particulate sampler	PET, PE, PES, PAN, PAA, RY, EVA, EP ALK	Fiber (67%) Fragments (30%) Granules (3%) 23.07–9,555 μm	0–4.18 nm^{-3} (items per cubic meter of air)	[23]

wind speed and direction, humidity, temperature, and cyclones, can affect the amount of MPs in urban air [17]. The amount of atmospheric MPs may be dependent on a number of factors. For instance, rainfall can change MP abundance [22]; however, no significant correlation had been found between MPs in atmospheric fallout and the rainfall in a study of Paris [17]. Another report showed that the deposition flux of MPs varied seasonally with lowest deposition flux in autumn, which was mostly due to the variability of meteorological conditions in different seasons [21]. In addition, consumption habits and socioeconomic status of local humans, transportation, and urbanization are also related to the amount of MPs in urban atmospheres.

In a closed or semi-closed compartment, MPs are usually produced through mechanical wear or damages of textile clothing and bedding such as pillows, blankets, and curtains. A study showed that the MP concentration, especially microfibers, in indoor air (1–60 fibers m^{-3}) was higher than that in outdoor air (0.3–1.5 fiber m^{-3}) [19]. Therefore, indoor exposure to airborne MP fibers or particles may pose a threat to human health [19, 34]. Comparatively, occupational air exposure to MPs may be of high risks than household exposure. It is noted that some special factories using high volumes of polymeric materials, and lack of efficient ventilation, may result in chronic exposure to high concentration of airborne MPs. Furthermore, indoor MPs can persistently enter outside atmospheres [19]. But only 30% of outdoor particles can penetrate the indoor rooms in terms of an estimation [35]. Therefore, indoor air is the main source of atmospheric MPs in the urban environment [18].

2.2 Fate and Distribution of Airborne MPs

Airborne MPs could become a source of contamination for terrestrial and aquatic ecosystems. Due to light and low density, dynamic exchange of MPs among various environmental systems occurs frequently [18]. Just like over the sea, atmospheric aerosols can spray and generate MP particles in the urban air [36, 37]. This process could be associated with the MP cycle in the urban environment. MPs in the urban atmosphere can be carried by wind and fall to the ground and plants on the surface and by precipitation or unstable atmospheric disturbances [38]. A recent study showed some similarities in morphological characteristics and chemical composition between marine MPs and terrestrial MPs, which indicates that marine MPs may be derived from terrestrial environments through atmospheric transportation and deposition. These MPs, major microfibers in the atmosphere, could be also transported and deposited on surfaces of ground in cities [39].

The environmental behavior of MPs in the atmosphere may be similar to other air pollutant particulate matters [18]. Influenced by density and buoyancy, atmospheric MPs present vertical distribution characteristics, usually higher concentrations near the ground. A recent study investigated the content of MPs at different altitudes of atmospheres and showed the highest MP concentration was at 1.7 m above the

ground [9]. Additionally, wind erosion should be considered as a transport driver of MPs in terrestrial environments [40]. For instance, an increase of wind speed leads to a decrease in atmospheric MP concentrations [24]. Similarly, outdoor temperature affects the migration of MPs in the atmosphere. Additionally, urban topography, like distances between buildings, and local meteorology and thermal circulation (heat islands perturbing air flow) could also affect the distribution of MPs in air [41], especially to low-density polymers such as PE and PP MPs [9, 42]. Compared with outdoor air, the migration behavior of MPs in a closed indoor environment is not subject to these restrictions; room partition, ventilation, and airflow can have impacts on the behavior of indoor MPs [35]. Of MPs, airborne nanoparticles (<100 nm) can rapidly diffuse in indoor compartments in terms of a recent analysis [43]. However, there are, to date, limited studies on atmospheric MPs especially in urban environments. Furthermore, there are no uniform method standards for analyzing atmospheric MPs. More studies are needed to investigate the environmental behavior of MPs in the urban atmosphere.

