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Review Article

Main pathways for microplastics in freshwater systems: A review on potential sources and drivers of microplastic pollution in rivers

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Abstract: Microplastics are ubiquitous in surface waters and sediments of freshwater systems. Reports of MP presence in high concentrations, even in remote regions, indicated that this emerging pollutant can be a serious problem for environmental health. Because of their diverse sources, tracking and identification of all entry routes of MPs into freshwater rivers remain unknown. Investigation of drivers of MP concentration and distribution in these systems can help reach a point of view about the potential sources of these particles. In this review, more than 100 documented papers about MP particles and their presence in surface waters and sediments of different freshwater systems (with a focus on rivers) were investigated. MP pollution in a river can be due to anthropogenic factors including point and non-point (diffuse) sources of MPs. In this regard, waste-water treatment plants are the most investigated point source of MPs. However, there is much less investigation on other point sources such as industrial wastewater. The most important diffuse sources of microplastics are urban land-use, which consists of various sources such as domestic sewage (point) and road runoff (non-point). Agricultural land-use as a diffuse and important source of MPs is also less studied in the literature. Water hydro dynamic (e.g. surface currents and stagnant water zones) and seasonal variability (e.g. rainfall) are important factors in MP distribution in rivers. Physio-chemical characteristics of MPs (including shape, size, color, and chemical composition) can serve as indicators of potential sources of particles; and are effective in MP distribution in riverine systems. It should be noted that freshwater rivers can be considered as both sink and source for MPs.

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Introduction

Human activities along with industrialization and the development of technology in the past decades have led to the destruction of natural environments (Dalvand et al., 2016). The entrance of large volumes of pollutants, including emerging pollutants (Jafari Ozumchelouei et al., 2020) into the environment, imposes direct (Mirzajani et al., 2016; Hamidian et al., 2019) and indirect (Mirzajani et al., 2015; Padash Barmchi et al., 2015; Rezaei Kalvani et al., 2019) effects to the surrounding ecosystems. Microplastics (MPs) have been introduced as one of the emerging environmental contaminants in the 21st century, especially in aquatic systems (Anderson et al., 2017). In recent decades, MP pollution identified as a global environmental problem (Lin et al., 2018), generally due to their small size and potential for widespread environmental dispersal (Horton et al., 2017); and consequently, their potential for adverse impacts on aquatic organisms (Jabeen et al., 2016; Abbasi et al., 2018). MPs may interact with chemicals such as heavy metals in aquatic environments (Wu et al., 2020). The presence of MPs is documented by many researchers in rivers (Moore et al., 2011; Castaneda et al., 2014; Vermaire et al., 2017), estuaries (Yonkos et al., 2015; Gray et al., 2018; Rodrigues et al., 2019), lakes (Eriksen et al., 2013; Ballent et al., 2016; Yuan et al., 2019), wetlands (Vianello et al., 2013; Lourenco et al., 2017; Sruthy and Ramasamy, 2017) and marine systems (Claessens et al., 2011; Dekiff et al., 2014; Zhang et al., 2019), all over the world.

Based on Thompson (2004), the term MP was attributed to the millimetric and sub-millimetric sized plastic particles (Dris et al., 2015). In 2008, the MP

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term was used for plastic particles smaller than 5 mm in size (Arthur et al., 2008). Nowadays, MPs are categorized into two size brackets: large microplastic particles (LMPP, 1-5 mm) and small microplastic particles (SMPP, smaller than 1mm) (Horton et al., 2017). MPs are divided into two categories, based on their origin: primary microplastics (such as pre-production pellets and abrasive scrubber microbeads) and secondary microplastics derived through fragmentation of larger plastic items due to physical abrasion and mainly UVB-photo oxidative degradation (Fischer et al., 2016). As there are different sources, MPs occur in diverse shapes such as fragments, pellets, fibers, and granules in environmental samples (Dalvand and Hamidian, 2023).

Generally, pollution sources are classified as point or non-point sources, based on entry location into the environment. Point sources are domestic outputs, livestock and manufacturing industries, commerce, and wastewater treatment plants; and non-point sources include forest cover, urban land-use, and agriculture land-use. In the field of MPs, floating plastic particles on river surfaces are likely to be generated on land and reach public waters through pathways similar to point and non-point pollutants (Kataoka et al., 2019). Due to the lack of reliable and comparable data about MP sources, the determination of the actual sources of MPs is still challenging (He et al., 2020). Tracing the pollution sources of MPs is the first step to understanding their initial footprint in the environment (Deng et al., 2020). Fluvial systems are important transport routes of MP contaminants to the larger aquatic systems such as the seas (Blair et al., 2017). Therefore, understanding the potential sources of MP particles in freshwater environments, especially in riverine systems, is required for MP pollution management in larger aquatic systems (Fahrenfeld et al., 2018).

Most of the studies on MPs have been conducted in marine than in freshwater ecosystems; for example, a review on microplastics in Iran showed that only three of the studies were conducted in freshwater ecosystems (Razeghi et al., 2021). In this review, we investigated documented papers on MP presence in surface waters and sediments of freshwater systems with a focus on freshwater rivers. In this way, the following items were evaluated: (1) source tracking of MPs with their physiochemical properties, (2) drivers of MPs concentration in freshwaters with emphasis on land-use types, and (3) factors affecting MP distribution in rivers.

Primary and secondary microplastics: Generally, primary and secondary MPs are different in shape, whereby primary MPs are more symmetrical and secondary MPs are more asymmetrical (Park et al., 2020). Primary microplastics are the raw materials that are specifically engineered (Dris et al., 2015; Duis and Coors, 2016). These types of plastics are in their original or close-to-original form when collected, such as resin pellets and microbeads (Driedger et al., 2015). Primary MPs are produced as resin pellets (raw materials for the production of plastic products) or additives for personal care products (microbeads in shower gels and peelings) (Wagner et al., 2014). Manufactured pellets directly spill from plastic product factories to freshwater rivers, in many cases (Peng et al., 2018). Whereas, scrubbers or microbeads may be present in industrial and domestic wastewater and enter the rivers via sewage outlets (Eerkes-Medrano et al., 2015). Wastewater treatment plants can be a source of microbead-type primary MPs to freshwater riverine systems (Estahbanati and Fahrenfeld, 2016).

