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Challenges and Treatment of Microplastics in Water

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Abstract

Microplastics are particularly problematic and could pose big treatment challenges. In today's world, plastic is an essential raw material. Since their invention in the 1930s, plastics have become ubiquitous in the manufacture of everyday products. Part of the problem stems from the fact that it can be difficult to pinpoint the exact source of the microplastics because of their relatively fragmented nature, small size, and a wide range of potential sources. Microplastics have become a threat to the environment, a concern reflected by sites with unusually high concentrations and a possibility of even greater concentrations in the future. Consequently, the use and subsequent release of microplastics must be drastically reduced as part of a global initiative even prior to the availability of research studies outlining the long-term risks involved. This chapter will interrogate key sources of microplastics, assess their capacity to problematize water resources in urban environments, as well as offer an analysis of its effects on the environment and some of the methodologies that can be applied to control it.

Keywords: plastic debris, environmental concern, water, personal care products, cosmetic products, microplastic, treatment

1. Introduction

Microplastic particles (MPPs) have become a global concern since they have been added to products that are used almost daily. MPPs can be found in a number of cosmetic and personal care products, including washing liquids, soaps, facial and body scrubs, toothpaste, and lotions. One of the primary issues is that the microplastics found in cosmetic and personal products are rinsed into the household drains without any precautionary recycling measures. The disposed MPPs as well as other types of plastic debris end up at the municipal wastewater treatment plants (WWTPs) because of the durability and frequent usage of synthetic polymers [1, 2]. Recent published research reports point to WWTPs as

possible sources of microplastics that pollute the aquatic systems [3–5]. On the other hand, researchers could not definitively corroborate the correlation between WWTPs and microplastic pollution found in rivers. There is an ongoing debate about whether discharged effluents substantially contribute to the microplastic buildup in the , there is a lack of certainty about how such pollutants function during the wastewater treatment facilities' transport processes. Both environmental scientists and plant design engineers would benefit from an in-depth understanding of the microplastics' transport pathways and accumulation during wastewater treatment processes. A comprehensive study can help enhance and expand current treatment plant processes for coping with and eliminating this pollutant type. The exact origin of microplastics is difficult to identify because of their fragment nature, small size, and varying sources. However, the disposal of plastics into the immediate environment should be addressed in a global initiative even prior to the full environmental risk assessment. Specifically, the presence of microplastics in the environment, MMPs with overly high concentrations at certain sites, and the certainty that these concentrations will continue increasing are sufficient as a justification for a global effort. This chapter will interrogate key sources of microplastics, assess their capacity to problematize water resources in urban environments, as well as offer an analysis of its effects on the environment and some of the methodologies that can be applied to control it.

2. Origin and characterization of microplastics

According to the National Oceanic and Atmospheric Administration (NOAA) from the US Department of Commerce, plastic is the most prevalent type of marine debris found in the ocean and Great Lakes [1] (Oceanic). Its presence in aquatic environments, including beaches, ocean surface waters, deep-sea sediments, freshwater lakes, and tributaries, has been investigated during the past decades. It is a consequence of the increasing production of plastic materials and the many gaps on its proper disposal; it has become a global issue [2].

According to literature, the amount of plastic entering the ocean is increasing very fast over the years. Currently, between 0.48 and 1.27 million tons of plastic waste enters the ocean annually, and it is expected to see this number doubling in the next 10 years [3]. These materials are suitable for many industrial applications because of the presence of stable carbon-hydrogen bonds but also make it resistant to disintegrate in the environment, and hence it tends to accumulate over the time [3].

There is not much agreement between authors about the definition of microplastics, but in general, it can be referred as synthetic organic polymer particles with a size smaller than 5 mm [4]. Many published studies refer to microplastics as plastic particles or debris which are less than 5 mm length, but there is no consensus about the lower limit. Some researchers adopt 0.5 or 1 mm as a cutoff between macro- or mesoplastic and microplastic. Most of the published data refer to plastic particles ranging from 1 to 5 mm [5–9]. Ballent et al. considered three categories of microplastics: fibers, fragments, and spherical beads [2]. Common plastic polymers include polypropylene (PP), polyethylene (PE), low-density polyethylene (LDPE), and polyacrylates [5].