3 Microplastics on Ground Surface of Urban Environments

High density of vehicles is another characteristic in urban areas. Some studies have shown that particles released by automobile tire wear are an important part of MPs on urban ground surfaces [27]. According to Unice et al. [44], tire wear degradation caused multiple-color paint to peel off road signs and then flowed into rivers through rainfall. Tire and road wear particles (TRWP) are formed at the frictional interface of the tire and road surface and consist of polymer-containing tread with pavement mineral and binder encrustations. Some scholars are consistent to recognize TRWP as an important source of MPs on urban surface grounds [45–48]. Due to its physical properties, tire wear could be mixed with particulate matters from the pavement or road dust and change into aggregates. It was pointed out that tire materials would account for up to 70% of MP release into the urban environment [49]. TRWP and their aggregates are eventually transported off the street through surface runoff or street cleaning and can migrate into the atmosphere by suspension [50, 51]. As another way, after crushing and recycling, these tire materials [52] can be used as filling embankment materials in lawns [53], playgrounds [54], and so on. In addition, the environmental concentration of automotive tire particles can be estimated by chemical markers, such as plastic additive in tire and rubber type [55]. The other sources of ground surface MPs include road sign paint shedding [9], beads in personal care products, and household dust generated by household plastic products [56]. Totally, these MPs can further enter into water bodies or atmospheres in the urban areas.

In the urban environment, another store of MPs is dust on the surface of the grounds. The main types of municipal waste disposal are usually dumped and exposed to sunlight. In this process, plastic waste has undergone a combination of biodegradation, photodegradation, thermal oxidation, and thermal degradation

[31, 32], as well as mechanical wear, and increases the chance of coarse plastic fragments breaking up into MPs. Therefore, many factors can determine the settlement of MPs in road dust or urban topsoil. For example, the practice of mowing grass on the roadside causes littering to be decomposed by lawn mowers, which includes plastic, and produces MPs in the process [29]. Street dust is an ideal indicator of urban environmental quality, since it can reflect pollutants from different media such as urban air, water, and soil [57]. The main sources of dust pollutants include vehicle traffic, road wear, brake pad tear and wear, road paint wear, and atmospheric deposition [58]. Pollutants generated by urban street construction can also be contained in street dust pollutants. A recent study showed that street dust was dominated by spherical particles, film, fragments, and fibers, among which large amounts of type particles were detected in the road dust in the city of Iran [38]. In another city, Bushehr, the majority of MPs was found as fibers (75.87%), and was detected in all street dust samples, with an MP concentration of 210–1,658 MP items 10 g^{-1} dust [59].

Large amounts of MPs can enter into aquatic environments through runoff from urban areas. The conveyance of MPs dependent on overland runoff can be viewed as a pathway of MPs from land to sea [56]. Flowing through the road and urban pavements, MPs are washed by the rain; some will enter the artificial pipes, and others will enter the natural reservoirs, such as ponds [27]. Additionally, a recent study showed that wind erosion would be considered as a transport pathway of MPs in terrestrial environments [40]. MPs on the surface of the ground can be blown into the atmosphere by wind through buoyancy. Therefore, MPs are itinerant on urban surface; and via various pathways, MPs likely migrate into other environmental matrices, such as aquatic environments.

4 Microplastics in Aquatic Environments of Urban Areas

4.1 Urban Natural Water Body

Urban river systems are important sinks for the discharge of various pollutants from local residential and industrial areas. Urban rivers can receive MPs via atmosphere, surface runoff, industrial production processes, and sewage treatment plants. Natural water body could provide a temporary reservoir of MPs in the short term [8]. Subsequently, these pollutants in urban rivers could enter into mainstreams, bigger river, or even open sea [8]. Some rivers and estuary environments have been identified to have heavy MP contamination. Rivers, especially those flowing through large cities, were considered to be the main source of land-based MPs entering the ocean [60]. In recent years, increasing studies have globally explored the presence of MPs in urban lakes and rivers (Table 2). Despite the variance of MP concentration, the presence of MPs has been widely determined in urban rivers in terms of previous studies (Table 2). Of these reports, the highest abundance of MPs was 8,925 $\pm$ 1,591 nm^{-3}, which was found in urban lakes in Wuhan, China [65]. According to Eriksen et al. [72], the