Secondary microplastics are produced by mechanical and photo-oxidative degradation and breakdown of plastic products including bags, bottles, clothing (synthetic clothing can be regarded either as a source of primary or secondary MP fibers), packaging, fishing lines, nets, and other litter types into smaller fragments (Browne et al., 2010; Dris et al., 2015; Mason et al., 2016; Shruti et al., 2019). Non-point or diffuse sources of pollution such as urban and agricultural land uses can deliver secondary MPs to the rivers (Blair et al., 2019). Secondary microplastics have rough surfaces and irregular shapes, generally (Rodrigues et al., 2019). These particles can be an indicator of weathering (photo-oxidation) and physical (abrasion by waves) defragmentation (Sadri and Thompson, 2014). For example, many of the identified MPs in the North Shore Channel in the USA have jagged edges. The presence of such edges suggested that these particles are formed from the fragmentation of larger plastic pieces (McCormick et al., 2014). Secondary MPs especially fragments and fibers are major sources of plastic particles, in many studied regions (Browne et al., 2010; Zhao et al., 2015; Dikareva and Simon, 2019; Rodrigues et al., 2019; Mao et al., 2020; Park et al., 2020). Based on the results of a global modeling study conducted on freshwater rivers, 80% of identified MPs originated from macroplastics i.e. originated from secondary sources (Van Wijnen et al., 2019).

Microplastic sources in freshwater systems, based on physiochemical properties

***Particle type (shape)*:** Morphological information from the MP samples can be used to indicate their potential origins. An accurate MP identification based on shape is useful to better understand the main drivers of MP distribution in the environment and for reducing input sources (Campanale et al., 2020). The shape of MPs is of great significance for assessing the source and migration of these particles in aquatic systems (Pan et al., 2020). MP shape is important, because of providing crucial information about whether a given particle is primary or secondary (Park et al., 2020). However, in contrast to primary MPs, the exact origin and entry pathways for secondary MPs remain unknown, especially for diffuse sources such as urban land-use. This likely is due to the heterogeneous and various compositions of MPs in aquatic systems (Scherer et al., 2020).

Pellets: Pellets are primary MPs and the presence of plastic pellets in a region can be in relation to population density and industrialization (Zhang and Liu, 2019; Campanale et al., 2020). High abundances of plastic pellets are reported in locations near industrial activities (Zbyszewski and Corcoran, 2011). For example, plastic waste produced by 226 plastic industries along two river basins in Mexico, was most probably responsible for the presence of MPs in river sediments (Shruti et al., 2019). Similarly, a substantial number of polystyrene spherules in the surface waters of the Rhine River in Germany was a result of highly numbered plastic manufacturers located along the river (Mani et al., 2015).

Microbeads: Microbeads used in many consumers' facial cleanser products are another type of primary MPs and have been identified as potential sources of MPs (Zhang et al., 2015). Spherical plastic particles in environmental matrices may be linked to spherical microbeads in facial cleansers and other cosmetic products (Eriksen et al., 2013; Smith et al., 2017). Polyethylene, polypropylene, and polystyrene are commonly used polyolefins in skin cleaners' production; with an appropriate range size of 74-420 µm (Duis and Coors, 2016); and PE spherules with this size range likely originated from personal care products (Mani et al., 2015).

Treated wastewater may contain substantial amounts of microbeads. Conventional wastewater treatment systems consist of three different stages, i.e. primary, secondary, and tertiary or advanced treatment (Mojoudi et al., 2018, 2019). In primary treatment, physical and chemical methods are applied for the removal of pollutants, while secondary and tertiary treatment stages use biological organisms for pollution remediation (Mansouri et al., 2013; Hamidian et al., 2016; Alavian Petroody et al., 2017; Mirzajani et al., 2017). In a study conducted in Slovenia, PE microbead concentration in wastewater treatment plant effluent during the average wastewater flow rate was estimated at 13.9 mg/m^3. The average number of microbead particles released into the river was estimated at 112,500,000 p/day (Kalcikova et al., 2017).

The presence of microbeads in rivers can be an indicator of development in the study areas (Zhang et al., 2015). Indeed, differences in consumer habits or cosmetics composition (mainly facial cleansers) in countries can be affected the abundance of these MP types in water systems (Lahens et al., 2018). For example, lacking microbead particles in Xiangxi River, indicated that using of this plastic type in personal care products is limited (Zhang et al., 2017). However, because of their micrometer size and using of larger mesh sizes in most studies, the contribution of microbeads to the MP litter pool is substantially underestimated or even not detected (Kalcikova et al., 2017). In addition, some spherical microbeads may be lost at 70°C temperature, followed by boiled wet peroxide oxidation used in many studies (Dean et al., 2018).

Fibers: The presence of these small MPs in aquatic systems can indicate the role of textile industry in MP abundance. In other words, inadequate treatment of domestic and industrial wastewater may result in the dominance of fiber MPs in freshwater rivers (Lahens et al., 2018). Higher concentrations of fibers are reported in the vicinity of textile industries (Alam et al., 2019). For example, the dominance of synthetic fibers in the surface waters of freshwater systems in Vietnam likely is a result of the presence of the textile and apparel industry in the surrounding city (Lahens et al., 2018). In small water bodies along the Yangtze River delta, sites with higher levels of microfibers were located near residential areas with high human activities and textile processing plants (Hu et al., 2018). In Mexico, the abundance of fibers in river sediments was attributed to the presence of 742 textile industries operating close to the riverine systems (Shruti et al., 2019). The dominance of fibers with low mobility in sediments of an industrial textile area in China indicated that textile factories in the surrounding areas are the main source of microfiber pollution in the river sediments (Deng et al., 2020).

Washing clothes (direct washing and machine washing) is a main source of MP fibers (Peng et al., 2017; Alam et al., 2019); and laundry wastewaters are an important contributor to MP pollution in rivers (Fan et al., 2019). Indeed, both washing machines and hand washing could be sources of fiber discharge in the canals and rivers (Lahens et al., 2018). For example, in a study in China, 97% of the total identified MPs were the main components of clothes (polyester, acrylic, and PET) (Peng et al., 2017). Slum areas with poor sanitary conditions for residents and consequently performing activities of bathing and washing in the river water could influence the fiber abundance in rivers (Alam et al., 2019).

Sewage sludge can be an important source of fibers (Zhang and Liu, 2018). The highest number of fibers was recorded in the site with the highest sewage input, in sediments of Thames tributaries in England. Applying sewage sludge to agricultural lands can lead to entering fibers into watercourses followed by arable lands (Horton et al., 2017). Based on the results of the MP pollution investigation in agricultural soils of the Dian Lake basin in China, fiber MPs contained 98% of the total identified plastic particles. Aggregation of most MP particles with soil indicated that there are considerable amounts of MPs in these soils; that are susceptible to transfer through irrigation and drainage (Zhang and Liu, 2018). In general, wastewater treatment plants likely are the main source of fiber MPs in rivers, especially in urban sections (Hitchcock and Mitrovic, 2019). Higher concentrations of these particles are reported downstream of wastewater treatment plants in the USA (McCormick et al., 2016). In Charleston harbor, dominance of fibers in surface waters was attributed to the presence of more wastewater treatment plants and pipes in this harbor (Gray et al., 2018).

