PREFACE

Today, plastic has become virtually indispensable in our daily lives. The wide plastic family is composed of a variety of materials designed to meet different needs of thousands of end products. The global plastic production has almost reached 350 million tons in 2017. Based on the current trends, a future scenario predicts that 40 billion tons of plastics will be produced by 2050. At the end, it leads to an ever-increasing quantity of plastic waste, much of which ends up in marine and freshwater environments. The long-term persistence of plastics in the water environment results in microplastics (particles below 5 mm), which are recognized globally as an emerging contaminant. Microplastic contamination in marine and freshwater bodies causes a lot of undesirable impacts, collectively on the global environment and humans. Not only the ecological hazards, but chemical and biological hazards are also associated with microplastics. A large number of additives incorporated in the polymer blend are leached out from microplastics, potentially causing toxic effects on both humans and aquatic organisms, if ingested. On the other hand, microplastics are efficient vectors that transfer heavy metals and micro-organisms bound to them over long distances.

Most of the microplastics studies have been conducted in Europe and United States, and very few investigations in Asian and African regions. Still many gaps exist in microplastics research, e.g., sources of origin, their fate inside human and organism bodies, and subsequent health implications. Researchers have largely focused on marine microplastics as the major portion of the plastic debris ends up in oceans. But freshwater ecosystems are exposed to microplastics often due to the greater proximity to densely populated areas and receiving discharges from wastewater treatment plant. Now, microplastics are reported to be found in drinking water, salt, beer, honey, etc. So, we will soon encounter its dangers. Therefore, it is an hourly need to discuss and investigate on this topic.

The Expert workshop on *"Microplastics in the Water Environment"* was held at the Island of Koh Samui, Thailand, August 18 – 22, 2019. The main objectives of the workshop were to provide the participants with state-of-the-art knowledge of microplastic pollution and its related implications, and secondly, identifying the research needs and concepts on the increasing threats to ecosystems, wildlife and human health. Selected papers from this workshop are presented in this book. This book will provide readers with an improved understanding of microplastics genesis and its threat, bear a holistic view on the microplastics problem and its inherent risk potential.

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CURRENT STATUS OF MICROPLASTICS CONTAMINATION IN MARINE AND FRESHWATER ENVIRONMENTS

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Abstract

Microplastics (MPs) are ubiquitously found all over the world, from densely populated areas to remote ones. The presence of MPs poses a great threat to the entire ecosystem. The pollutants mainly come from daily use products such as cosmetics, paints, etc. (primary MPs); or the breakdown of larger macroplastic debris under environmental conditions (secondary MPs). MPs enter aquatic environments through terrestrial and land-based activities. Since the last few decades, about 93-236 thousand metric tonnes of MP particles have accumulated in the marine environment due to improper disposal of waste plastics. With this situation, this paper reviews sources of MPs and the existing state of MPs in the marine and freshwater environments. In marine environment, MPs are found in their highest concentrations along coastlines and within mid-ocean gyres. Fiber and fragment are the majority morphologies of MPs found in oceans. While a large number of studies on MPs have focused on the marine environment, few are reported in the freshwater environment.

1 Introduction

The plastic waste poses a serious threat to the aquatic wildlife and ecosystem. The Convention on Biological Diversity reported that currently 663 species of aquatic biota are known to be impacted by plastic pollution through entanglement or ingestion, including mammals, birds, and reptiles [1]. Ingested plastics can cause internal damage, reduce feeding, disturb the digestive enzyme system or hormone balance and have an impact on reproduction. In recent years, a particular concern is the occurrence of smaller pieces of plastic debris including those not visible to the naked eye, referred to as MPs. According to 5 Gyres Institute, it is estimated that a total of 15-51 trillion MP particles have accumulated in the ocean, weighing between 93 and 236 thousand metric tons [2].

The term MPs has been defined differently by various researchers. Gregory and Andrady [3] defined MPs as the barely visible particles that pass through a 500 μm sieve but retained on a 67 μm sieve (0.06 – 0.5 mm in diameter), and particles larger than this were called mesoplastics, while others as Fendall and Sewell [4] and Moore [5] defined the MPs as being in the size range < 5 mm (recognizing 333 μm as a practical lower limit, when neuston nets are used for sampling). This is in line with the definition of the European Commission in the Marine Strategy Framework Directive (2008/56/EG), particles < 5 mm are considered as MPs [6]. In addition, the MPs have the

following properties: (1) Solid phase materials, (2) Insoluble in water, (3) Synthetic, (4) Non-degradable, (5) Made from plastic.