Table 2 MP pollution in urban water environments

Sample collection	Location	Assay methods	Concentration	Forms of MPs	Size	Polymer types	Reference
Water	Urban water in Shanghai, China	μ-FTIR	80–7,400 items m^{-3}	Majority of fibers: 37–88%	Majority were 100–1,000 μm	PES: 27.7%, rayon: 14.4%, PP: 8.7%	[8]
	Ciwalengke River, Majalaya, Indonesia	Raman spectroscopy	5,850 ± 3,280 particles m^{-3}	Fiber: 65% Fragment or other forms: 35%	50–100 μm: 116 L^{-1}, 101–300 μm: 44 L^{-1}, 301–500 μm: 64 L^{-1}, 501–1,000 μm: 64 L^{-1}, 1,000–2000 μm: 54 L^{-1}	Polyester and nylon	[61]
	Jiaojiang, Oujiang, Minjiang estuaries, China	Micro-Raman spectroscopy	100.0–4,100.0 nm^{-3}	Over 90% for fiber and granule	Over 90% for 0.5–5.0 mm Over 70% for <2 mm	Total of 41 MPs: 21 particles PP, 16 particles PE, 3 particles PTFE, 1 particle PVC	[62]
	Auckland, New Zealand	FTIR	17–303 items m^{-3}	Fragment: 39% Fiber: 34% Film, foam, pellet	Majority were 63–500 μm	PHM, EEAC, PP, PE, EVA, EPDT, EVAC	[7]
	Four estuarine rivers in the Chesapeake Bay, USA	Raman microspectroscopy	<1.0–>560 g km^{-2}	Fragments (0.3–5.0 mm), synthetic fibers, extruded polystyrene	–	PE	[63]
	Raritan and Passaic rivers, New Jersey	Pyr-GC/MS, HS-SPME/GC-ITMS	28,000–3,000,000 particles km^{-2}	Fragment: 38% Foam, line (fiber, filament), film, pellet	1 mm to >4.5 mm: 71% 0.3–0.99 mm	2-Butanone, 4-(2,6-trimethyl-1-cyclohexen-1yl)	[64]
	Urban lakes and reaches in Wuhan, China	FTIR	1,660.0 ± 639.1–8,925 ± 1,591 nm^{-3}	Fiber: 52.9–95.6%, granule, film, pellet	<2 mm: 80%	PET, PP, PE, nylon, PS	[65]
	The Pearl River along Guangzhou City, China	Microscopy	379–7,924 items m^{-3}	Fiber: 80.9% Fragments: 18.9% Films: 2.2%	0.02–1 mm: 44.8% 1–2 mm: 36.5%	PP: 35.7% PE: 28.6% PET: 28.6% Other: 7.1%	[60]
Sediment	The River Tame and its tributaries in Birmingham, UK	(FTIR)	165 particles kg^{-1} (mean)	Fragments: 49%; fibers: 22%; foams, films, irregular spheres, and commercial fragments	250 μm to 1 mm: 46%	PE: 50% PVC: 30% PMMA: 20%	[66]
	The fjord (Byfjorden) in	FTIR	12,000–200,000 particles kg^{-1} dw	Majority were fibers, next were fragments and spheres	<100 μm: over 95% <25 μm: 56.3–70.1%	PUR/Acr resins, 37.3%; R3, 16.8%; PP, 9.5%; EVA,	[67]

(continued)

Table 2 (continued)