Lines are probably pieces of fishing lines, ropes, and nets from local shipping and fishery activities (Zhang et al., 2015; Mao et al., 2020). Also, they can be a result of fragmentation and degradation of larger plastic debris (Free et al., 2014). In Goiana estuary, the highest amounts of threads in surface waters were attributed to fishing activities (Lima et al., 2014). Also, the dominance of fibers in surface waters and river sediments of Three Gorges Reservoir in the Yangtze River was attributed to the development of the fishery industry in this region (Di and Wang, 2018). The high proportion of fibers in the surface waters of the Yongjiang River in China was mainly attributed to the shedding from textiles, fishery, and shipping (Zhang et al., 2019).

Fragments: Fragmentation and degradation of larger plastic debris can lead to the production of a type of secondary MPs called fragments (Free et al., 2014; Kay et al., 2018; Shruti et al., 2019). These irregular shape particles are associated with population density and recreational activities in many cases (Mani et al., 2015; Zhang et al., 2015; Blair et al., 2019). The presence of fragments in sediments can be in relation to the tourist areas and hotels, shops, and residential population (Ramirez et al., 2019). In England, the dominance of fragments in river bed sediments of Tame River and its tributaries indicated the pre-dominance of secondary MPs in this freshwater system. These results suggested that the main driver of MP pollution in this catchment is the degradation of larger plastics from terrestrial sources such as landfill or litter (Tibbetts et al., 2018). In the Changjiang estuary, material quality in surface waters fragments and large plastic products on markets were similar indicating that some MPs most probably have the same origin as large plastic wastes (Xu et al., 2018).

Films: Films are irregularly shaped MPs formed by the breakdown of larger plastic particles (Wang et al., 2020). Film MPs are thin flexible pieces of plastic debris and are mainly made of polyethylene (Wu et al., 2020; Xu et al., 2020). Film shape particles can be an indicator of the high demand for packaging in a region (Naidoo et al., 2015). Mulching used in engineering and agricultural activities can be a potential source of film shape MPs (Wen et al., 2018). The decomposition of agricultural materials is also a source of films (Ding et al., 2019). Color film MPs may be in association with the paint industry (Dikareva and Simon, 2019). For example, in a study on the surface waters of the Snake and Columbia rivers in the USA, site with high numbers of films was influenced by fishing activities (Kapp and Yeatman, 2018).

Foams: Foams are granule-shaped, soft, and lightweight MPs (Wagner et al., 2014; Wu et al., 2020). Foam and Styrofoam are made from closed-cell extruded polystyrene foam and are extensively used in thermal insulation and craft applications (Zhang et al., 2015). The dominance of expanded polystyrene in freshwater systems can be in relation to its wide usage in insulated boxes for the transport of fresh food and take-away food in an area and consequently entering rivers followed by improperly disposed (Fok and Cheung, 2015). Indeed, foams are littering related to MPs (Cable et al., 2017). For example, the dominance of Styrofoam in combined sewer system outfalls indicates the substantial contribution of storm water runoff in foam abundance in Mohawk River (Smith et al., 2017). In regions with low levels of developing and industrial activities, the majority of granular particles are probably foams with irregular shapes (Mao et al., 2020).

Particle size: Size patterns in MPs may be related to the particle origins (Zhang et al., 2015). For example, rounded pellets with 0.5 mm in size and less are attributed to beauty or cleaning products, and pellets with 5 mm in size are virgin pellets, probably (Gallagher et al., 2016). In a study conducted on river sediments of the St. Lawrence River in Canada, microbeads with smaller diameters (mean: 0.7 mm) were observed in locations receiving effluents (Castaneda et al., 2014). Also, the dominance of smaller size MPs (smaller than 500 μm) in the surface waters of Pearl River in China was attributed to the particles from wastewater treatment plants (Yan et al., 2019). No significant correlation was observed between plastic pellets/beads and wastewater effluent in the surface waters of 29 Great Lakes tributaries. Because personal care product-related beads are smaller than the 333 μm mesh size used in this study, these beads were attributed to industrial sources with larger sizes (Baldwin et al., 2016). In the Raritan River, higher abundances of primary MPs in smaller size categories (63, 125, and 250 μm) were observed downstream of the wastewater treatment plant. Personal care products may be responsible for this. In contrast, the average percentage of secondary MPs was higher in larger size categories of MPs in this study area (Estahbanati and Fahrenfeld, 2016).

The presence of large particles such as polystyrene foam with diameters larger than 1 mm may indicate the very recent emmition (Mani and Burkhardt-Holm, 2020). For example, predominance of large size MPs in a river suggested that weathering extent of their parent plastic products is relatively weak. Improperly disposed plastic wastes and relatively short transport distance can be responsible for this (Zhang et al., 2017). Also, a high proportion of large-sized MPs in Wuhan along the Yangtze River indicated the impact of plastic litter generated by human activities on MP abundance (Xiong et al., 2019).

Particle color: A vast range of colors for MPs particles in a region is an indication of a wide range of its sources (Gallagher et al., 2016). For example, the lack of natural colors in fibers indicates the dominance of industrially processed fibers in a study region (Dris et al., 2018); and the dominance of colored microfibers in a system may be attributed to the municipal wastewater (including domestic wastewater) as a major source of these particle types. Clothing and packaging are potential sources of colored MPs; and fishing nets, lines, and plastic bags are probable sources of transparent MPs in urban freshwaters (Wang et al., 2017; Wen et al., 2018).

Dominance of white MPs in a region can be attributed to the remaining particles for certain times periods in the environment and affected by environmental weathering processes; such as fading of color due to UV light, and that the plastic was originally produced colorless. However, the amount of colorless plastic is lower in rivers than on beaches (Pan et al., 2020; Wong et al., 2020). Spherical polyethylene microbeads with blue color can be a signal for personal care products such as toothpaste in wastewater streams (Smith et al., 2017; Carr et al., 2016). The presence of paint chips in the highest amounts during the late rainy season in the Goiana estuary was attributed to the capture season and shipping activities (Lima et al., 2014).

The presence of black fragments in a river can originate from automotive parts and tires, electronic wires and cables, and roof covering (Dikareva and Simon, 2019). In a study on river sediments of Thames River tributaries, colored angular fragments were identified. This particle type was matched with particles collected from road-based coating and paints. Directly derived MPs from road surfaces may be transported via road surface runoff and entering the watercourses, finally (Horton et al., 2017). Similarly, black fragments were the dominant type of MPs in the Charleston Harbor estuary in the USA. This was likely in relation to the tire wear particles produced followed by abrasion of tires on roadway surfaces (Gray et al., 2018). Results of a modeling study on European rivers indicated that tire and road wear particles are the largest land-based sources of MP input to the surface water of these freshwater systems (Siegfried et al., 2017).

