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Occurrence of Microplastics in the Asian Freshwater Environments: A Review

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Abstract

Microplastics pollution has become a worldwide common problem. Despite the growing numbers in researches regarding the microplastics, the understanding of microplastics in the freshwater environment are still less. This paper overviews the present knowledge and findings on the occurrence of microplastics in water and sediment of the freshwater environments in Asia. The review also covers the size distribution, polymers, morphological characteristics and sources of microplastics to the freshwater systems. Perspective of the adsorption of heavy metals on the microplastics to the freshwater systems are also discussed in this review.

Keywords: Microplastics; Heavy metals adsorption; Freshwater environment; Plastic pollution

Introduction

Plastic pollution has become one of the greatest problem worldwide due to its adverse effects. Municipal wastes from heavily populated urban areas, industrial untreated wastes, and land activities are the major sources of plastic pollution in the freshwater environment. Plastics have been used extensively for many purposes due to their durability, low cost and resistance to corrosion [1], thus, increase the plastic demands over years. Plastic wastes were estimated to be around 42 – 79 million tonnes in Asia [2], and according to the World Bank [3], Southeast Asia countries (i.e. Thailand, Malaysia and Philippines) recycle only 18–25 % of their plastic wastes every year. Developed country likes Japan however, recycles about 83 % of their plastics [4]. China which is the world largest plastic producer, only recycles ~30% of their plastics [5]. Some smaller Asian developing countries such as Cambodia, Myanmar and Brunei Darussalam do not recycle their plastic wastes due to having the limited or almost none plastic recycling industries [6]. The plastic wastes mismanagement may pose severe threats to the ecosystem and human health, thus can extensively pollute the water, sediment, soil and air. Natural factors such as wind blowing, water body sizes and their residence times, storm waters, and floods may also contribute to the distribution of plastics in the freshwater environments [7], such as, rivers, lakes and ponds. Once plastics entering the aquatic environment, they are subject to physical, chemical, and biological processes,

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which give effects to the breakdown of large particles of plastic to the smaller one. Researchers have considered 5 mm and less as microplastics [8–9] and fall into two groups: primary and secondary microplastics, depending on their sources of origin. Primary microplastics like microbeads are resulted from the final products of industries such as personal care and cosmetic products [10], meanwhile secondary microplastics are from the breakdown of large plastics when exposed to hydrolysis, ultraviolet radiation (UV) and mechanical forces [11]. Plastics in micro sizes exhibit high hydrophobicity, large surface area, and thus have the ability to trap other pollutants on their surface.

Yin et al. [12] reported that environmental pollution associated with plastic debris is not only restricted to marine environment, but also had been found in ponds, lakes and rivers. This review extensively focuses on the occurrence of microplastics in the freshwater environments of Asia from 2014 to 2021, in term of size distribution, polymers, morphological characteristics and sources. A short description on the adsorption of heavy metals on the microplastics will be discussed too.

Occurrence and size distribution of microplastics

Asia is the world's largest continent that provides home to almost 60 % of the global population [13], inhabitants and encompasses about 30 % of the Earth's total land area. Despite the fact that freshwater in Asia has a high risk of being polluted by microplastic, studies conducted are still limited but have started to increase exponentially over time. The sources of microplastics may come from the cosmetic and personal care products such as scrubs, soaps, lotions, and toothpastes containing microbeads [14], industrial and domestic wastewater [15], plastic litter degradation [16], fishing activities [17], landfills runoff and unmanaged waste dumps [18]. Microplastics can either being transported across the environmental compartments such as from land to river or persisted in that particular area and broke down through thermal, photo- or bio-degradation. This processes will lead to greater problems in term of aesthetical value and human health as well as ecosystem. Table 1 shows the diversity in microplastic properties came across during sample collection, indicating various sources.

When rivers or lakes are located near to the major sources of microplastics like industrial outputs, wastewater treatment plants and densely populated urban areas, microplastics loads can be higher. A study conducted by Di and Wang [19] in Three Gorges Reservoir, China showed that the average of microplastics tend to be highest in urban areas, followed by suburban and rural areas. These significant spatial variations between different areas can also be observed in Taihu Lake, China [20], lakes in Wuhan City, China [21], rivers in Japan [22] and rivers in Kuching, Malaysia [23]. Geographic and topographic properties of the waterbody also influence the microplastics abundance. Yuan et al. [24] reported that lake size, shoreline morphology, and even the existence of obstructing structures has a great influence on the microplastics level.