Based on the above facts, main goal of this paper is to create an overview about current situations of MP pollution in marine and fresh water environments.

2 Sources of MPs

MPs originate from a variety of sources, but these can be categorized as primary and secondary sources. These pollutants get washed down the sink, as they are too small to be filtered by sewage-treatment plants, consequently ending up in the fresh systems (i.e., rivers, lakes, or canals) and ultimately in the oceans.

2.1 Primary source

The primary sources of MPs include microbeads in cleaning and cosmetic, as shown in Figure 1, or manufactured pellets used in feedstock or plastic production. The plastic materials applied as ingredients in cosmetic formulations include the two main categories of plastics typically made from petroleum carbon sources. Thermoplastics include polyethylene (PE), polypropylene (PP), polystyrene (PS), polytetrafluoroethylene (Teflon), and polymethyl methacrylate, while thermoset plastics include e.g., polyesters, polyurethanes [7]. Based on the usage of PE microbeads in personal care products, Gouin et al. [8] estimated that the U.S. population may be emitting about 263 t/yr of PE microbeads or approximately 2.4 mg per person per day.

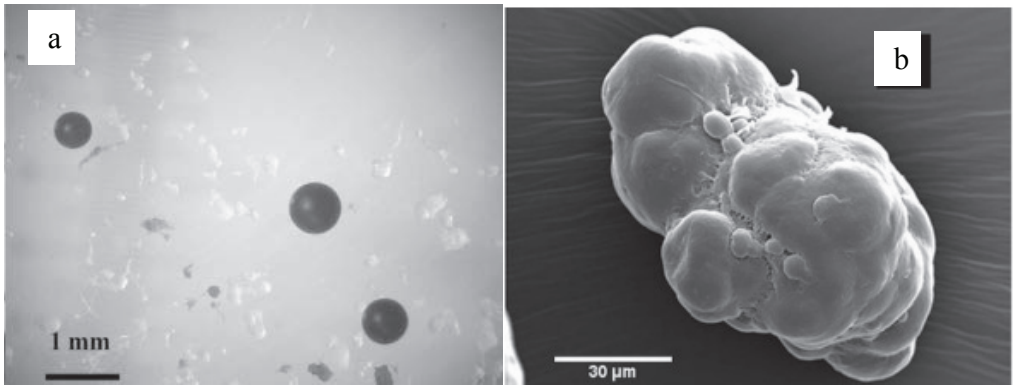

Figure 1: (a) Photomicrographs of a microbead sample from the sea surface of Lantau Island, Hongkong; (b) Scanning electron microscopy (SEM) of a typical rough facial scrub plastic microbead particle [9]

Plastic resin pellets or flakes and plastic powder or fluff are another important source of primary MPs. Plastic pellets (around 5 mm diameter) and powders (less than 0.5 mm) are generally with the shape of a cylinder or a disk [10]. These plastic particles are the industrial feed stock for production of plastic products and transported to manufacturing sites, where they are re-melted and molded into a wide range of final products. They can be unintentionally released to the

environment after an accidental loss during transport or with run-off from processing facilities, i.e. often as a result of improper handling.

2.2 Secondary source

The secondary sources of MPs include fibers from textile laundering or fragments from the breakdown of larger plastic items. Large plastic debris on sea and land degrades over time into smaller particles until they end up as MPs when exposed to some factors in the environments (Figure 2). This is the most likely process for the generation of secondary MPs in the marine environment [11]. It is important to note that the formation of MPs is influenced by a combination of environmental factors and the properties of the polymer.

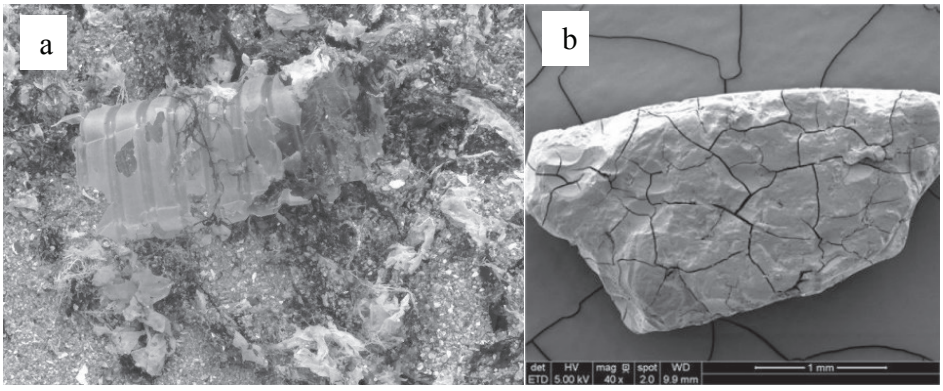

Figure 2: (a) Degradation and fragmentation of plastic under environmental factor; (b) the cracks seen at the surface are caused by photochemical degradation