Many studies have been investigating the presence of plastic materials in different aquatic environments. However, some of them have been focusing on microbeads, which are primary microplastics in spherical shape. Those are mostly used in health and personal care products, and others have been studying more broad range of material classified as microplastics, including primary and secondary microplastics. Primary microplastics refer to microparticles that are manufactured in the previously mentioned scale, and secondary microplastics are the products of the degradation of larger plastic material, from mechanical or photooxidative pathways [4, 9, 10]. The lack of standardization causes difficulty in the comparison of results and the discussion of potential solutions for this environmental issue.

Primary microplastics comprehend particles used in personal care products with exfoliating purposes, such as facial cleansers and moisturizers, shampoos, cosmetics, and shaving products. Most of the microbeads in these products are composed of polyethylene (PE) and polypropylene (PP) [1, 2], and it is used for emulsion stabilization, viscosity regulation, and skin conditioning [5]. After being used, these products are washed down the drains, and microplastics are carried via wastewater to municipal wastewater treatment plants that can eventually reach the environment. Primary microplastics also include industrial abrasives or “scrubbers” used to blast clean surfaces, plastic powders used in modeling, particles used in drilling fluids for oil and gas exploration, and also raw materials used for plastic fabrication for many industrial applications [4, 5, 10, 11].

Since secondary microplastics are generated for the breakdown of larger plastic materials, there are many sources that can contribute to its presence in the environment. According to the review done by Duis and Corrs, 75–90% of the plastic found in aquatic environment originates from land-based sources and 10–25% from ocean-based sources [4]. With regard to the land-based sources, they assumed that the most important route of secondary microplastics into the environment is the loss from inappropriate managing of landfill sites and during waste collection. There are also routes related to the action of natural phenomena (such hurricanes, tsunamis, and strong sea), agricultural activities, the use of synthetic textiles, and other different human activities [4]. Based on various published studies, Duis and Corrs [4] summarized the sources of primary and secondary microplastics as shown in **Table 1**.

In 2014, Desforges and coworkers [9] documented the abundance, composition, and distribution of microplastics in the northeastern Pacific Ocean and coastal British Columbia. Considering fibers and fragments, a concentration range varying from 8 to 9200 particles per m³ was observed. As it is shown on the map (**Figure 1**), lower concentrations were observed in offshore Pacific waters, and higher concentrations were registered nearshore with the prevalent presence of fibers. According to this study, the materials found near urban areas are likely to be from land-based sources. In specific areas, the material appeared to be composed of debris that have been trapped and concentrated by the natural ocean activity [9].

In a recent study conducted by Ballent and coworkers, the presence of microplastics in the Canadian shoreline of Lake Ontario was investigated, evaluating its abundance and distribution pattern in three depositional zones: nearshore, tributary, and beaches (**Figure 2**). The influence of microplastic pollution on benthic ecosystems and its effect in the food chain were also analyzed [2].

Primary microplastics
Personal care products containing microplastics as exfoliants/abrasives
Specific medical applications (e.g., dentist tooth polish)
Drilling fluids for oil and gas exploration
Industrial abrasives
Preproduction plastics, production scrap, plastic degranulate: accidental losses, runoff from processing facilities
Secondary microplastics
General littering and dumping of plastic waste
Losses of waste during waste collection, from landfill sites and recycling facilities
Losses of plastic materials during natural disasters
Plastic mulching synthetic polymer particles used to improve soil quality and as composting additive
Abrasion/release of fibers from synthetic textiles
Release of fibers from hygiene products
Abrasions from car tyres
Paints based on synthetic polymers (ship paints, other protective paints, house paint, road paint): abrasion during use and paint removal, spills, illegal dumping
Abrasions from other plastic materials (e.g., household plastics)
Plastic items in organic waste
Plastic-coated or laminated paper: losses in paper recycling facilities
Material lost or discarded from fishing vessels and aquaculture facilities
Material lost or discarded from merchant ships (including lost cargo), recreational boats, oil and gas platforms

Table 1. Overview of sources for primary and secondary microplastics present in the environment [4].

