TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Department of Civil Engineering and Architecture

MICROPLASTICS IN WASTEWATER -*A REVIEW*

MIKROPLAST REOVEES - ÜLEVAADE

MASTERS THESIS

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TALLINN 2021

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THESIS TASK

Student: TAYYAB SHAHID

Study programme, ENVIRNMENTAL ENGG AND MANGEMETN EABM

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Thesis topic:

(in English) *MICROPLASTICS IN WASTEWATER: A REVIEW*

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Thesis main objectives based on scientific publications:

1. Overview of the Microplastics, incl. sampling
2. Consequences of Microplastics on humna health
3. Characterising the Microplastics in WWTPs
4. Removal Techniques of Microplasticsps

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CONTENTS

LIST OF ABBERIVIATIONS

MP	Microplastic
MPs	Microplastics
WWTP	Wastewater Treatment Plant
WWTPs	Wastewater Treatment Plants
ACS	American Chemical Society
RSC	Royal Society of Chemistry
EPS	Extracellular polymeric substances
ECHA	European Chemicals Agency
EU	European Union
RSF	Rapid Sand Filter
MBR	Membrane Bioreactor

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1. INTRODUCTION

Microplastics can be found in a variety of places, from the atmosphere, land, oceans, freshwater, and also the sediment of an Arctic freshwater lake. Because of their limited volume (particle debris size is typically less than 5 mm) and large specific surface region, polycyclic aromatic hydrocarbons, heavy metals, polybrominated diphenyl ethers, pharmaceuticals, and personal care products are also pollutants that they would adsorb from environmental media. As a result of their aggregation in cells, microplastics often cause chronic toxicity. Wastewater treatment plants (WWTPs) are the principal receivers of terrestrial microplastics until they reach natural marine environments, where they are converted to secondary microplastics. Microplastics found in urban wastewater are often the product of everyday social actions. Polyester and polyamide fabrics, for example, are often shed from clothing during wash and personal care products such as toothpaste, cleanser, and shower gel end up in WWTPs due to our daily use[1].

Microbeads in personal care materials and synthetic textile fabrics are examples of primary MPs, which have an initial diameter of 5 mm or less before entering the atmosphere. Larger plastic particles (such as bottles, packaging, and bags) may break up and form secondary MPs when exposed to sunlight and other environmental media or mechanical stress. Plastics are rarely pure polymers since they are normally mixed with a variety of chemicals such as plasticizers, flame retardants, and pigments during the manufacturing process. As a result, heavy metals, polybrominated diphenyl ethers, polychlorinated biphenyls, other chemicals such as polyfluoroalkyl compounds, pharmaceuticals, and personal care goods will also be transported by MPs. MPs are therefore difficult to degrade due to weathering, aging, and microbial processes, resulting in massive accumulation in the atmosphere [2].

The aim of this analysis is to include a systematic overview in order to gain a deeper understanding of the fate of MPs in WWTPs. The below are the specific goals: i. Overview of the Microplastics, incl. Sampling, ii. Consequences of Microplastics on humna health, iii. Characterising the Microplastics in WWTPs and iv. Removal Techniques of Microplasticsps. So for better understandings six different articles are reviewed and their extract is written in this work and these articles are named as Paper 1, Paper 2 or Paper 3 and so on. Impacts on human health of microplastics are also analysed and for this Paper 5 is analysed. Paper 3 has more importance as it gives better understandings for the removal of microplastics from different wwtps all over the globe. For sampling of micrplastic Paper 6 is taken into account and for characterisation of MPs Paper 1 data is analysed. At the end EU regulations are also dicussed that what steps they are initiating to encounter the microplastics.

Untreated microplastics are typically discharged from WWTPs, join water sources, and ultimately collect in the atmosphere, according to research. As a result, it is critical to investigate the performance of microplastics in WWTPs using various treatment methods and to comprehend the process of microplastic removal in order to lessen the quantity of microplastics arriving the natural aquatic environment. However, there are few reports that enlighten the microplastics reduction pathways of major WWTP treatment technologies[1].

In a Shanghai WWTP, however, the microplastics removal efficiencies fell to 49.56 percent, 26.01 percent, and 0.78 percent, respectively, for the same treatment methods. These results indicate that deducing the role of a specific treatment protocol in the elimination of microplastics in a WWTP from a single investigation is exceedingly difficult. Further to that, existing methods to microplastics removal analysis depend primarily on qualitative instead of quantitative results. As a result, new methods for assessing the removal efficiency of microplastics in WWTPs must be created [1].