Degradation is a chemical change that drastically reduces the average molecular weight of the polymer [12]. Degradation is generally classified according to agencies causing it such as: (a) Biodegradation – action of living organisms usually microbes; (b) Photodegradation – action of light (usually sunlight in outdoor exposure); (c) Thermooxidative degradation – slow oxidative breakdown at moderate temperatures; (d) Thermal degradation – action of high temperatures; and (e) Hydrolysis – reaction with water. The dominant cause of degradation of plastics outdoors is solar UV radiation, which facilitates the oxidative degradation of polymers [13]. With common polymers such as LDPE, HDPE, PP and nylons exposed to the marine environment, it is primarily the UV-B radiation in sunlight that initiates photo-oxidative degradation. Once initiated, the degradation can also proceed thermooxidatively without the need for further exposure to UV radiation. The autocatalytic degradation reaction sequence can progress as long as oxygen is available to the system [12]. During advanced stages of degradation, the plastic debris typically discolors, develops surface features, becoming weak and brittle (embrittle) in consequence over time. Any mechanical force (e.g., wind, wave, animal bite and human activity) can break the highly degraded, embrittled plastics into fragments.

Fibers from synthetic textiles are one of the sources to secondary MPs in the environments (Figure 3). Synthetic fibers are produced from crude oil through polymerization, polycondensation or polyaddition processes [14]. Textiles made from synthetic materials commonly consist either of fibers made out of long filaments or of fibers that have been cut into shorter fibers. In 1950, there was an annual production of 2.1 million tons of synthetic fibers. With increased demand, the production reached 49.6 million tons in 2010 [15]. Textile synthetic fibers are not only used in clothes but also in furniture, geotextiles, cloth, footballs, backpacks, cuddly toys, buildings, and agriculture.

Different kinds of fabrics have different abilities to shed fibers. The "sheddability" depends on the fabric type, the texture, the yarn type, the nature and the number of the fiber types involved. It also depends on whether the fabric is made out of staple fibers or filaments. According to Astrom [14], most fibers are lost from synthetic fleece and microfleece, and there was a large difference between the various fleece fabrics and the rest of the fabrics. According to Browne et al. [16], a synthetic fleece jacket can release around 1,900 fibers every wash. The authors also concluded that using detergent results in more shedding compared with using water alone. The size of fibrous plastic particles has a wide range according to different studies. Thompson et al. [17] set the size to 20 µm in diameter, while Napper et al. [18] concluded that average fiber size ranged between 11.9 and 17.7 µm in diameter, and 5.0 and 7.8 mm in length. Compared with other plastics found in oceans, like pellets or nibs, fibers have a greater surface to volume ratio. This could mean that they can attract more chemicals than other MPs.

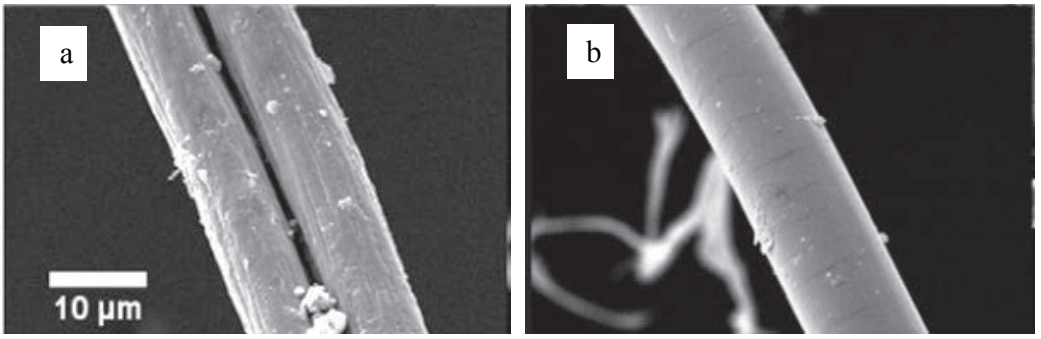

Figure 3: Scanning electron microscopy image (SEM) of typical fibers: (a) Polyester Cotton Blend; (b) Polyester [18]