Chemical composition: Polyethylene (PE) and polypropylene (PP) are the main types of plastic polymers littering freshwater shorelines (Zbyszewski et al., 2014). Indeed, they are more susceptible to transportation by wind, waves, and currents (Browne et al., 2010; Corcoran et al., 2015). PE and PP with low specific densities (lower than water) are transported by rainwater or rivers and distributed in aqueous systems, widespread (Klein et al., 2015). These low densities of less than 1.0 g/cm^3 resulted in high detection frequency in water and sediments (Wang et al., 2020). Relative long persistence and enrichment of PE in the environment is related to its weaker photo-degradability compared with other polymers (Xu et al., 2020). PE and PP can be useful indicators for monitoring MP pollution in the environment (Wang et al., 2020). PE and PP are commonly found in consumer products (e.g. plastic bags, bottles, caps, films, and containers). These types of polymers are used in personal care and cosmetic products (PCCPs) such as abrasive, film forming, viscosity controlling and binder for powders (Zhao et al., 2015). PE and PP are used in the packaging industry and the presence of these polymers in environmental matrices can be an indicator of the urban origins of microplastics (Sadri and Thompson, 2014). PP and PE can be also used to make floor covering (Mao et al., 2020).

The dominance of PP in the bottom sediments of six rivers in China was attributed to the fragmentation of abandoned plastic debris into smaller MPs. Thus, these types of plastics are secondary MPs derived from land-based sources, most likely (Peng et al., 2018). In sub-surface waters of three urban estuaries in China, the highest abundances of PP and PE were attributed to the fracture of larger debris including consumer products (Zhao et al., 2015). In Pearl River, the presence of PP and PE polymers indicates that urban pollution can be an important source of these polymer types (Yan et al., 2019). The pellets found in a site near a sewage treatment plant beside Yongjiang River were composed of PE. This suggested that wastewater treatment plants effluents can be a possible source of cosmetic polyethylene microbead for rivers (Zhang et al., 2019). PE and PP were the most identified polymers in many studied rivers and lakes, including beach sediments of lakes Huron, Erie, and St. Clair with an overall PE/PP ratio of 60/38 (Zbyszewski et al., 2014), beach sediments of Lake Ontario (Corcoran et al., 2015), surface waters of all lakes and rivers of Switzerland (Faure et al., 2015), shore sediments and surface waters of the Rhine and Main rivers in Germany (Klein et al., 2015; Mani et al., 2015), surface waters of Yangtze River and its tributaries (Zhang et al., 2015), Yulin river (Mao et al., 2020), Zhangjiang river (Pan et al., 2020), and subsurface waters of three urban estuaries in China (Zhao et al., 2015). Polystyrene (PS) is one of the most produced polymers, followed by PE and PP. This polymer type (mainly in the form of expanded polystyrene) with floating ability on surface water, is easily transported by surface runoff and waterways into freshwater systems (Klein et al., 2015). PS MPs have spherical shapes, predominately (Mani et al., 2019). PS foams are likely to be suspended in water, while PS fragments prefer to sink into the sediments (Wu et al., 2020).

Polyvinylchloride (PVC) and polyethylene terephthalate (PET) are of the high production volume polymers globally (Klein et al., 2015). The presence of PVC in a system can be an indication of land-based origin of plastic debris (Zhao et al., 2015). PET is a common material for producing bottles and containers and is also widely used for fabrics (Xu et al., 2020). Identification of polyester (PES) polymer type in a system may be attributed to the washing of clothes (Peng et al., 2018). For example, the presence of PES MPs in a freshwater river in Indonesia was attributed to the shredding of clothing from textile industries and washing out of clothing done by peoples (Alam et al., 2019). High densities (higher than water) of such polymers complicate their separation from environmental samples (Klein et al., 2015). In general, the abundant of high-density polymers is higher in sediments than surface waters (Jiang et al., 2019). For example, a higher proportion of PVC was found in the sediments of Maozhou River compared to those in water, because of its higher density than other major MPs (Wu et al., 2020). Polyester/polyethylene terephthalate (PET) was the most polymer type (41%) identified in sediments of the river Thames in the UK, rather than PP (15%), PE (6%), and PS (3%). These results were likely because of using an effective method to remove dense particles from sediment samples (Horton et al., 2017). The presence of these high-density polymers in surface waters may be due to the powerful vertical movement of water (Amrutha and Warrier, 2020).

Factors affecting microplastic abundance in freshwater systems

Population density and land-use type: Basin characteristics, including population density, percentage of watershed in urban land-use, and percent of impervious cover are reported as important effecting factors on MP concentration in freshwater rivers (Baldwin et al., 2016; Kataoka et al., 2019). Based on documented reports, industrialization and intensive human activities are more important parameters in MP abundance in a region (Su et al., 2018; Shruti et al., 2019; Yan et al., 2019; Zhang et al., 2019). The effect of land-use type on MP concentration is less examined in the literature.

***Residential (urban/suburban) land-use*:** Higher concentrations of MPs are reported in residential and urban populated areas with high anthropogenic activities (Yonkos et al., 2014; Mani et al., 2015; Zhang et al., 2015; Cable et al., 2017; Lahens et al., 2018; Nel et al., 2018; Peng et al., 2018; Wen et al., 2018; Ding et al., 2019; Zhang et al., 2019). In other words, MP concentration is very effected by population density, anthropogenic activities and urban development (Yonkos et al., 2014; Wen et al., 2018; Eo et al., 2019; Pan et al., 2020). Indeed, densely populated and more developed areas are important for MP pollution, in comparison to areas with forest or agriculture land-uses (Yonkos et al., 2014; Dean et al., 2018; Watkins et al., 2019). Urban runoff represents a common pathway for transporting MP particles from land-based sources to freshwater rivers (Campanale et al., 2020).

In Auckland streams, New Zealand, MP concentration was correlated with population density and residential land-use in surface waters; and with industrial and residential land-use in sediments. Residential land cover with activities such as dumping of rubbish into the streams and on the banks, input from building sites, roads, and domestic sewage effluent can be a predictor of MP pollution in urban streams (Dikareva and Simon, 2019). Also, in benthic sediments of river Tame, England, MP abundance in the more urban section was 65% higher than in the more rural section of the river; and its concentration was decreased with distance from the urban center (Tibbetts et al., 2018). In conducted studies on different freshwater bodies in China, concentration of MPs increased gradually as the river flows from the countryside to the central city (Di and Wang, 2018; Luo et al., 2019). This is highlighting the importance of local sources of plastics in these regions (Naidoo et al., 2015). Generally, lower concentrations of MPs are recorded in sites far from the urban regions with less development and lower levels of anthropogenic activities (Lin et al., 2018; Su et al., 2018; Yan et al., 2019). Low levels of MP pollution in five studied rivers in the Tibet Plateau were attributed to the limited human impact in these areas (Jiang et al., 2019). Low MP concentration in less populated areas can be in a similar range with natural reserves (Klein et al., 2015). For example, in a study on Grand Teton National Park in the USA, no detectable MPs were reported (Kapp and Yeatman, 2018). However, a lack of proper waste management in under-developed areas can result in the transport of MPs by surface runoff (Mao et al., 2020).