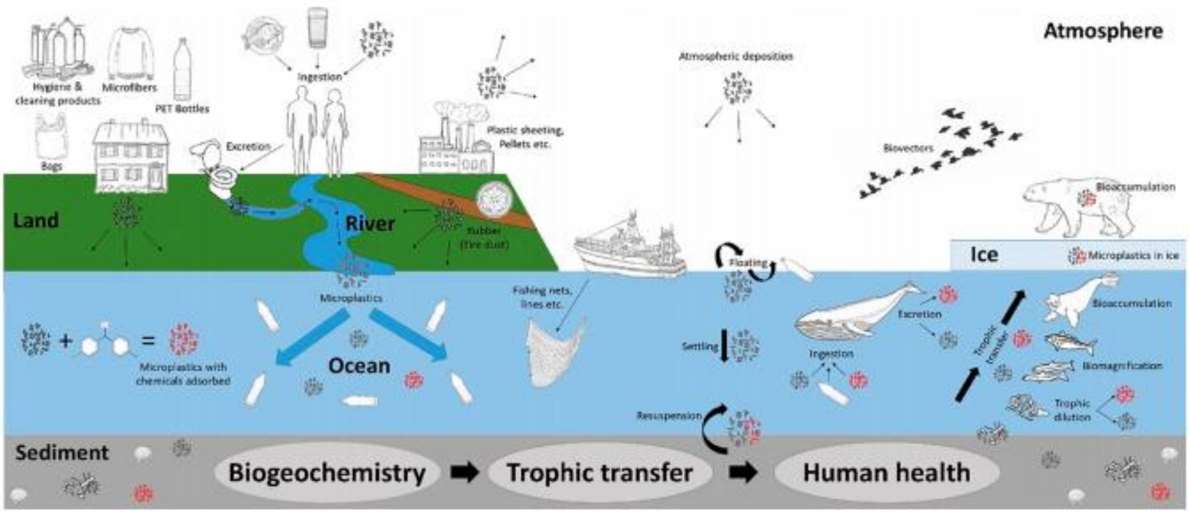


Figure 1 Model of the plastic waste loop and the relationships between human wellbeing and the environment [3]

MAIN PUBLICATIONS USED IN THE THESIS

Paper 1. "A review of the removal of microplastics in global wastewater treatment plants"[1]

Paper 2. "Removal and generation of microplastics in wastewater treatment plants: A review" [2]

Paper 3. "Effects of microplastics on wastewater and sewage sludge treatment and their removal: A review"[4]

Paper 4. "The removal of microplastics in the wastewater treatment process and their potential impact on anaerobic digestion due to pollutants association"[5]

Paper 5. "Microplastics pollution in wastewater: Characteristics, occurrence and removal technologies"[6]

Paper 6. "An assessment of microplastic inputs into the aquatic environment from wastewater streams"[7]

2. METHODOLOGY

Literature search for this thesis included Science Direct (http://www.sciencedirect.com), Web of Science (https://webofknowledge.com), Springer Link (http://link.springer.com), ACS Publications (http://pubs.acs.org), and RSC Publishing (http://pubs.rsc.org) were included throughout the literature for this study. Microplastic, drainage, wastewater treatment systems, plastic fragments, micro debris, and plastic waste were among the search terms. Also looked at the reference lists of the publications found in the literature review to see if any other findings were important.

Possible publications available until April 2020 were included in the search. According to the search results, Thompson described microplastic for the first time in Science in 2004. A study of related journals was also taken into the study. Based on their abstracts, columns, and statistics, the journals were independently analyzed to exclude obsolete documents. Six related papers on microplastics in global WWTPs were eventually considered.

Screening, grit, primary sedimentation, biological process, secondary sedimentation, and disinfection are all part of the urban wastewater treatment process. Tertiary treatment has become common in recent years as a way to improve the removal of organic matter, nitrogen, phosphorus, and emerging pollutants. Coagulation and sedimentation, filtration, activated carbon adsorption, advanced oxidation, and membrane systems are the most often used tertiary treatment methods. Each phase in the wastewater treatment process serves a certain purpose, but the removal of microplastics from wastewater is unique and new methods for assessing the removal efficiency of microplastics in WWTPs must be created.