3 MPs in marine environment

MPs enter the marine environment via different pathways (terrestrial and marine-based activities), as shown in Figure 4. Plastic litters with a terrestrial source contribute ~80% of the plastics found in marine litter [12]. MPs used both in cosmetics and as air-blasting media can enter waterways via domestic or industrial drainage systems [19]. Wastewater treatment plants can trap macro-plastics and some small plastic debris within oxidation ponds or sewage sludge, but a large proportion of MPs will pass through such filtration systems [4, 20]. With approximately half the world's

population residing on coasts, these kinds of plastic have a high potential to enter the marine environment via rivers and wastewater systems, or by being blown off-shore [5, 21].

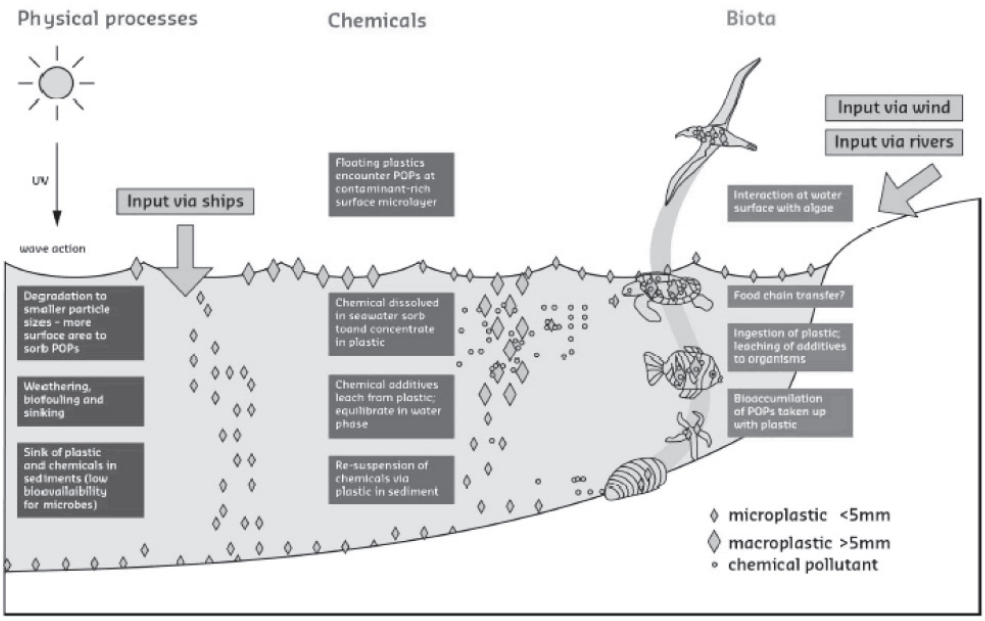

Figure 4: Sources of marine MPs and the various physical, chemical and biological processes affecting MPs in the marine environment [22]

Plastics that enter river systems either directly or with wastewater effluent or in refuse site leachates will then be transported to the sea. Some studies have shown, how the high unidirectional flow of freshwater systems drives the movement of plastic debris into the oceans [23, 24]. Using water samples from two Los Angeles (California, USA) rivers collected in 2004–2005, Moore [5] quantified the number of plastic fragments present that were <5 mm in diameter. Extrapolating the resultant data revealed that these two rivers alone would release over 2 billion plastic particles into the marine environment over 3 days. Extreme weather, such as flash flooding or hurricanes, can exacerbate this transfer of terrestrial debris from land to the sea [25, 26]. Studies conducted by Moore et al. [24] showed that MPs in Californian waters near the mouth of a modified Los Angeles storm water conveyance system increased from 10 plastic items/m^3 to 60 plastic items/m^3 following a storm.

Coastal tourism, recreational and commercial fishing, marine vessels and marine-industries (e.g., aquaculture, oil-rigs) are all sources of plastic that can directly enter the marine environment, posing a risk to biota. Tourism and recreational activities account for an array of plastics being discarded along beaches and coastal resorts [19], although it is worth noting that marine debris observed on beaches will also arise from materials carried on in-shore- and ocean currents [21]. Fishing gear is one of the most commonly noted plastic debris items with a marine source [12].