Larger freshwater areas have tendency to dilute the concentration of microplastics while shoreline and an elevation can generate a circulation zone at the center of water bodies which help to accumulate microplastics from the surrounding areas, as can be observed in Qinhai Lake, China [25], where the highest abundance of microplastics was detected in the mid-region of the lake. This occurred because the surface current is prominent in larger lakes, causing lake stratification. The circulation of warm water downwind and deeper cold water upwind causes the movement of the microplastics too.

Table 1 Examples of the range of microplastic properties reported during samples collection

Study area	Sample type	Abundance	Size range	Polymer type	Shape	Ref.
CHINA						
Three Gorges Reservoir	Surface water	1597 - 12,611 items m^{-3}	< 0.5 – 5.0 mm	PS , PP , PE, PC, PVC	Fiber, Fragment, Pellet, Film, Styrofoam	[19]
	Sediment	25 - 300 items kg^{-1}				
Wei River	Surface water	3.67 - 10.70 items L^{-1}	< 0.5 - > 5.0 mm	PE, PVC, PS	Fiber, Fragment, Pellet, Film, Foam	[33]
	Sediment	360 - 1320 items kg^{-1}				
Zhangjiang River	Surface water	246 items m^{-3}	0.5 – 1.00 mm	PP, PE, PS, PES, PET, PE , PP	Fragment, Fiber, Pellet, Line, Film, Foam	[34]
Shanghai Urban Districts	Sediment	802 items kg^{-1}	0.1 – 5.0 mm	PP, PE, Rayon , Others	Sphere, Fiber, Fragment	[35]
Beijing River	Sediment	178 - 544 items kg^{-1}	1.0 – 5.0 mm	PE, PP	Not identified	[36]
Manas River Basin	Surface water	21 - 49 items L^{-1}	0.1 – 1.0 mm	PVC, PE, PA, PET	Fiber, Fragment, Film, Other	[37]
Maozhou River	Surface water	4 - 26 items L^{-1}	0.1 – 5.0 mm	PE, PP, PS , PVC	Fragment Foam, Fiber, Film	[38]
	Sediment	35 - 56 items kg^{-1}				
Three Gorges Reservoir	Surface water	3407×10^3 - $13{,}617\times10^3$ items km^{-2}	0.1 – 5.0 mm	PE , PP , PS	Fragment Sheet, Line, Foam	[28]
Xiangxi River	Surface water	0.55×10^5 - 342×10^5 items km^{-2}	0.1 – 5.0 mm	PE, PP, PS	Fragment, Sheet, Line, Foam	[39]
	Sediment	80 - 864 items m^{-2}		PE, PP, PS, PET		
Dongting Lake	Surface water	1345.24±560.81 items m^{-3}	<0.5 – 5.0 mm	PS , PET , PP , PE , PVC	Fragment, Fiber, Pellet, Film	[40]
	Sediment	388.57±66.19 items kg^{-1}				
Taihu Lake	Surface water	3.40 - 25.80 items L^{-1}	0.005 – 5.0 mm	PET, PE, PP	Fragment Fibre, Pellet, Film	[20]
	Sediment	11 - 235 items kg^{-1}				
Lakes in Wuhan City	Surface water	1660 - 8925 items m^{-3}	0.05 – 5.0 mm	PET , PP , PE , PA , PS	Fiber, Granule, Pellet Film	[21]
Dongting Lake Hong Lake	Surface water	900 - 2800 items m^{-3} 1250 - 4650 items m^{-3}	0.05 – 5.0 mm	PE, PP, PS, PVC	Fiber, Granule, Film	[41]
Lake Ulansuhai	Surface water	1760 - 10,120 items m^{-3}	< 0.5 – 5.0 mm	PE , PS , PET	Fiber, Film, Fragment, Grain	[42]
Qinghai Lake	Surface water	0.05×10^5 - 7.58×10^5 items km^{-2}	>0.1 – 5.0 mm	PE, PP, PET, PS, PC, PA, EVA	Fiber, Fragment, Sheet, Foam	[25]
	Sediment	67 - 1292 items m^{-2}				
Lakes in Changsha	Surface water	2425 – 7050 items m^{-3}	<0.5 – 5.0 mm	PET , PP , PE , PA , PS , PVC	Fragment, Film, Line, Foam	[12]
Poyang Lake	Surface water	5 - 34 items L^{-1}	<0.1 - >5.0	PP, PE , PA , PVC	Fiber, Film, Fragment, Pellet	[24]
	Sediment	54 - 506 items kg^{-1}				
Tibet Plateau	Sediment	8 - 563 items m^{-2}	< 0.5 – 5.00	PE, PP, PS, PET, PVC	Sheet, Line, Fragment, Foam	[43]
CHINA-NEPAL						
Mount Everest (snow, river, lake)	Snow	30 -119 particles/L	<0.1 – 4.0 mm	PE, acrylic, nylon, PP	Fiber, fragment	[44]
	River and lake surface water	0 – 2 particles/L				