Sample collection	Location	Assay methods	Concentration	Forms of MPs	Size	Polymer types	Reference
	western Norway					9.3%; PA, 4.5%; PEST, 4.7%; PE, 3.9%; PChl, 2.2%	
	An estuary in Tasmania, Australia	Centrifugation and filtration	Core A ($N = 7$): 211 MPs B ($N = 7$): 252 MPs	Fiber: 87% Sheet: 9% Fragment: 3% Beads: 1%	Core A: 137 in 63 μm, 49 in 100 μm, 24 in 1 mm, 1 in 4 mm Core B: 132 in 63 μm, 93 in 100 μm, 27 in 1 mm	–	[68]
	Ciwalengke River, Majalaya district, Indonesia	Raman spectroscopy	30.3 ± 15.9 MP particles kg^{-1} (dry sediments)	Fiber: 91% Fragment: 9%	50–100 μm: 12 L^{-1}, 101–300 μm: 10 L^{-1}, 301–500 μm: 36 L^{-1}, 501–1,000 μm: 52 L^{-1}, 1,000–2,000 μm: 72 L^{-1}	Polyester, nylon	[61]
	Eighteen streams in and around Auckland, New Zealand	Malvern Mastersizer 2000 laser diffraction particle analysis, FTIR	9–80 items kg^{-1}	Fragment: 79% Fiber: 20% Film, foam	Majority were 63–500 μm	PHM, EEAC, PP, PE, EVA, EPDT, EVAC	[7]
	Urban water areas in Changsha, China	Microscopy, SEM	270.17 ± 48.23–866.59 ± 37.96 items kg^{-1}	Fragments: 50.82% Fiber: 28.15% Film: 18.14% Foam: <10%	Majority (58.31%) were <1 mm	PS: 29.41% PE: 19.12% PET: 14.71% Few: PP, PA, PVC	[69]
	Vembanad Lake, India	Micro-Raman spectroscopy	$252.80 \times 10^6 \pm 25.76 \times 10^6$ particles km^{-2}(mean)	Dominance: Film and foam Fragments, fiber/line, pellets	–	HDPE, LDPE, PP, PS	[70]
	Edgbaston Pool in Birmingham, UK	Microscopy	250–300 particles kg^{-1} dried sediment	Fragment, foam, film, fiber	–	–	[71]
	The River Kelvin in Glasgow, UK	SEM-EDS	161–432 MPs kg^{-1} dry sediment	Fiber: 88%, pellet: 0.25–0.7 mm, fragment	–	–	[2]
	The Pearl River along Guangzhou City, China	Microscopy	80–9,597 items kg^{-1}	Fiber: 54.7%, fragments: 43.3%, films: 1.9%	0.02–1 mm: 63.3%, 1–2 mm: 29.5%, 2–3 mm: 7.6%, 3–4 mm: 3.3%, 4–5 mm: 1.6%	PP: 26.2% PE: 47.6%	[60]

average abundance of MPs was about 43,000 km^{-2} in the lakes near cities; the highest abundance is up to 466,000 km^{-2}. Morritt et al. [73] compared the size of MP fragments in the Thames in the UK and found that sewage treatment plants were the main source of MPs.

Abundance of MPs in urban freshwater is closely related to anthropic activities; high density of population usually causes high abundance of MPs [74]. Lasee et al. [75] demonstrated that the presence of large amounts of MPs in water bodies around densely populated urban areas. Another study also confirmed that human factors affected the abundance of MPs in urban regions [65]. Nevertheless, some researchers reported relatively high concentrations of MPs in remote freshwater environments, with extremely low population densities and low levels of industrialization [39, 76]. Even though the reason is largely unknown, we speculate that complex mechanisms can be involved in this transport process.

MPs in urban rivers might deposit into sediment and more likely to accumulate through sedimentation. On the contrary, MPs in the sediment can be released into water bodies under the action of water flushing [69]. Peng et al. [14] proved that urban river sediment might be a reservoir of land-based MPs and also a source of marine MPs. They surveyed sediment in the rivers of Shanghai, China, and found that secondary MPs accounted for the majority of the MPs in urban water environments. However, due to the lack of the practice of waste classification in China and other developing countries, most of plastic productions has not been recycled for the usage, which leads to the big possibility that primary plastic can be fragmented into MPs, which is ultimately discharged into water environments of urban areas.

4.2 Municipal Sewage System

In municipal sewage system, wastewater treatment plants (WWTPs) are attributed to a major pathway for MPs to enter into the aquatic environment in urban areas. To date, the presence of MPs at WWTPs has been widely reported in Australia [77], Europe [78–80], and the USA [81, 82]. In a recent study, researchers have investigated MPs at a full-scale WWTP, Eastern China, with two parallel wastewater treatment systems, including oxidation ditch and membrane bioreactor. They found that MP concentrations increased across the treatment systems and depended on the facility of the treatment process. Influent MPs were removed by 99.5% in membrane bioreactor system, while 97% in oxidation ditch system [83]. Other investigators reported that MP removal at WWTPs could reach around 99%, but the residual MPs discharged into surface water receivers were still in huge amount [81, 84]. These MPs from WWTPs will continuously be discharged into urban rivers as one of the important sources for freshwater MPs [85].