The size of the watershed (catchment area) can affect MP abundance, in addition to population density (Gallagher et al., 2016; Mani and Burkhardt-Holm, 2020). For example, in the USA, Winyah Bay with greater concentration of MPs in surface waters has a larger drainage area in comparison to Charleston Harbor with higher population (Gray et al., 2018). MP density in the Jiaojiang estuary with the smallest catchment area, runoff, population, and urban development than other estuaries, was not the lowest one (Zhao et al., 2015). Sites with high levels of MPs were more recorded in residential areas and sediments of the Brisbane River in Australia. However, MP hotspots were present in various land-use areas and were almost evenly distributed along the river (He et al., 2020). However, areas with small watersheds and low population densities have lower concentrations of MPs, generally (Yonkos et al., 2014).

***Industrial land-use*:** Direct industrial discharge emitting into the rivers can result in the increase of MP abundance and the creation of local MP hotspots (Mani et al., 2019; Scherer et al., 2020). The presence of numerous industries, especially with a trade of plastic powders, pellets, and other raw materials in a region can increase MP abundance in the environment (Naidoo et al., 2015). So, the number of factories and industrial parks in a catchment area should be considered in MP studies. In some regions, industrial activities are more effective than population density for MP pollution (Wong et al., 2020).

In China, MP concentration in the downstream industrial section of the Haihe River was significantly higher than that in the upstream urban section. This was attributed to the industrial wastewater from plastic manufacturing with incomplete removal of MPs (Liu et al., 2020). In England, high MP abundance in Itchen River estuary was attributed to the passing river through areas with various industries, including notably polyethylene bags and sheet wrapping companies on the river banks (Gallagher et al., 2016). In a small river in Austria, emitting of industrial MPs (such as micropellet) was estimated approximately 200 gram/day under normal operating conditions. Borealis plastic manufacturing was the first identified point source of industrial MP litter in freshwater systems (Lechner and Ramler, 2015). Local MP pollution in water and sediments of a river passing from the textile industrial area in China was strongly suspected to originate from the textile industrial wastewater (Deng et al., 2020).

Agricultural land-use: Population size and industrial activities alone may not determine level of MP pollution within a river catchment area (Klein et al., 2015; Gray et al., 2018). Regions with agricultural activities (and consequently agricultural runoff) are introduced as hotspot areas for MPs pollution, in some cases (Kapp and Yeatman, 2018). Agricultural activities on the river banks can introduce MPs into the soil through organic fertilizers, in some areas (Zhang et al., 2019). Sewage sludge application and irrigation wastewater in agricultural lands are an identified source of MP particles (Kay et al., 2018; Zhang and Liu, 2018). For example, the application of biosolids (from wastewater treatment plants) in agricultural lands of Hunter and Bega catchments in Australia; and consequently, entering MPs via surface runoff into waterways are introduced as an important affecting factor on MP pollution in these areas (Hitchcock and Mitrovic, 2019). In China, high values of MPs were recorded in locations without concentrated industrial activities or sewage treatment, but with many farmlands and some villages (Xu et al., 2020).

Recreational land-use/forest cover: Tourism and recreational activities can increase MP concentration in an area, in some cases (Di and Wang, 2018; Su et al., 2018). Indeed, in tourist areas, the consumption of single-use plastics can be increased the MP load (Tsering et al., 2021). For example, the MP source in Tibet Plateau was attributed to the daily activities of residents and tourists; with regard to the presence of no fisheries and ships activities near the sampling sites and very little activity along rivers (Jiang et al., 2019). Although, the results of the investigation of MP pollution in three estuaries in Australia indicated that MP abundance is not affected by tourism activities in warmer months (Hitchcock and Mitrovic, 2019). Similarly, the lowest concentrations of MPs were recorded in a forest park area, in a study conducted on Maozhou River in Asia (Wu et al., 2020).

Wastewater effluents: Domestic sewage originating from point sources plays an important role in MP pollution (Mao et al., 2020). Indeed, a number of sewage and wastewater treatment facilities can be affected by MP pollution in a freshwater system (Eo et al., 2019; Watkins et al., 2019; Liu et al., 2020). Since the small-size MPs may not be effectively removed and pass through the filtration systems of wastewater treatment plants, their effluents can contribute to the MP loading of receiving waters (Hitchcock and Mitrovic, 2019; Han et al., 2020). These effluents are introduced as an important point source of MPs to water bodies especially for urban rivers (McCormick et al., 2014; Mani et al., 2015; McCormick et al., 2016; Cable et al., 2017; Smith et al., 2017; Kay et al., 2018), because of creation a sharping increase in MPs abundance in surface waters (Mao et al., 2020). MP concentration in downstream of wastewater treatment plants is much higher than in upstream sites, in most cases (McCormick et al., 2014; Estahbanati and Fahrenfeld, 2016; Vermaire et al., 2017). For example, in the USA, average MP flux downstream of wastewater treatment plants estimated 1,338,757 particles/day (McCormick et al., 2016).

Microplastic pollution in freshwater systems was attributed to the effect of wastewater treatment plants effluents (Leslie et al., 2017; Di and Wang, 2018; Tibbetts et al., 2018; Shruti et al., 2019). For example, similar polymer types in Qing River water and effluent outfalls indicate that microplastics in this river are derived mainly from the effluent outfalls (Wang et al., 2020). In contrast, no significant upstream-downstream evolution of MP contamination is observed in some of the freshwater (Dris et al., 2015; Lin et al., 2018; Nel et al., 2018). For example, the results of a study on effluent discharges in southern California suggested that both secondary and tertiary effluent discharges are not significant sources of MPs to surface waters (Carr et al., 2016). Results of a global modeling study on freshwater rivers indicated that sewerage discharges including car tire wear, synthetic laundry fibers and personal care products are responsible for 20% of exported MPs from rivers to the coastal seas (Van Wijnen et al., 2019).

Tributary streams: Tributaries are important input pathways for rivers that introduced MPs into the main streams and can act as important sources of MPs in the rivers (Park et al., 2020; Zhang et al., 2019). These sub-branches of water act as potential vectors of MP particles from all over the basin to the final waterway

(Klein et al., 2015; Smith et al., 2017). Importance of tributaries is due to the convergence of flows at confluences points and occurrence of complicated hydrodynamic patterns, and consequently generating the large scale turbulence structures. Also, associated fluid motion may agitate the deposited MPs and increase in their abundances in surface water (Lin et al., 2018). Higher concentrations of plastic particles are reported in confluences zones suggesting that tributaries play an important role in transport of MPs in a catchment area (Peng et al., 2017; Zhang et al., 2017; Lin et al., 2018; Zhang et al., 2019). For example, more abundances of MPs in shore sediments of Rhine River in Germany are recorded in the vicinity of confluence with Main tributary, and lower abundances is recorded before the confluence of the two rivers. Also, equally colored EPDM pellets (blue) and PP pellets (silver) in the Main mouth and downstream of the river's confluence can be an indicator of the traceable influence of the Main plastic burden on Rhine plastic pollution (Klein et al., 2015). Also, comparable MP abundances in the surface waters of Xiangxi River with main stream of the Yangtze River in China, suggested that this tributary is an important contributor to MP abundance in the Yangtze River (Zhang et al., 2015). Similarity, in the surface waters of the Snake and Columbia rivers in USA, a site with the highest number of MPs was located in downriver from the confluence with the three rivers (Kapp and Yeatman, 2018).