Table 1 Examples of the range of microplastic properties reported during samples collection (*continued*)

Study area	Sample type	Abundance	Size range	Polymer type	Shape	Ref.
INDIA						
Netravathi River	Water	288 items m^{-3}	0.3 – 5.0 mm	PE , PET , PP , PVC	Fiber, Film , Fragment	[31]
	Sediment	96 items kg^{-1}		PE , PET , PP		
Ganga River	Sediment	99.27 - 409.86 items kg^{-1}	< 5.0 mm	PET , PE , PP, PS , Others	Fiber, Filament, Fragment, Foam, Film	[45]
Veeranam Lake	Surface water	28 items km^{-2}	0.3 – 1.0 mm	PA , PE , PS , PP , PVC	Fragment, Film, Fiber, Pellet	[46]
	Sediment	309 items kg^{-1}				
Red Hills Lake	Surface water	6 items L^{-1}	0.3 – 2.0 mm	HDPE, LDPE, PP, PS	Fiber, Fragment, Film, Pellet	[47]
	Sediment	27 items kg^{-1}				
Vembanad Lake	Sediment	252.80 ± 25.76 items m^{-2}	< 5.0 mm	HDPE, LDPE, PP, PS	Fragment, Film, Foam, Fiber, Pellet	[48]
INDONESIA						
Ciwalengke River	Surface water	5.85 ± 3.28 items L^{-1}	0.05 – 2.0 mm	PA, PET	Fiber, Fragment, Others	[32]
	Sediment	0.03 ± 0.02 items g^{-1}				
Surabaya River	Surface water	1.47 - 43.11 items m^{-3}	1.0 – 5.0 mm	LDPE, PP, PS, PE, PET	Film, Fragment, Fiber, Foam, Pellet	[49]
	Middle water	0.76 - 12.56 items m^{-3}				
	Bottom water	1.43 - 34.63 items m^{-3}				
Citarum River	Surface water	0.057 ± 0.025 items m^{-3}	0.125 – 5.0 mm	PE , PP	Fragment, Fiber, Film, Filament	[50]
	Sediment	0.17 ± 0.01 items g^{-1}		PE, PP		
JAPAN						
Rivers in Japan	Surface water	1.62 - 1.85 items m^{-3}	0.1 – 5.0 mm	PE , PET , PP , PS , Others	Fiber Pellet, Sheet, Sphere	[51]
Rivers in Japan	Surface water	1.6 items m^{-3}	0.3 – 5.0 mm	PE PP, PS	Fragment	[22]
MALAYSIA						
Dungun River	Surface water	102.8 items m^{-3}	<0.5 – 5.0 mm	PP , PAN , Rayon	Fiber, Fragment	[11]
Rivers in Kuching	Surface water	137 pieces	>0.45 – 5.0 mm	PP , EVA , PA , PS , PMMA	Filament, Fragment, Fiber, Film, Bead	[23]
Cherating River	Surface water	0.0042 ± 0.0033 items m^{-3}	0.1 – 5.0 mm	Not identified	Fragment Film, Foam, Line, Pellet	[52]
Klang River	Surface water	2.47 ± 1.19 items L^{-1}	<0.3 - >1.0 mm	PA , PE	Fiber, Pellet, Fragment	[53]
Skudai River	Sediment	200 ± 80 items kg^{-1}	<0.1 – 5.00 mm	Not identified	Fragment Fiber, Film	[54]
Tebrau River		680 ± 140 items kg^{-1}				
Langat River	Surface water	12 pieces	0.037 – 5.0 mm	PE, PS	Fragment, Film, Granule, Tube, Foam, Pellet	[55]
Cempaka Lake		5 pieces				