The estimation showed that China released about 209.7 trillion MP microbeads (306.9 t) per year into the water environment, 80% of which came from sewage treatment plants [86]. Primary MPs are originally derived from personal care products such as toothpaste, cleansing gels, and soap and enter the sewage treatment

plants through sewers [87]. Secondary MPs are produced by the treatment process of the facility in sewage treatment plants, mostly via photolysis, oxidation, and degradation [4]. Of these MPs in municipal sewage systems, fibers such as polyester and nylon in synthetic garments [88] are the main types [6]. Peng et al. [14] identified the amount of polyester, rayon, and other microfibers, which indicates that clothes washing lead to a large part of microfibers entering water bodies. Except for microfiber, a small number of other MPs types, such as chips and films, are available in WWTPs. Despite the variance of the composition of MPs in different sewage treatment plants, fibers were commonly reported as the dominated morphotype [8]. Mark et al. [6] conducted a comparative test of MPs in wastewater discharged from marine sediments, sewage treatment plants, and wastewater originally from washing machines. The ratio of polyester fibers in marine sediments and sewage was similar to that used for textiles; further analysis showed that a piece of clothing can fall off more than 1,900 fibers per wash, releasing up to 100 fibers per liter of discharged sewage. It is predicted that more fibers will enter the sewage treatment in winter. Dris et al. [16] collected raw water, sedimentation water, and treated conventional water from the Seine-Center wastewater treatment plant downstream of the Paris water. After assay they found high concentration of MPs, i.e., 260×10^3–320×10^3 particles m^{-3}, in the raw water. The majority of the MPs were fibers and in the size of mm scale. The domination of microfibers in the wastewater can be due to the washing machine. After pretreatment before cloth washing, the amount of MPs was greatly reduced to 14×10^3–50×10^3 particles m^{-3}, and the MP dimensions all decreased to below 1,000 μm. It indicated an effective approach of the removal of MPs in the sewage treatment plant.

The fate of MPs across the treatment system in the WWTP is also associated with the accumulation of MPs in sludge. After trapped in the sewage treatment plant, the sludge may contain a large amount of MPs, which may be applied for agriculture, and result in MP contamination in farmland soil [9, 89]. Lassen et al. [49] reported that $1.00–24.0 \times 10^3$ MP particles kg^{-1} ($\geq$10 μm) were contained in sludge of a sewage treatment plant in Germany. According to a study in Vancouver, Canada, the wastewater treatment plant retained up to 99% of MPs and mostly accumulated in the sludge [85]. In the sludge, content of microfibers was up to 9.7 ± 3.7 fibers g^{-1} and higher than other MP shapes. Another study showed that average numbers of MPs were $22.7 \pm 12.1 \times 10^3$ particles kg^{-1} (dry sludge) in waste sewage sludge collected from 28 WWTPs in China [90]. In fact, a large proportion of MPs in the sewage tend to mix with the sludge and precipitate in WWTPs [91]. According to a survey in two sewage treatment plants in Turkey, the removal rate of MPs can be up to 73–79% [87]. Despite practical efficiency of MP removal in WWTP, a large amount of MPs can still be released into the sewage outlet. Therefore, pioneering and targeting designs need to be developed to elevate MP removal in WWTP [60].

5 Microplastics in Municipal Solid Waste

With the development of urbanization, solid waste is dramatically increasing [92]. It is estimated that about one billion tons of municipal solid waste is globally produced; less than 200 million tons are processed in waste-to-energy plants. There is a large amount of plastic waste in solid waste. In 2017, China's plastic production was 84.58 million tons [93]. It was estimated that 8.82 million tons of plastic waste were poorly managed in China, of which 133.353 million tons entered the ocean in 2010 [94]. Although some plastic wastes have been recyclable, the majority is often mixed with other types of domestic wastes [95] and burned or landfilled together with municipal solid wastes [92]. Landfill is a waste treatment strategy all around the world. Due to poor management, landfills are predicted to store 21–24% of global plastic waste [42]. A large amount of plastics are buried in landfills and are subject to relatively more severe environmental conditions, including the leachate pH (from 4.5 to 9), high salinity, temperature fluctuations, the generation of gas (such as carbon dioxide and methane), physical stress, and microbial degradation. These can cause plastics to break into smaller fragments and produce MPs or even NPs [5].