In this specific study, the material was counted and sorted between three categories: fibers, fragments, and spherical beads. Many factors were shown to be decisive on the distribution of microplastics. This includes the fact that this aquatic environment is surrounded by highly urbanized and industrialized areas, morphology of the shorelines, variations in topography, and so on [2]. Also, according to the author [2], the density and shape of microplastic particles may also impact distribution patterns in Lake Ontario. Even though the polymers which microplastics are made of (such as PE and PP) have lower density than the water, the material was found in the sediment, and it can be attributed the increase of the net density of microplastic particles by biofouling, adsorption of natural substances on the surface, inclusion of inorganic fillers during manufacturing, and fecal express. With regard to the shape of the material collected from Lake Ontario, it was observed that more fibers were found on the sediments and more microbeads were found on the surface water [2].

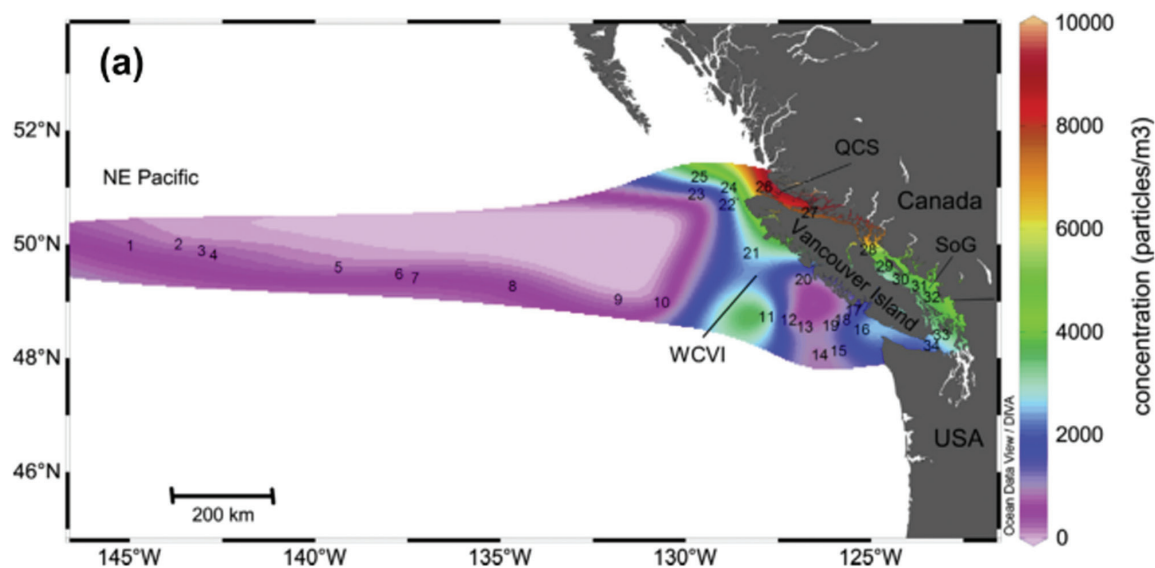


Figure 1. Total microplastic concentrations (particles/m³; detected particles >62 µm) in subsurface waters (4.5 m) of the NE Pacific Ocean in and around coastal British Columbia, Canada [9].