Table 1 Examples of the range of microplastic properties reported during samples collection (*continued*)

Study area	Sample type	Abundance	Size range	Polymer type	Shape	Ref.
MONGOLIA						
Selenga River	Sediment	1.34 pieces m^{-2}	< 5.0 mm	PE, PS, PP, PVC, PET, PU	Fragment, Fiber, Foam, Film	[56]
Tuul River	Sediment	603±251 items kg^{-1}	<0.03 - <3.5 mm	PES, PE, PS, ABS, PVC, PA	Fragment, Fiber, Foam Film	[57]
Lake Hovsgol	Sediment	20,264 items km^{-2}	0.355 - >4.75 mm	Not identified	Fragment, Fiber, Film	[7]
PAKISTAN						
Ravi River	Surface water	2074±3651 items m^{-3}	0.3 – 5.0 mm	HDPE	Fragment	[58]
	Sediment	3726±9030 items m^{-2}		LDPE, PP, PS	Fiber, Sheet, Foam, Bead	
Rawal Lake	Surface water	0.142 items/0.1 L	< 5.0 mm	PE, PP, PES PET, PVC	Fiber, Pellet, Fragment	[59]
	Sediment	1.04 items/0.01 kg				
S. KOREA						
Nakdong River	Surface water and Sediment	1971±62 items m^{-3}	0.02 – 5.0 mm	PP , PES , PE , PA , PS , Alkyd , Acrylic , PEVA , PU , PVC	Fragment Fiber, Sphere, Film	[60]
Han River	Surface water	7.0 – 102 items m^{-3}	0.1 – 5.0 mm	PE, PS, PP, PU, PTFE, PES, Silicone	Fragment, Fiber	[61]
THAILAND						
Chao Phraya River	Surface water	80±65 items m^{-3}	0.05 – 5.0 mm	PP	Fragment, Fiber	[62]
	Sediment	91±13 items kg^{-1}		PS, PE	Pellet, Film	
Aquaculture Zone	Surface water	140 items m^{-3}	0.05 – 5.0 mm	PP, PE, PS, Copolymer	Fragment, Film, Fiber	[63]
	Sediment	76 items kg^{-1}		PP, PE, PS, Copolymer, Other		
VIETNAM						
Saigon River	Surface water	10 - 519,000 items m^{-3}	0.05 – 4.85 mm	PE, PET, PES, PP, Rayon	Fibre , Fragment	[64]

Microplastics with high surface area like fibers and irregular shape particles with low density tend to flow with the turbulence and lake currents to the center of the lake, and then to the shore [26]. Liu et al. [27] stated that dam construction also exerted a notable alteration on microplastics abundance by reducing the flow velocity through water impoundment. Thus, microplastics from upstream will be accumulated right behind the dam and reduce the chances to flow to the downstream [28]. Microplastics abundance were slightly higher during the dry season compared to the rainy season which manifest that a greater amount of rainfall can increase the flux and aid in the dispersal of microplastics across the freshwater system [29–30]. Heavy rain also escalated land run-off into rivers or lakes and allowed microplastic particles to float on water surface as identified in Netravathi River, India [31] and in Ciwalengke River, Indonesia [32]. This showed that the rate of precipitation alone is insufficient to be used in comparing the microplastic abundances since other factors such as sampling techniques and study regions also important in microplastic assessment.