Sampling systems and laboratory methods: Selection an improper sampling system or laboratory method for analysis of environmental samples may affect recorded densities and cause an underestimation of actual abundances of MPs. For example, using large sizes of mesh (500 or 333 μm) to sieve sediments or filtering of water may result in capturing only a small fraction of MPs and exclud smaller size fractions of particles (for example, loss of microfibers with smaller size than selected mesh size) (Castaneda et al., 2014; Lechner et al., 2014; Baldwin et al., 2016). In contrast, using smaller mesh sizes (for example, 153 μm) can result in the observation of higher abundances of MP particles (Estahbanati and Fahrenfeld, 2016; Cable et al., 2017). In other words, using nets with smaller mesh size (100 μm or less) or bulk sampling can result in the collection of more MP particles and more accurately measuring environmental concentrations (Miller et al., 2017; Kapp and Yeatman, 2018). For example, greater abundances of plastic particles were estimated using the smaller volume bottle samples (100 L) taken nearshore than open water samples taken with a manta trawl, in Ottawa River (Vermaire et al., 2017). However, MP distribution in water bodies is usually heterogeneous. Thus, small sampling volumes may miss debris present on the water surface. Limited water volume filtered by sieve or net may be contributed to reporting of low MP densities (Moore et al., 2011; Zhao et al., 2014; Dris et al., 2015; Di and Wang, 2018). For example, a small sample volume in the grab sample method may result in difficulty to extrapolation of pollution concentration (Miller et al., 2017). In the surface waters of the Changjiang estuary in China, lower concentrations of MPs were observed in comparison with a similar study (Zhao et al., 2014). This was likely attributed to differences in sampling methodology (neustonic trawls used in 2014 versus pump used in 2018 study), deeper water depth and smaller pore size of steel sieve in 2014 study, lacking of particle identification by μ-FTIR in the 2014 study and consequently inclusion of suspected non-plastic particles in results and higher density estimate of MPs (Xu et al., 2018).

The recovery rate of MPs from water and sediments by density separation method may influence reported MP concentrations (Gray et al., 2018). For example, using a saturated NaCl (sodium chloride) solution for density separation of MPs from sediments created an underestimation in MP concentration in many cases (Wang et al., 2016; Gray et al., 2018). In this method, MPs with a density lower than 1.2 g/cm^3 are extracted and denser particles such as PVC or PET could not floated up and consequently not be extracted (Wang et al., 2016; Dikareva and Simon, 2019). Using of $ZnCl_2$ (zinc chloride) for MP separation can increase the recovery rate of MPs from environmental matrices (Rodrigues et al., 2018).

Factors affecting microplastic distribution in freshwater systems

Seasonal variations: Sampling season was introduced as an important factor in MP distribution in freshwaters. In many cases, higher concentrations of MPs are reported in wet seasons (Eo et al., 2019; Ramirez et al., 2019), especially after rain. This can be attributed to the higher rainfall during the wet season and consequently transport of plastic particles from inland areas to the streams and rivers, by surface runoff (Moore et al., 2011; Lima et al., 2014; Faure et al., 2015; Cheung et al., 2016; Xiong et al., 2018; Alam et al., 2019). Also, this can be due to the reactivation of particles that have been deposited at the river banks. Positive correlations are recorded between precipitation and the number of MPs in some rivers. This is more likely indicating the land-use origin of MPs (Wong et al., 2020).

The flow of water, municipal discharges from cities and drag and sedimentation of plastic items after rainfall events can result in larger abundances of MPs in rainy seasons (Ramirez et al., 2019). For example, the highest abundances of MPs in surface waters of Xiangxi River, China, reported in July 2015. Heavy rainfall events in this month and an increase in surface runoff, which could carry plastic wastes within the watershed into the river, are considered for these results. In this study, the lowest MP abundance in January 2016 suggested that the input of plastic debris in the dry season is less and MPs from rainy seasons do not persist in river (Zhang et al., 2017). Occurring major storm events (such as Hurricane Irene in USA; and Typhoon Soulik in China) and consequently great landfalls can increase MP concentration in aquatic systems. Heavy rains and winds can lead to the entering of large amounts of land-based plastic debris into the rivers and estuaries (Yonkos et al., 2014; Zhao et al., 2015).

An increase in riverine flush in rainy seasons and discharging of high volumes of freshwater into the estuaries following the high river flow can transport MPs generated in the river basin to these important sections of rivers (Lima et al., 2014). It seems that higher river flow in the rainy season results in a decrease in MP concentration in rivers, especially in the upper sections (Tang et al., 2018). For example, the mean MPs concentration in river sediments of two catchments in England decreased to 64 and 81% in the channel beds of river Irwell and river Mersey, respectively after catchment-wide flooding (Hurley et al., 2018). The results of a study on water and sediments of a remote river in China indicated that pollution levels during the dry season are approximately two to three times higher than those during the rainy season. This was attributed to the dilution of shoreline MPs by intense rainfall during the rainy season (Liu et al., 2021).

Water hydrodynamic: Hydrological conditions and hydrodynamic factors including channel current, channel geometry and stagnant water zones can influence MPs particles distribution in riverine systems, in addition to demographic factors (Klein et al., 2015). Factors affecting sediment deposition (such as water currents and shoreline topography) may be affected the distribution of MPs. For example, in a study conducted on St. Lawrence River sediments in Canada, one of the sites without MPs, near a pulp and paper mill, had the coarsest sediments and not a depositional zone for these particles (Castaneda et al., 2014).

Surface current direction is an effective factor on distribution of MPs (Fok and Cheung, 2015). River flow dynamics likely is the major contributor of MPs abundance in some area (He et al., 2020). But, absence of distinct patterns in the variations of MPs in a study region, indicating that anthropogenic effects have a stronger influence on MP abundance than environmental factors (Mani and Burkhardt-Holm, 2020). Hydrodynamic conditions in rivers are stronger than in lakes. This can facilitate evacuation of MPs from river canals (Wang et al., 2017). In contrast, other hydrological conditions in a river system may be facilitating the retention of MPs. For example, smaller water volume in rivers is an important factor in MP concentration (Su et al., 2018). In other words, the size of the water body is important for MP concentration (Luo et al., 2019). Small water bodies have the ability to terrestrial runoff accumulation, pollutants, and stressors without the potential for dilution present in larger catchments (Hu et al., 2018). Residence time can also affect the concentration of MP particles in the environment. Residence time in sediments is higher than in water, generally (Gray et al., 2018).