The presence of MPs in municipal solid waste was supported by a series of experiments and analysis [96]. Alimi et al. [97] proved that MPs could be intruded into soil through landfill leachates. Kilponen [98] found that MPs in a creek were stemmed from an old closed landfill leachate. He et al. [5] studied the occurrence and characteristics of MPs in different MSW landfill leachates and explored the potential of MPs as a source of MSW landfills. Seventeen different kinds of plastics were detected in landfill leachate, with leading polymer types of PE (34.94%) and PP (34.94%). They concluded that differences of plastic types in leachates might be related to regional differences in waste composition and landfill conditions. The MPs in landfill leachate were almost irregular in shape and rough in edges, which indicated the fragmentation process of larger plastic wastes in landfills [99]. The fragmentation might be the long-term process of producing MPs according to analysis [5]. Most of these plastics were in the size of 100–1,000 μm (74.88%); the number of MP particles increased with the decrease of MP sizes. The high percentage of small MPs indicated that smaller plastic fragments were more likely broken and further carried by leachate in the landfill environment. These small-sized MPs could be easily uptaken by soil biota, even microorganisms in landfill, which lead to a latent ecology risk [100–103]. Taking the typical megacity Shanghai, for example, Su et al. provided a systematic overview of MP pollution characteristics in landfill systems by investigating the MP abundances and fates in leachate and refuse over different landfill age [104]. The results indicated that abundance, size, and polymer type varied from landfill age, and the oxidative degradation of polyethylene MPs occurred in the landfill process, especially for the landfill time of more than 20 years. This study concluded that the fates of MPs in landfills were determined by the increase consumptions of plastic products and the degradation process of MPs in landfills.

Landfills are not the ultimate destination of plastics, but a potential source of MPs in other environmental matrices. The MPs in the leachate can leak into the environment through leachate leakage and discharging from the leachate collection treatment system. Foose et al. [105] demonstrated that leakage in the landfill system was a pathway of MPs entering the aquatic environment. Additionally, soil application of tiny solid components of landfills may introduce MPs into the terrestrial environment. MPs can accumulate in the soil and may be transported and redistributed by wind or flow into the aquatic environment via surface runoff [106, 107]. In addition, the MPs contained in the landfills can also be discharged through the ventilation of the aeration or closed landfill in the aerated bioreactor landfills.

6 Conclusions

In urban environments, MPs can be produced in the process of tire wear, landfill and sewage treatment, construction, industrial activity, household laundry, and so on. Due to lightweight and low density, MPs can easily float and transform within urban ecosystems. Meteorological conditions are the key factors for the migration of MPs in urban atmospheres. Wind erosion should be considered as a transport pathway of MPs, which makes MPs float in the atmosphere for a long time, and fill into different parts of a city, making it easier for humans to contact with MPs through breathing. Storm-water runoff is important for the conveyance of MP into the aquatic environment, which can be deemed as a pathway of MP from land to water bodies [56]. Rainfall also can result in atmospheric MPs falling down the surface of the ground and eventually enter into urban rivers. A large amount of MPs are produced by washing machines, cosmetics, plastic beads, and other processes and then enter into sewage treatment plants through municipal sewers. After treatment of sewage treatment plants, concentration of MPs can largely reduce in the outfall water; but MPs will be accumulated in the sludge. Additionally, MPs have also been found in landfills and can leak into other environmental matrices. We can conclude that a mass of MPs can migrate among the ground, the air, the water, and even the ocean. Distribution and transformation of MPs are closely related to urban eco-environments and human activities.

To date, knowledge about MPs in urban environments is very limited. Future researches need to focus on several aspects:

1. Standard sampling methods should be developed to facilitate the comparison of MP distribution in different cities.
2. More research work needs to investigate MP content in urban atmospheres, to further explore the joint pollution of MPs with other pollutants, and to analyze latent health risks.
3. More work is necessary to discover the source and fate of MPs in multiple urban environments.
4. New technology and methods need to be developed to control MPs, especially microfiber released from household cloth washing to WWPT and urban rivers.

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