Microplastic properties like their buoyancy and the ability to persist for a long time are primarily dictated by their polymer forms. There are various polymers associated with different common products that are used in the plastics production industry, as summarized in Table 2. A study in Zhangjiang River, China revealed that the three dominant types of polymer in that area are PP, PE and PS [34], where they are among the most abundance polymers found in aquatic ecosystems and accounted for 74 % of the global plastic manufacturing in 2015 [65], as also reported by other researchers [5, 12, 19, 28, 38]. PET, PP and PE were the dominant plastic polymers in Dongting Lake, China [40], several lakes in Wuhan City, China [21], Netravathi River, India [31] and Ganga River, India [45]. Other plastic polymers were unable to detect in their samples due to the usage of non-suitable digestion solution during the microplastics extraction from samples, where the separation solution should be denser to separate PVC, PET and HDPE. However, most of these studies preferred to use NaCl method which does not separate HDPE properly from the samples, thus, failure to result the presence of those polymers. Other factor may also influence the increase of PVC plastic found in their samples such as, PVC was widely used in many field including construction, medical and packaging. However, under certain circumstances, PVC was proved to be able to release toxic plasticizers such as dibutyl phthalate and dioctyl phthalate [12]. With emphasis on consumer concerns, PP production has risen in recent years as a replacement for PVC and also PET, hence, contributes to a high percentage of the plastic debris.

The fate of different plastic polymers in the freshwater environment is greatly influenced by their density. The plastic polymer densities that lower than water (e.g. PP and PE) would be float at the surface water, while the polymers with higher density than water (e.g. PET and PVC) usually would sink [17]. Lower density polymers are also expected to disperse long distances across the freshwater compartments due to their position that is prone to wind and water movement. However, Abeynayaka et al. [51] and Eo et al. [60] found the presence of PET floating in suspension due to many factors including alteration of the polymer density through interaction with biofilms and air bubble, water turbulent, biofouling, and resuspension.

Morphological characteristics and sources of microplastics

Typical microplastics shapes found in Asian freshwater environments are fiber, fragment, pellet and film [33–34, 46–47, 49, 62]. Fiber is defined by a slander-shaped long and fibrous line, while fragment is a hard and jagged piece resulted from degraded plastic items. Film is a thin layered of flimsy plastic debris, and pellet is circular and cylindrical in shape. Examples of these shapes were shown in Figure 1. Other particle structures such as foam, bead, sheet, filament and granule were also observed in several studies [45, 50, 55, 58].

The morphological of microplastics is one of the ways researchers described microplastics based on their physical appearance. The morphological features and sources for several microplastic types are shown in Table 3. The description however, usually was varied and subjective, depending on the researchers or descriptors point of view. Although there are still no standard categories available for the microplastic morphological characteristics, most authors were using the similar approaches in categorizing them in several categories such as fibers, fragments, films, beads, pellets, foams, spheres, and filaments (Tables 1 and 3).

Table 2 Potential sources of different plastic polymers

Polymer	Source	Ref.
Polypropylene (PP)	Household appliance, pipes, packaging, hygiene products	[27, 51, 58]
Polyethylene (PE)	Clothing, food containers, fishing nets, mulch	[12, 47]
Polystyrene (PS)	Construction materials, packaging, disposable utensils	[51, 58]
Polyethylene terephthalate (PET)	Clothing, carpets, fishing nets, beverage bottles	[12, 66]
Polyvinyl chloride (PVC)	Building materials, packaging, disposable medical supplies, plastic films	[12, 59]
Polyamide (PA)	Automotive, textiles, fishing lines, cleaning products	[58 46]
Polyester (PES)	Textiles, industrial abrasives, yarns and ropes	[67, 68]
Polycarbonate (PC)	Automotive, pharmaceutical, building and construction, sport equipment	[69, 70]
Polyethylvinyl acetate (PEVA)	Pharmaceutical, road marking, automotive, packaging, electronics	[70]
Polyacrylonitrile (PAN)	Textiles, coating materials, face masks	[66, 71]
Polymethyl methacrylate (PMMA)	Personal care products, electronics, shatterproof windows, aircraft canopy	[67, 72]
Polytetrafluoroethylene (PTFE)	Teflon coated pans, personal care products	[70, 73]
Polyurethane (PU)	Construction and coating materials, personal care products	[67, 74]
Acrylonitrile butadiene styrene (ABS)	Electronics, automotive, cosmetics, hub caps	[67, 71]
Acrylic (AC)	Clothing, ropes, paint, lenses, medical devices	[8, 60]
Alkyd (AKD)	Clothing, packaging, ropes, coating materials	[75, 76]
Rayon	Personal hygiene products, fishing gears, textiles	[11, 7477
Silicone	Kitchenware, protective coatings, electronics, laundry	[78, 79]

Table 3 Morphological features and potential sources of different plastic particles