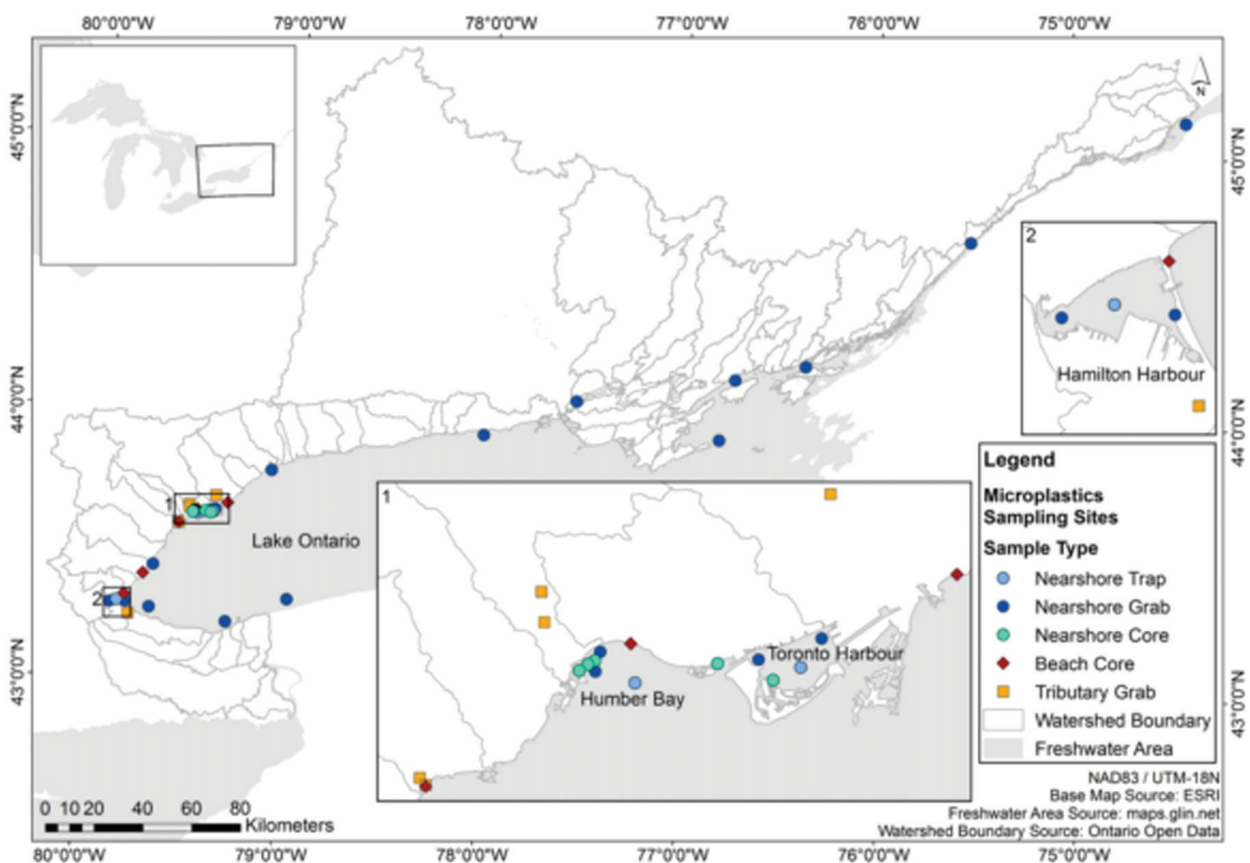


Figure 2. Sampling sites by depositional environment and instrument type for which microplastics in sediments in Lake Ontario and the St. Lawrence River were analyzed. Watershed boundaries indicate the regions that drain directly into Lake Ontario and the St. Lawrence River [2].

3. Impact of microplastics on environment

According to Anderson et al. [5], there are numerous ways through which microplastics and associated contaminants can be incorporated by the aquatic biota (**Figure 3**). This includes filter feeding, suspension feeding, inhalation at air-water surface, and consumption of prey exposed to microplastics or via direct ingestion; hence, microplastics can be assimilated into the food chain at different trophic levels [5]. Because of its particularly small size, microplastics are easily ingested by plankton and filter feeding animals which are not capable of properly selecting their food [5]. In literature, there are studies that indicate the presence of microplastics in the aquatic biota since 1960, and a few studies have been investigating the microplastic's uptake by aquatic mammals and seabirds [5].

It has been proven by many studies that microplastics are entering our food web, and as top predators, human beings are exposed to its potential harms. A study reported by Davidson and coworkers [12] investigated the presence of microplastics in Manila clams in British Columbia. It was found that every clam analyzed had at least one piece of microplastic and the concentration in individual clams ranged from 0.07 to 5.5 particles per gram. In Brazil, an investigation conducted by Miranda [13] detected significant amounts of MMP in the stomachs of two important edible species of fish. According to review published by Santillo, MMPs have been identified in different marine species from various countries around the world such as Canada, Brazil, Portugal, China, Indonesia, the USA, and Spain and important regions such as the North Pacific central gyre, North Atlantic, English Channel, North Sea, Baltic Sea, and central Mediterranean [14].