Discarded or lost fishing gear, including plastic monofilament line and nylon netting, is typically neutrally buoyant and can, therefore, drift at variable depths within the oceans. The distribution of MPs and their concentrations in the marine environment are shown in Table 1.

Table 1: MPs distribution in marine environments

Water body Name and location	**References**	**Max. and Min. abundance**	**MPs shape and polymer type**
Surface sediment Coastal mangrove, Singapore, Asia	Nor and Obbard [27]	Max: 15.7 items/ 250 g dried, Mean: 9.2 items/ 250 g dried Represents size <40 μm: 58%	Fibers 72.0% Films 23.3% Granules 4.7% Polypropylene, polyvinyl chloride, polyethylene, nylon
Surface water Baltic Sea, Stockholm Archipelago, Sweden	Gewert et al. [28]	Mean: 109,800 items/km^2	Polypropylene: 53% Polyethylene: 24%
Surface water Iskenderun Bay and Mersin Bay, Turkey	Gündoğdu & Çevik [29]	Iskenderun Bay 0.2254 item/ m^2 (mean size: 2.77 mm) Mersin Bay 0.6827 item/ m^2 (mean size: 3.01 mm)	Plastic Fragments: 60.1% Plastic Films: 45.9%
Benthic sediment Baltic Sea, South Eastern	Zobkov & Esiukova [30]	Mean: 34 items/ kg dried	Fibers Fragments Films
Sand, Norderney, German East Frisian Islands, Germany	Dekiff et al. [31]	Max: 2.3 items/ kg dried Min: 1.3 items/ kg dired	PP, PE, polyethylene terephthalate, PVC, PS and PA
Sand, Slovenian coast Shoreline and Infralittoral, Slovenia	Laglbauer et al. [32]	Shoreline: Mean: 133 items/ kg dried Infralittoral: Mean: 155.6 items/ kg dried Represents size: 0.25 – 1 mm: 26% 1 – 5 mm: 74%	Shoreline, Fibers: 96% Films: 4% Infralittoral, Fibers: 75% Fragments: 21% Films: 4%

4 MPs in freshwater environment

The body of knowledge on the accumulation and effects of plastics in freshwater and terrestrial systems is much less than in marine systems [33]. In the last few years, studies of MPs in freshwater environments are rapidly advancing, with MP particles found across a range of freshwater environments worldwide, including lakes and rivers. Area of water surface, depth, wind, currents, and density of particles are all factors determining transport and fate of particles within these aquatic systems.

A significant direct input of primary MPs to fresh water environments has been identified as being through the application of sewage sludge containing synthetic fibers or MPs from personal care or household products. Secondary sources of MPs derive from plastic litter during municipal solid waste collection, processing and land-filling. This includes large plastic items and sanitary waste input to rivers via combined sewage overflows. Runoff via drainage ditches from agricultural land or storm drains from roads containing plastics such as tire wear particles, vehicle-derived debris or fragments of road-marking paints is another significant source of riverine MP loads [34]. Additionally, wind action may also transport lighter plastic items into water bodies or across land [35], and there is evidence to suggest that anthropogenic fibers can be transported and deposited by atmospheric fallout. The MP sources and flows throughout terrestrial and freshwater are shown in Figure 5.