Shape	Morphological feature	Source	Ref.
Foam	Light and soft	Transportation packaging, cosmetics, thermal insulation materials	[28, 38]
Sheet	Flexible, thin and flat	Packaging materials and plastic bags	[28, 80]
Filament	Thread-like structure and thin	Fishing nets and line, clothing	[13, 23]
Granule	Spherical, grain-shaped	Degraded plastic items, cleaning products, cosmetics	[21]

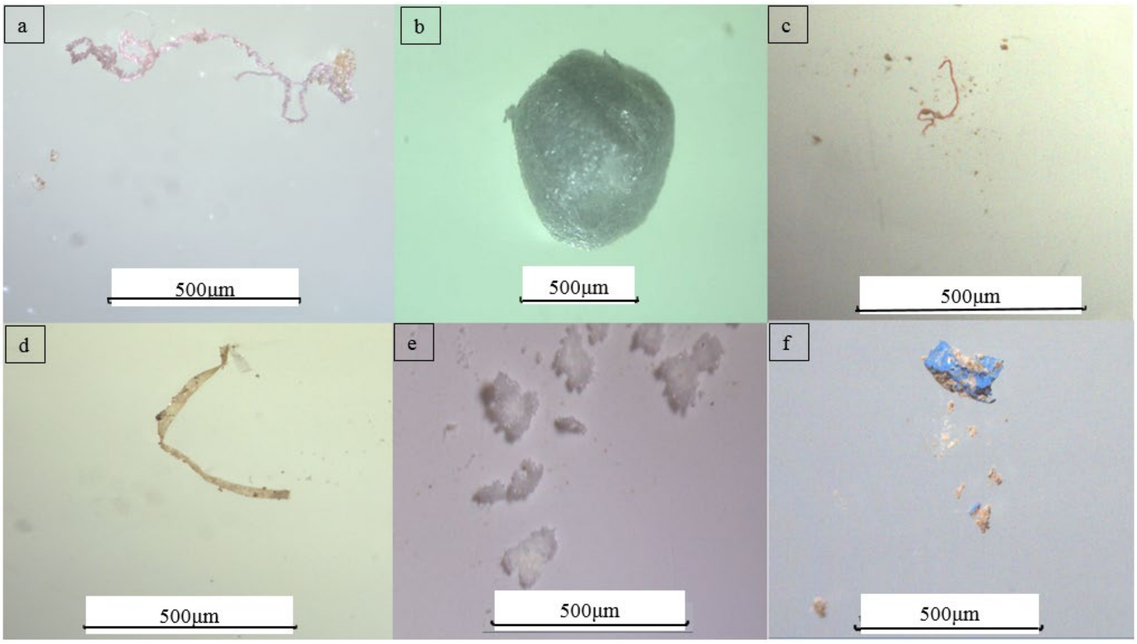

Figure 1 Typical photographs of microplastics. a: fiber, b and e: foams, c: filament, d: film, f: fragment (Credit photographs: Dr. Farah Akmal Idrus)

Morphological characteristics of microplastics are essential in determining their possible origins. For instance, microbeads which are known as the important raw material in the plastic production industry may also appear in freshwater environments from wastewater systems containing rinsed facial cleanser [81]. Microbeads are mainly incorporated with personal care products like facial scrub and soap. However, due to their tiny sizes, microbeads were easily escaped the wastewater treatment plants and thus end up in the river or lake, as shown in the study by Johnson et al. [23] in Kuap, Maong and Sarawak Rivers, Malaysia. Microbeads were made from several plastic polymers such as PE, PP, PET, PMMA and PA. Increased awareness of the disadvantages of these polymers to the aquatic environment has led some countries in Asia to restrict the use of microbeads in personal care materials and cosmetics. South Korea, for example, has banned microbeads in their personal care and cosmetic products, and subsequently showed a reduction of microbeads in the Han River and its tributaries [61]. The Association of Southeast Asian Nations (ASEAN) Cosmetic Association [82] recommended that the use of plastic microbeads to be discontinued in rinse off personal care products in all Southeast Asia countries.