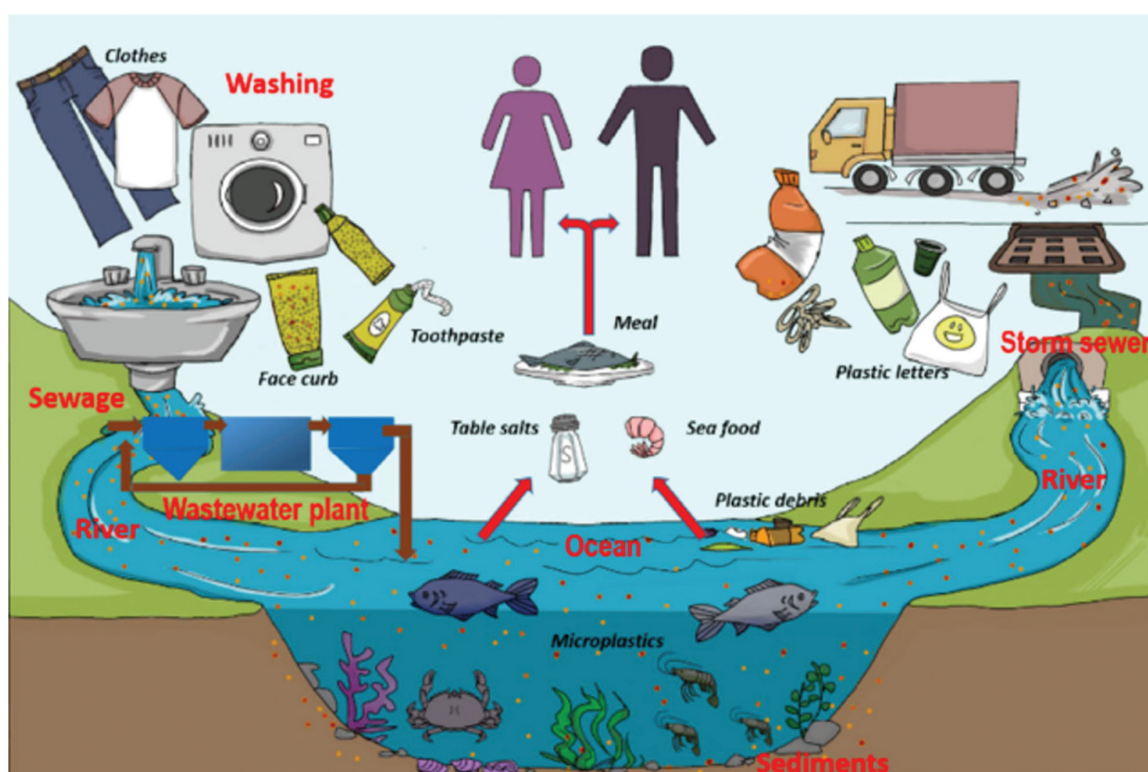


Figure 3. Microplastic pollution in aquatic environments and impacts on food chains [3].

Microplastics can be hazardous to aquatic organisms through different pathways [5, 7]. First, the ingestion of microplastics can cause physical blockage, internal abrasions, and internal and external wounds, and hence the organisms can be harmed by expending energy for egestion, can suffer from starvation and debilitation, and can result in death [3–5, 7]. Second, the organisms can be exposed to the leakage of toxic additives such as plasticizers, stabilizers, pigments, fillers, and flame retardants. These substances cannot only be toxic but also carcinogenic or endocrine active, which can impact reproductive functions of the species [5, 7, 14, 15]. Furthermore, because of its large surface-to-volume ratio and some of its inherent characteristics, microplastics are capable of absorbing various contaminants, such as heavy metals, chlorinated and aromatic compounds, and potentially persistent organic pollutants due to its hydrophobic nature [3, 5, 9, 16, 17].

In more recent studies, the ecological impact of microplastics as carriers of toxic compounds has been investigated [3, 5, 7, 9]. It has been reported that one of the many routes through which microplastics can reach the environment is through the low efficiency of water and wastewater treatment plants in retaining this material [3, 5]. Since there is a great deal of substances in these plants and microbeads can absorb and concentrate toxic hydrophobic substances, it can work as delivery systems of these substances to the aquatic environment [3].