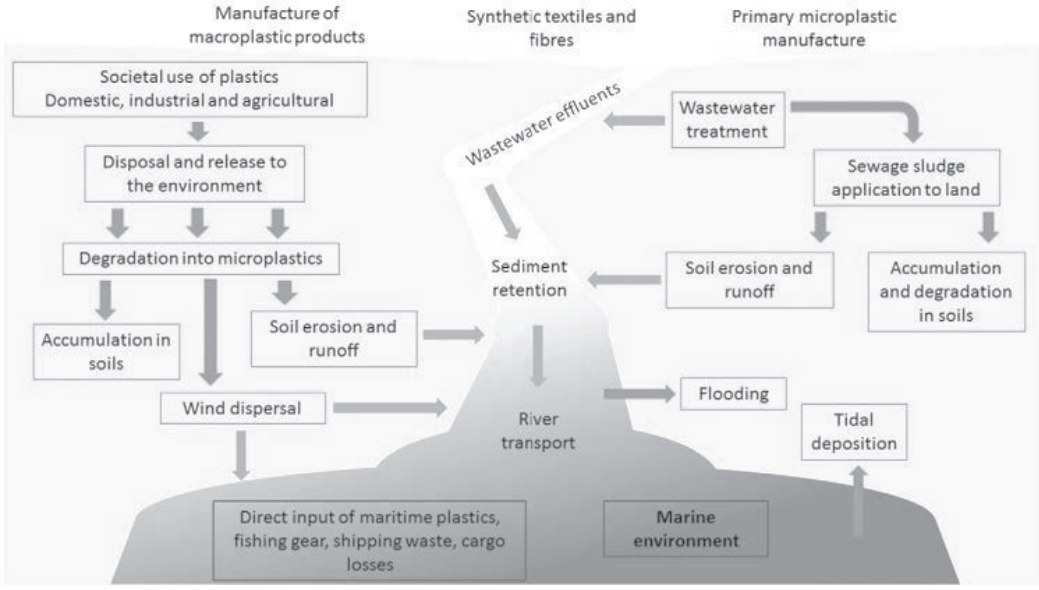

Figure 5: MPs sources and flows throughout terrestrial, freshwater and marine environments [36]

In freshwater environment, MPs have been found in North America, in the Los Angeles basin [37], the North Shore Channel of Chicago [38], Lake Winnipeg [39] and the Great Lakes [34, 40]; in Europe, in Lake Geneva [41], Seine River, Marne River [42], the Austrian Danube River [43], the

Rhine and Main Rivers, Germany [44], and the UK Tamar estuary [45]; and in Asia, in Lake Hovsgol, Mongolia [46], Beijiang River [47], Taihu Lake [48].

According to Free et al. [46], MPs in surface water in Lake Hovsgol, Mongolia in 2014 varied from 20,264 to 44,435 items/km^2. Fragments and films were the most abundant MPs types; no plastic microbeads and few pellets were observed. MPs density decreased with distance from the southwestern shore, the most populated and accessible section of the park, and was distributed by the prevailing winds. Another study by Wang et al. [47] found the concentrations of MPs ranged from 178 ± 69 to 544 ± 107 items/kg sediment. PE, PP, and copolymers were identified in majority. In North America, the average abundance of MPs varied from 43,000 to 466,000 items/km^2 in surface water of the Laurentian Great Lakes. Many MP particles were multi-colored spheres, which were compared to and are suspected to be microbeads from consumer products [34]. The MPs detected in these studies are of varied origins including primary and secondary sources and also different compositions, as shown in Table 2.

Table 2: MPs distribution in fresh water environments

Water body Name and location	**References**	**Max. and Min. abundance**	**MPs shape and polymer type**
Surface water, Lake Hovsgol, Mongolia, Asia	Free et al. [46]	Max: 44,435 items/km^2, Mean: 20,264 items/km^2 Represents size < 4.75 mm: 81%	Fragment: 40% Film: 38% Line/fiber: 20%
Sediment, Beijiang River, China, Asia	Wang et al. [47]	Max: 544 ± 107 items/kg Mean: not indicated Abundance range: 178–554 items/ kg	PE: 42 – 66% PP: 17 – 33 % Copolymers: 6 – 32%
Surface water Laurentian Great Lakes, USA, North America	Eriksen et al. [34]	Max: 466,000 items/ km^2 Mean: 43,000 items/ km^2 Represents size 0.355 – 0.999 mm: 81%	Fragment Pellet
Shore Sediment, Rhine River, Main River, Germany	Klein et al. [44]	Max: 3763 items/ kg Min: 228 items/ kg Max:1368 items/ kg Min: 786 items/ kg Abundance size: 630 − 5,000 µm (weight) 63 − 200 µm (particles)	63 − 200 µm Fibers: 50% Spheres: 13% Fragments: 37% 630 – 5,000 µm Fibers: 13% Spheres: 5% Fragments: 51%

5 Conclusions

MPs are plastic particles smaller than 5 mm that get washed down the sink as they are too small to be filtered by sewage treatment plants, consequently ending up in the river systems and ultimately in the oceans. Currently, large quantities of studies on MPs in the marine environment have been widely carried out, while few were available in the freshwater environment. The effects of MPs on the aquatic environments and humans are still being studied. However, there is much evidence for significant harm to the pollution on wildlife and human health. As shown in the paper, MPs were found in both freshwater and marine environments all over the world from the Northern hemisphere (Europe, North America) to the Southern hemisphere (Asia, Africa). MPs with morphologies of fibers and fragments are dominant in most of the reported studies. Moreover, PP and PE are the most abundant MPs in both fresh and marine environments.

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