Fiber, in the other hand, had easily be seen in water column and sediment with its mean sources were from laundry activities, as shown in Saigon River [64], Nakdong River [60] and Ciwalengke River [32]. Fishing activities linked to the usage of nets and shipping activities also contributed to the release of fiber into Rawal Lake, Pakistan [59]. Atmospheric deposition is responsible for the appearance of natural fiber-like wool, cellulose-based artificial fiber (e.g. viscose and rayon) and synthetic fiber originated from petrochemical substances (e.g. PA, PP, PES). Previously, atmospheric deposition of microplastics received less attention. Cai et al. [83] have done a study on this matter at Dongguan City, China, and found out that fiber, foam, fragment and film available in the atmospheric fallout. Their finding was the evidence of the connection of the dust deposition, and the land and aquatic environment were associated with the transportation of microplastics. Wind blowing can help to transport light and low density solid litters including microplastics from their sources to other locations such as into the lakes and rivers. This atmospheric transport and deposition is crucial in dispersing microplastics across the freshwater system not only in the city area, but also in remote areas like the Hovsgol Lake, Mongolia [7]. Hovsgol Lake is a small mountain lake and situated around the residents' area and tourist camps where have very poor waste management system. The small size lake may have concentrated its microplastics density, subsequently increased their residence time. Study by Napper et al. [44] on the microplastics occurrence in the snow, stream and lake on the Mount Everest, that located in the border of Nepal-China, reported that microfibers were the dominant microplastics found there, which were consistent with fibers from outdoor clothing. Mount Everest is located very far from the human populations and the nearest city was about 160 km away. Therefore, it was suspected the existence of microfibers in this region was influenced by the wind blowing as the Mount Everest always seen the prolonged strong winds.

Fragments are formed from the breakdown or fragmentation of larger plastic items which exist in the surroundings due to improper waste management practices. Irresponsible act of human leads to the vast number of plastic debris mainly in rivers and lakes associated with tourism and recreational activities [31, 55, 59]. Fragment particles were observed to be rough and irregular in Dungun River, Malaysia [8]. Further analysis showed that the surface of these fragments were agglutinated with grooves, flakes and adhering particles which explained the rugged feeling and at the same time boosted their adsorption to other foreign matter. This finding allowed researchers to investigate the background of the particles whether they had faced oxidative weathering, mechanical or biological degradation [84]. Surface water of Surabaya River, Indonesia were dominated with film [49]. The same results were also obtained in Skudai and Tebrau Rivers, Malaysia [54], Pearl River, China [30] and Wei River, China [33].

Film-shaped may come from the fragmentation and the degraded plastic bags, wrapping materials and agricultural mulch, as reported in China [85] where the introduction of plastic film technology in their agricultural sector during late 70's has become a controversial issue due to the adverse impacts they possess. Although the usage of plastic mulch film enhances the agricultural output in China by retaining soil's moisture and preventing insect and disease, its delicate feature causes the rising of thin film in inland waters through surface run-off [40, 86]. Plastic bags which are still widely used in Asia, are the main source of film-shaped microplastics. Recycling of plastic bags was only less than 5 % but the production was massive (~ 5 trillion/ year) [87], thus, it may become one of the environmental threat. PE is the common polymer in the plastic bags. The existence of film microplastics in the aquatic environments often came from the larger plastic (e.g. macroplastics) fragmentation and degradation. Lakes and rivers that located closely to a densely populated area have tendency to obtain more film-shaped microplastics, as shown in many studies [7, 12, 19, 24, 31, 33, 37–38, 41–42, 46, 49, 52, 54, 57, 60–61]. The long carbon chain of PE and its hydrophobicity in the plastic bags hinder them to easily undergo the biodegradation process normally [88]. However, the biotic and abiotic reactions can make the biodegradation process to occur via the enzymes and chemical processes related to microorganisms (e.g. bacteria and algae). This breakdown process could be seen on the SEM images by the presence of fractures, grooves, flakes, cracks, and pits.

Potential of adsorption and accumulation of heavy metals on microplastics

Plastics not only contain polymers, but other chemicals (such as heavy metals) have been added for some important functionality during the manufacturing process. Metal-based additives are cheap but they have strong heat resistance and weathering. They also may act as biocides, antimicrobial agents, lubricants, pigments for colours, stabilizers and plastic hardness [89–90]. Heavy metals have been reported to exist in aquatic ecosystems over a long term and capable to interact with microplastics either through addition of additives during plastic manufacturing processes or adsorption from the surrounding ambience. Natural-occurring heavy metals come either from environmental processes or environmental contamination. However, the adsorption capability of heavy metals on microplastics were mostly proven by introducing microplastic particles like PE, PP, PA, and PVC in metallic solutions in the laboratory experiments. Data on the heavy metals adsorption accumulated on the microplastics in the actual freshwater environments especially in Asia is very limited.