Many research efforts have been put on trying to identify which are the main contributors for microplastic pollution. Scientists in the Ministry of the Environment and Climate Change (MOECC) have been studying the presence of microplastics in the Great Lakes [18]. They collected surface water samples in 2014 from nearshore areas in Lake Erie downstream of Detroit-Windsor, near the mouth of the Grand River, and near Fort Erie. According to the collected data, microbeads (primary microplastics) comprised approximately 14% of the material collected. Also, higher concentration of microplastics near to highly urbanized areas such as Humber Bay of Toronto was observed [18]. Greater amount of secondary microplastics were found, which includes fragments from broken down litter, shavings from cuttings/trimmings of plastic, foam from Styrofoam packaging, and fibers. It was also observed that after rainstorms occur, there was an increase of the presence of microplastics due to the drag of particles from roads and landscape [18]. They also studied the composition of the effluent from a wastewater treatment, and it was observed that microbeads comprised 30% of the microplastics found in the effluent samples. From urban streams in the Toronto area, microbeads were found in lower amount (less than 2%), but fibers accounted for the greatest amount of microplastic particles in those samples [18].

It is very hard to determine the origin of the microplastics due to its small size, fragment nature, and unknown range of possible sources [2]. The potential origin of polyurethane particles is foam from furniture, adhesives such as construction glue products, surface coating, and sealing applications. Some particles (black, opaque with rubberlike consistency) are probably from vehicle tires, from both natural wear-down process during driving and shredding of used tires for recycling purposes. The origin of fiber material is probably from the production, washing, and natural aging of textiles (synthetic clothes and carpets). The potential source of some particles (amber-colored beads) include exchange medium for water purification and softening, as well in various medical and industrial applications [2]. Another source of microplastics in aquatic environments is the drag of this material by storm and extreme weather events.

According to the results obtained from Ballent's study in 2015, most the spherical beads (microbeads) found in sediments were from non-cosmetic source; however, it is possible

that some of the fragments found in the samples originated from cosmetic products such as toothpaste and face washes. Nevertheless, the inclusion of microbeads manufactured for use in cosmetic products to the List of Toxic Substances in Schedule 1 of the Environmental Protection Act of 1999 is still important [2]. In 2013, it was found that microbeads comprised approximately 58% of the microplastics (smaller than 1mm in size) collected from the surface of the Great Lake, and this material is comparable to particles used in cosmetic products [19].

As consequence of numerous investigations on the effect of microplastics in aquatic environments, microbeads were officially declared toxic by the Canadian in June of 2016. According to the federal government, sale of shower gels, toothpaste, and facial scrubs containing microbeads will be banned in July 2018, and the use of microbeads in natural health products and nonprescription drugs will be prohibited in 2019 [20].

4. Water and wastewater treatment plants

Water and wastewater treatment plants (WWTPs) receive wastewater from households, institutions, commercial establishments, and industries and sometimes also from rainwater runoff from urban areas. WWTPs focus on the removal of large solid debris and reduce the concentration of nutrient and organic material. To complete this, a combination of physical, chemical, and biological processes is used. Some facilities also include a final treatment using disk filter or membrane bioreactor (MBR) to reduce the amount of particulate material in the effluent water [16].

Typically, a wastewater treatment plant is divided into three main steps as shown in **Figure 4**: primary, secondary, and tertiary treatments [15]. Usually, a preliminary treatment is applied to remove solid materials that can hinder the following steps of the process, which can include coarse screening, grit removal, and grinding of large objects [21]. The primary treatment uses sedimentation and skimming to remove settleable organic and inorganic solids, and besides removing income biochemical oxygen demand and oil and grease, it can reach 50–70% removal of total suspended solids [21]. The secondary treatment focuses on the removal of residual organic and suspended solids. It usually applies biological treatments such as activated sludge, trickling filters, and rotating biological contactors [21]. Some facilities apply a tertiary or advanced treatment to remove nitrogen, phosphorus, additional suspended solids, refractory organics, heavy metals, and dissolved solids [21].