Lacustrine zones with very low surface velocity must be considered in MP studies. A decrease in water flow facilitates the deposition of suspended particles while floating debris including MPs can accumulate at the river surface (Zhang et al., 2017). For sediments, sites with very low surface velocity such as wetland parks are subjected to higher concentrations of MP particles (Ding et al., 2019). In this regard, reservoirs are important areas for the accumulation of MPs and the highest abundances of these particles are reported in the vicinity of dams (Zhang et al., 2015; Wen et al., 2018; Shruti et al., 2019). Concentrations of MPs were most probably increased with moving toward the dams. The inability of MP transported from upstream to across the dam and their accumulation behind the dam is likely responsible for higher concentration in the vicinity of reservoirs (Zhang et al., 2015). For example, in a typical urban river in China, the detection of the lowest MP abundance in the site located in front of the dam indicated that almost 80% of MPs in the water were retained by the dam (Wang et al., 2020). Decrease of water velocity and water standing behind the dam in sites near the dams facilitate flocculation and eventual deposition and accumulation of MP particles in sediments rather than flowing away with the water (Wen et al., 2018; Shruti et al., 2019). Higher concentrations of MP particles in sediments of reservoirs of dams than in surface water are likely due to MP particles settling out of the water column into sediments in the slower-moving waters of impoundment (Watkins et al., 2019). The proximity of sampling locations to the ports and the creation of a harboring effect can result in the accumulation of MPs following the low water flow (Naidoo et al., 2015; Ballent et al., 2016). For example, in a study on the surface waters of the Three Gorges Dam in China, one of the sampling sites was next to a port and had a higher concentration of MPs compared to nearby locations (Zhang et al., 2015). Also, in another study in the surface waters of this region, a site located between two busy ports on the upper and lower reaches had higher abundances of these particles (Di and Wang, 2018).

Particle properties (e.g. density, shape and size): Particle type and particle density can affect the spatial variability of MPs in freshwater systems (Hurley et al., 2018). Relatively low densities of most MP particles (than water) result in tendency of these particles to flowing on the surface waters (Peng et al., 2017; Alam et al., 2019). Less dense MPs are more susceptible to transportation by wind, waves, and currents (Browne et al., 2010). For example, lower abundances of expanded polystyrene and low-density plastics in the dry season in beach sediments of Pearl River estuary were attributed to the strong northeast monsoon winds during winter and removed the EPS debris from shorelines (Cheung et al., 2016). In England, after flood occurrence in the Irwell and Mersey catchments, fragments decreased to 40% and microbeads increased to 45% in river sediments, in comparison to before flooding. Also, microbeads were completely cleaned in seven sites during the flooding event (Hurley et al., 2018). Generally, polymer distribution in sediments of freshwater systems is more diverse than surface water (Scherer et al., 2020). In locations with weak hydrodynamic conditions, sedimentation of high-density MPs (heavier than 1 g/cm^3) occurs; and low-density MPs (lighter than 1 g/cm^3) are observed in surface waters (Zhang et al., 2017). For example, Lin et al. (2018) believe that no observation of microbeads in the surface waters of Pearl River in China is the result of a higher density of microbeads (heavier than 1 g/cm^3) in comparison to freshwater and consequently easily deposition of this type of MPs in river sediments (Lin et al., 2018).

MP density increases with decreasing size of particles (Zhao et al., 2014; Hu et al., 2018; Eo et al., 2019). Higher densities of larger MPs and tendency to settle in water can result in its distribution in freshwater sediments (Alam et al., 2019). However, the smallest size fractions are the most common in water columns and sediments (Dikareva and Simon, 2019). For example, small MP particles (S-MPP≤1 mm) accounted for 67% of MPs, in a study on the surface waters of the Yangtze estuary (Zhao et al., 2014). Similarly, 72% of identified plastic particles in surface waters of 29 Great Lakes tributaries lay in the smallest size fraction (0.355-0.99 mm). The majority of smallest size fractions compared to 1-4.75 mm size fraction (26%) in this region indicates the inverse relationship between MP concentration and particle size (Baldwin et al., 2016). The ability of smaller particles of MPs carried away by runoff in comparison to larger particles, may be a reason for dominance of particles less than 0.5 mm (500 µm) in riverine systems (Yan et al., 2019).

Other affecting factors: Vertical distribution of MPs in an aquatic system is affected by more factors rather than density (Wang et al., 2017) and other fate and transport processes, including degradation, uptake by biota, dilution, settling, or skimming of particles during transport are important in MP distribution in riverine waters (Estahbanati and Fahrenfeld, 2016; Zhang et al., 2017). For example, similar dominance of microfibers in surface waters and sediments of Ottawa River suggested that MPs in sediments settled out of the water column despite the plastics being less dense than freshwater. This was likely due to MP aggregation with particulate organic and inorganic materials (Vermaire et al., 2017). Indeed, aggregation and biofouling interactions and consequently increased density and decreased buoyancy of particles can result in presence of low-density polymers in bed sediments (Eo et al., 2019). For example, polyethylene and polypropylene particles generally float on the water surface. The presence and dominance of this polymer type in sediments are attributed to the biofouling and accumulation of materials on the polymer surfaces and consequently their sinking and depositing in the sediments (Amrutha and Warrier, 2020). In a study conducted on the Han River in South Korea, MP concentrations in 2 m below the surface of the river were significantly higher than at the surface water. This was explained by interactions such as aggregates and biofouling; and consequently increased density of MPs at the water surface and fall into the deeper sections of the water column (Park et al., 2020). MP concentration in surface sediments of the Haihe River in China was strongly correlated with both total organic carbon and sediment grain size (Liu et al., 2020). Soft bottom streams with finer sediments and lower flows trap more particles of MPs (Dikareva and Simon, 2019). For example, fiber shape distribution in rivers is influenced by drivers of fine sediment dynamics in rivers, because of its smaller size than other MP types (Blair et al., 2019). The dominance of small-sized MPs in a river in China was attributed to the sand effect (Ding et al., 2019). However, larger-sized MPs are more abundant in benthic sediments than in surface waters (Simon-Sanchez et al., 2019).

Freshwater rivers: Sink or source for microplastics?

Land-based discharges are a potential major source of plastic debris and riverine transport is the most crucial pathway for MPs to open seas (Lam et al., 2020). Rivers are considered as sinks for dense MPs with potentially adverse environmental impacts (Horton et al., 2017; Xu et al., 2020). Because of similar abundances of MPs in river sediments of many studied regions with the most contaminated marine sediments, river sediments can act as a key sink for MP deposition, retention, accumulation and consequently pollution; and urban rivers can considered important hotspot areas for MP pollution in mega-cities (Castaneda et al., 2014; Nel et al., 2018; Peng et al., 2018; He et al., 2020; Scherer et al., 2020).