Wang et al. [36] in their study of heavy metals in the microplastics collected from the sediment of the Beijiang River, China, found out that the concentration of heavy metals was very much higher than the concentration of those metals from the surrounding sediment. Titanium (Ti) was the highest concentration, up to 38,823 $\mu g\ g^{-1}$ from the microplastics. Zinc (Zn) was recorded the second higher concentration (2,414–14,815 $\mu g\ g^{-1}$); cooper (Cu) and lead (Pb) concentrations were between 38 and 500 $\mu g\ g^{-1}$. Cadmium (Cd) and nickel (Ni) obtained the lowest concentrations (<18 $\mu g\ g^{-1}$). Ti (i.e. TiO_2) was usually added in the plastic production manufacturing for UV blockers and pigments function, and they could release into the water after the plastics degraded. Attention should be paid to TiO_2 as its high content can adversely affect aquatic animals such as fish, and invertebrates (e.g. shrimp, crabs, clams), including certain algae and bacteria. Other heavy metals can also cause the harmful effects to aquatic animals and humans. Cd, Cu and Zn for examples are toxic to mammals and can accumulate in liver and kidney. Continuous exposure of Cd and Pb to the fish and prawn may cause toxicity to them and also to human that consumed them [91–93]. Ni and Chromium (Cr) can cause behavior alteration to the prawn and fish that make them to loss of balance in swimming.

In Ta and Babel [62–63] studies, heavy metals (Cr, Cu, Ni, Pb) from the microplastics were found higher in the aquaculture zone than in the Chao Phraya River water, Thailand. Heavy metals can accumulate in higher concentration in the freshwater ecosystem in a long exposure time. The interaction between microplastics and heavy metals maybe related to the modification of the microplastic surface via photo-oxidation process. Ta and Babel [62–63] claimed the growth of biofilms on the aging microplastics surface could enhance the accumulation of metals. This idea supported by the finding of Wang et al. [94]. In their laboratory experiments, they found out that the surface of aging PET, PS and PVC due to UV radiation have developed small wrinkles which were deepened as the aging time prolong, until formed cracks. The metals (e.g. Cu, Zn, Cd, Cu, Pb) adsorption capacities on these aging microplastics were increased. The adsorption also getting better with the increasing temperature and the longer exposure time to metals, but not necessarily showing a linear relationship [95].

Conclusion

The occurrence of microplastics in the freshwater environment has shown a huge concern, and related studies are showing an increase in numbers over years. In this review, occurrence and distribution of microplastics were detected in several freshwater systems, such as rivers and lakes. The distribution of microplastics also depended on the closeness location of the rivers or lakes with the sources of microplastics, for examples, industrial and domestic wastewaters, landfills, and waste dumps. Focus should be given to the transportation of microplastics from the long distance regions via the windblown, as this is one of the important ways, but less attention was given to it, that brought microplastics from other locations to the rivers, lakes and other remote areas. There are various polymers associated with plastic production and the fate of the polymers in the freshwater environments is influenced by their density. Lightweight and less dense microplastics commonly found floating on the surface water, while the denser microplastics were found in/on the sediments. The morphological of microplastics described by their physical appearance such as fiber, fragment, film, bead, pellet, foam and filament. Determining the morphological characteristics of microplastics are important in order to know their origins. Apart from polymers, microplastics are also contain heavy metals that added during the plastic production as heat and weathering resistances, biocides, antimicrobial agents and colour pigments. Heavy metals however, is also one of the pollutants in freshwater systems. Therefore, concern arise on the concentrations of heavy metals from the microplastics released into the water and sediment, either by the metal-based additives or by the adsorption from surrounding environment, as microplastics could be one of the sources of heavy metals into this particular environment. More studies are suggested to conduct in more rivers, lakes, ponds and perhaps in the snows and rainwaters in order to gather comprehensive data on the impact of occurrence, distribution, fate, ingestion by the organisms and the ability of the combine effects of microplastics and heavy metals to aquatic organisms and also human health.

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