Currently, the contribution of the WWTPs to the discharge of large amounts of microplastics into the environment is still a debate between the authors. Also, the lack of standardization on the methodology applied to collect and interpret data makes it more difficult to reach a common sense about the link between microplastic pollution in aquatic systems and the WWTPs.

Per published studies, there are three main contamination routes for freshwater systems: effluent discharged from WWTPs, overflow of wastewater sewers during high rain events, and runoff from sludge applied to agricultural land [5, 19]. It is estimated that approximately 80% of the microplastics in oceans originate from land-based sources and another 18% from aquaculture or fishing industries [5]. According to Ziajahromi et al., land-based sources include urban runoff and effluent discharge from WWTPs [17].

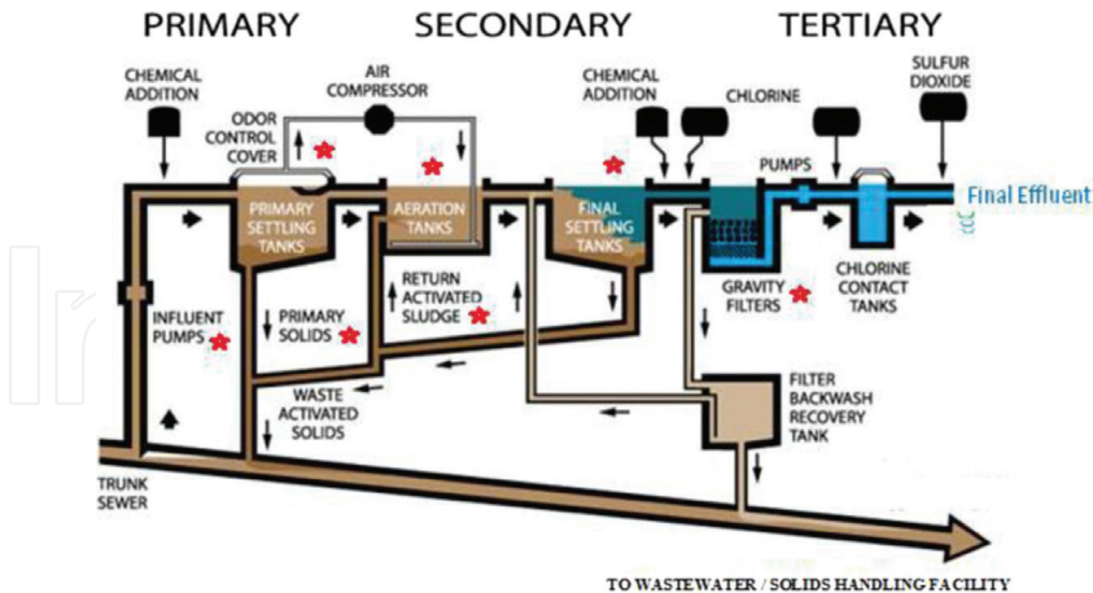


Figure 4. Typical processes of a tertiary WRP. Primary, secondary, and tertiary processes are indicated (modified) [15].

According to Carr et al., most of the microplastics from the influent are removed in the primary treatment zones in which solid skimming and sludge settling processes are applied. In a study published in 2016, effluent discharges from tertiary and secondary plants in Southern California were investigated. The importance of understanding the fate and pathways of microplastics in each step of the WWTPs was highlighted [15]. For samples collected in different points along the treatment process, filtration process was applied using an assembled stack of sieves with mesh size between 400 and 45 μm to identify the presence of microplastics in each step. For tertiary plants, it was observed that effluent discharge is not a significant source of microplastics. On the other hand, for secondary effluents microplastics were present and can contribute to the contamination of oceans and surface water [15].