The results of a study on the Amsterdam canal area demonstrated that MP suspended in the water phase have the potential to be transported to the sea with other suspended particulates and that sediments may be a sink for MPs (Leslie et al., 2017). Indeed, not all plastic pollution generated from a river catchment appears to be transferred to the open seas; and a proportion is likely to be deposited in benthic or shoreline sediments, especially in the slow-moving parts of a river (He et al., 2020). MP concentration in sediments of Elbe River was on average 600,000-fold higher in sediments compared to the water phase (Scherer et al., 2020).

Urban rivers are a potentially important source of MP to downstream environments (McCormick et al., 2014; Cheung et al., 2016; Estahbanati and Fahrenfeld, 2016; Peng et al., 2017; Luo et al., 2019). The average transport of MPs in surface waters of nine rivers in USA, was estimated 488 million pieces/year/-river. This indicated that rivers represent a substantial flux of plastic to downstream ecosystems (McCormick et al., 2016). In a study conducted on surface waters of the Danube River in Austria, plastic litter discharge from the river into the Black Sea was estimated to have an average of about 7.5 g/1000 m^3/s at a mean flow rate (6444 m^3/s). Also, the total entry of plastics at the mouth of river is estimated at 48.2 g/second, 173.6 kg/hour, 4.2 ton/day and 1533 ton/year. The results of this study demonstrated that the river Danube is a transport route for plastic raw materials (Lechner et al., 2014).

In Germany, the mean MP concentration exported from the surface waters of the Rhine River into the North Sea was estimated about 64-69% of original Rhine discharges, that was 191.6 million MP particles/day (daily freight discharges: focus on the water surface). Results of this study indicated that the Rhine River, with considerable MP pollution, is an important contributor to the MP mass in the North Sea (Mani et al., 2015). In Italy, floating MP released by the Po River was estimated between 2.2 and 3.8 ton/day and between 785 and 1402 ton/year (Atwood et al., 2019). In China, the total annual load of MPs through the Nakdong River was estimated 5.4 trillion particles, or 53.3 tons; based on MP abundance in surface and subsurface water at the river mouth across four seasons (Eo et al., 2019). A similar share of MP types (dominance of fibers) in surface waters of the Yangtze estuary and East China Sea indicated a possible MP flux from the river to the sea. The results of this study demonstrated that rivers have a huge effect on MP abundance in marine environments (Zhao et al., 2014). According to the mentioned above, it seems that rivers act as temporary sinks of MPs and a key medium allowing these particles to enter the open seas (Tsering et al., 2021).

Conclusion

Based on the conducted review, the sources of MPs in freshwaters can be tracked easier by investigating different properties of them, including particle type, polymer chemical composition, particle size, and particle color. The examples for potential sources are identified using of physiochemical properties as follows: fiber-shaped MPs are in association with wastewater treatment plant effluents and textile industries, in most cases; pellet MPs are in relation with industrial activities and cosmetic products; and fragments can be indicators of dominance of secondary MPs in a system. High abundances of small-sized MPs are reported in downstream of wastewater treatment plants, and small-sized pellets are attributed to the beauty products. Black fragments are associated with tire wear particles, and white particles are indicators of weathering processes. Finally, the presence of PE and PP in freshwater systems indicates the urban origin (consumer products) of MP particles; and these polymers can be used as indicators of MP pollution in a region, because of their high production and high recovery rates from environmental matrices.

Several parameters can affect MP concentration in a river system. Population density is investigated in many studies. This important factor was in direct relationship with MP abundance in most cases. Indeed, many researchers are believed that high population density can increase MPs abundances in a river. But others believe that population cannot determine the level of MP abundance, alone; and other factors such as watershed size can affect MP amount. Land-use types, including residential (urban, suburban, and rural), industrial, agricultural, recreational, or forest (land cover) are of the important affecting factors on MP amount. Urban land-use in combination with population density is the most examined and introduced as the most important source of MP pollution in rivers. However, because of its diverse sources including point (such as domestic) and non-point (road runoff) sources, it should be examined more carefully. Agricultural land-use can be considered as hotspot regions for MP pollution and introducing the fiber and film MPs into the riverine systems, but less investigated worldwide. Also, industrial wastewater is less examined, in comparison to other important point sources (wastewater treatment plants) for MP pollution. The effect of wastewater treatment plant effluent on MP concentration is investigated in several riverine systems, and introduced as one of the important point sources of MPs. Concentrations of MPs in many of the rivers were highest in the confluence points with tributary streams. These locations can act as hotspots for MP pollution and are important in MP studies. MPs Source tracking in a watershed area can be easier by investigation of tributary streams. One of the most important and effective parameters in the estimation of MP concentrations in aquatic systems is sampling systems and laboratory methods. For example, using different sampling instruments (net sampling or bulk sampling) in surface waters created different results in reviewed studies. Also, using nets with different mesh sizes for filtering surface waters can alter estimated concentrations of MPs (effect of particle size on concentration). In addition, the type of selected solution for separation (for example NaCl or $ZnCl_2$ with different densities) of particles from environmental matrices can affect estimated concentrations of MPs.

The most important affecting factors on microplastic distribution in freshwater systems are as follows. The effect of seasonal variations is investigated in several studies. Rain and storm events and consequently surface runoff can alter MP loads in water and sediments of freshwater. Higher concentrations of MPs are recorded after rainfall events in most cases. Factors affecting water hydrodynamics can affect MP distribution in water and sediments of freshwater systems. River flow velocity and surface current direction are effective factors. Low surface velocity behind the dams may lead to the accumulation of different MP types in surface waters and sediments of these locations. This theory is confirmed by several studies conducted in the Three Gorges Dam in the Yangtze River in China. Low water flow in the vicinity of the ports may also affect MP distribution in these locations. Particle properties of MPs including shape, density, and size, can influence their distribution in freshwater systems. For example, particles denser than surface water deposited in bottom sediments of the water body (considering hydrodynamic conditions). River water can act as an important source of MPs for larger systems. However, river sediments are important hotspots for MP pollution.

Recommendation

MPs are still categorized as emerging pollutants. It seems that, source identification is the most unknown part of MP studies. MP pollution with regard to the land-use type should be further investigated. For better understanding, domestic wastewater, industrial wastewater of plastic-related factories, road runoff, and agricultural runoff should be specifically studied; rather than the conventional investigations of wastewater treatment plants and urban sections of rivers in recent years. It should be noted that source tracking of MPs in a system is not a one-dimensional project and should be operated in several consecutive steps, including anthropogenic-related and hydrodynamic-related sections. This can be a long-term project and it is best to be conducted in a watershed scale.

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