Another study conducted in Australia by Ziajahromi investigated the composition of the effluent along primary, secondary, and tertiary treatment. This study detected 0.28, 0.48, and 1.54 microplastics per liter in each respective treatment step. Dayachenko and coworkers [22] observed the presence of 0.09 particles every approximately 4 l of effluent, but this number could reach 0.64 particles in the peak flow of a WWTP in the USA, which uses wet peroxide oxidation. Most of the particles were classified as secondary, and the presence of microbeads accounted for only 10% of the total [17]. Estahbanati and Fahrenfeld investigated the contribution of WWTPs for microplastic pollution in freshwater environment in the USA. In a study of the spatial distribution pattern of MMP in a WWTP, the major presence of secondary microplastics along the treatment process was observed, but the concentration of primary microplastic increased downstream of WWTP was noticed. According to Ziajahromi, although the number of particles does not seem to be quite threatening, when taking into consideration the enormous amount of water that is treated and discharged on daily basis by these facilities, these numbers can represent a very large amount of microplastics entering an aquatic environment. Based on the study of twelve WWTPs in Germany, a study conducted by Mintenig revealed that these facilities can be a sink as well as a source of microplastics which have significant contribution to environment pollution [24].

5. Challenges of preventing microplastic pollution

There are many challenges related to the investigation of microplastic pollution about prevention. Although the interest of the scientific community has been growing toward this subject and the number of published studies has been increasing, the lack of solid definition of what can be considered as microplastic makes it difficult to compare the results obtained in different investigations. Also, there are differences between the methodologies applied on the studies; hence, the results are not always comparable between themselves.

When it comes to the practical application, one of the challenges to prevent microplastic pollution on the water bodies is the lack of technology that effectively retains this kind of material at wastewater facilities. Many researches have been focusing on analyzing the presence of microplastics on the final effluent; the details about the removal of this microplastic in each step of the WWTPs are still unknown. In a previous study, very high removal of microplastics in small capacity wastewater treatment plants was observed [23]. But, even with high removal, small quantities would be discharged into water bodies and would continue causing harmful consequences to the environment.

According to Beljanski et al., there are available technologies that can effectively remove microplastics during wastewater treatment, but they can be expensive, can be difficult to install in existing facilities, and are only used when high-quality standards are required. Membrane bioreactors are an example after primary and secondary treatment, using cross-flow filtration, diffusing only water and small particles. Another drawback of this technology is the high demand for energy and hence higher cost of operation. In a study published in 2016, Beljanski et al. investigated the design of a low-cost, energy-efficient system with easy retrofiltration. Two different filter media were investigated in terms of clogging, retrofiltration capacity, and short-term durability [25].

In Canada, there are many facilities which use membrane technology during the treatment process, but it is not reported that it is a role specifically for microplastic removal. Previous studies in other locations have shown that membrane processes can reduce the amount of microplastic in the final effluent water, but there are many questions about the economic feasibility of its utilization due to the high cost of implementation. In 2016, Michielssen et al. evaluated the efficiency of different unit processes at three WWTPs in removing small anthropogenic litter (SAL). The facilities from which the samples were obtained employed either secondary treatment (activated sludge) or tertiary treatment (granular sand filtration) as the final step, as well as a pilot membrane bioreactor system that finishes treatment with microfiltration. It was observed that the membrane bioreactor plant retained a higher percentage of SAL (99.4%) [8].

6. Conclusion

The presence of microplastics is becoming a dangerous environmental concern. Part of the problem stems from the fact that it can be difficult to pinpoint the exact source of the microplastics because of their relatively fragmented nature, small size, and a wide range of potential

sources. Microplastics have become a threat to the environment, a concern reflected by sites with unusually high concentrations and a possibility of even greater concentrations in the future. As a consequence, the use and subsequent release of microplastics must be drastically reduced as part of a global initiative even prior to the availability of research studies outlining the long-term risks involved. Monitoring programs can play a key role in the prevention and management of microplastic pollution. The majority of countries, on the other hand, have not developed a strategic approach to researching the primary sources of microplastics accumulating in the water sources or methods of effectually addressing their specific properties. Some nonprofit organizations have committed to collecting and investigating data from various regions in an attempt to track and interrogate these concerns globally, specifically in difficult-to-access or isolated locations. Researchers need to collaborate on an effort that can provide a practical strategy for minimizing applications of microplastics. Although several research projects have examined the effects of microplastics in relation to the final effluent, the particular dynamics involved in the microplastic removal during each separate step of the wastewater treatment plant are still unknown. Thus, it is critical that low-cost and energy-efficient membrane bioreactor systems are designed and implemented, for applications such as primary and secondary treatments at wastewater treatment plants.

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