3. HOW REALLY MICROPLASTICS AFFECT HUMAN HEALTH AND THE ENVIRONMENT

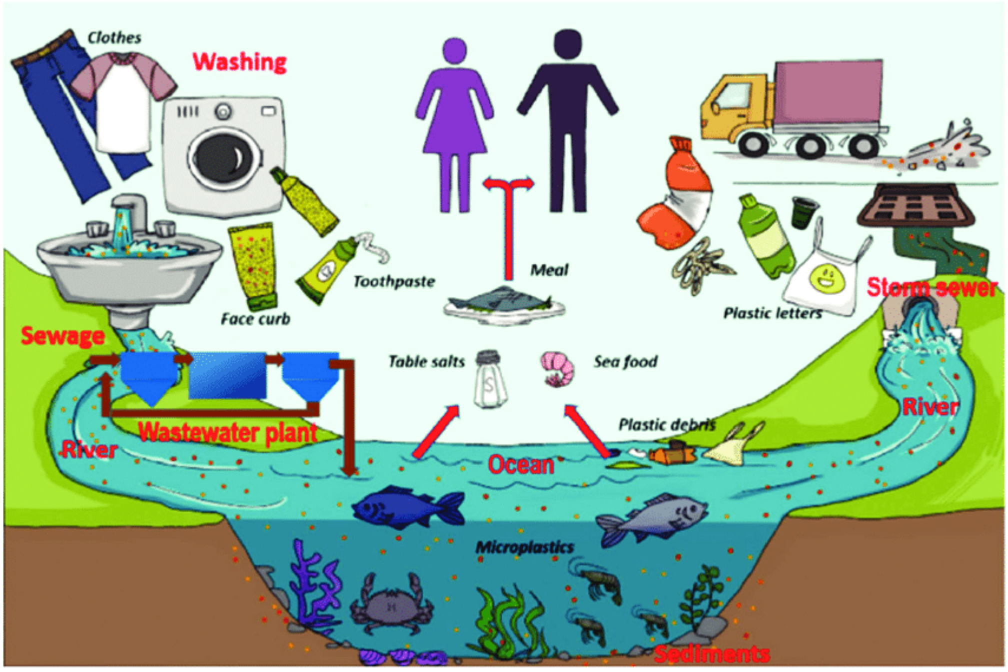


Figure 2 Microplastic pollution in aquatic environments and impacts on food chains[8]

Plastic pollution is now one of the world's most significant environmental threats, with its prevalence and consequences posing environmental, ecological, and human health risks[9]. There have been more studies on the effects of microplastics on organisms than on macroplastics, including an emphasis on marine species. Macroplastics affect large animals (e.g. large fish, reptiles, birds, and mammals), while microplastics affect smaller organisms (e.g. zooplankton, worms, coral, crustaceans, mollusks, and small fish)[10]. Microplastics, on the other hand, affect more animals in the marine world than macroplastics due to the greater species diversity of smaller organisms in aquatic environments[6].

Macroplastics have a detrimental impact on vertebrates like mammals, rodents, and water birds because they prohibit them from doing things like swimming, breathing, and feeding, as well as reducing their survival ability and inhibiting development and reproduction [11].

The effects of macroplastics on two sea turtles are accessed due to the entanglement of fishing nets and plastics, which are thrown into the water[12]. Turtles can ingest macroplastics if they misidentify the plastics with their food. Huge bits of plastic and fish net often catch and entangle them, resulting in a decrease in food intake and predator avoidance. Because of the blockage of the intestine and cloaca caused by the presence of macroplastics in animals, species experienced digestive system and obstruction injury, as well as a loss of reproductive capacity in females [13]. The mortality of marine mammals (such as the manatee) was thought to be caused by plastics clogging their digestive tracts [6].

The secondary consequences of macroplastics on large animals will be due to the leaching of chemicals such as trace metals and other chemicals (e.g. persistent organic pollutants) from the plastics into the animals' digestive tracts, causing developmental and reproductive defects. Plastics on the shore are also recognized as a cause leading to a drop in sand temperature, which has a significant impact on the sex ratios of reptiles (e.g. turtles) who laid their eggs on beaches [14].

Microplastics join the marine biota in a variety of areas, including filter-feeding, suspension-feeding, digestion of microplastic-affected prey, and direct ingestion[15]. Microplastics could be consumed by aquatic organisms such as zooplankton, whales, and water birds, and plastic fragments could be transported through trophic layers and biomagnified across the food chain [16]. Microplastics of smaller sizes are more commonly eaten by marine animals, while larger animals can ingest and accumulate more plastic in their bodies [17].

Microplastics have been present in a range of marine creatures ranging from first consumers to natural predators, including coral, polychaete worms, sea cucumbers, zooplankton, crustaceans, mollusks, whales, reptiles, water birds, and sea mammals, of which some animals are capable of excretion or egestion whereas others hold, absorb, and immobilize microplastics in their circulation[18]. Microplastic ingestion may have mechanical consequences, such as the polymer adhering to the exterior surface, obstructing movement and clogging the digestive tract, or chemical effects, such as inflammation, hepatic tension, and decreased development [19]. The three mechanisms i.e. tension of absorption (physical blockage, energy consumption for egestion), (ii) leakage of chemicals from plastic (plasticizers), and (iii) susceptibility to toxins correlated with microplastics (e.g. residual organic pollutants) seem to be linked to the possible toxicity of microplastics[20]. Plastics, on the other hand, can modify abiotic qualities in the atmosphere directly or indirectly by altering light penetration into the water column and sedimentation characteristics[21]. Plastics can produce a variety of chemicals, such as bisphenol and phthalates, which have molecular and whole-organism effects on living organisms. Furthermore, plastic particles in the marine atmosphere can be correlated with trace metals such as Cd, Cu, Ni, Pb, Zn, and Co, increasing trace metal toxicity concentrations in aquatic animals that eat the particles [22]

Microplastics have wide surface areas and are hydrophobic, enabling them to absorb chemical contaminants such as polycyclic aromatic hydrocarbons, polybrominated diphenyl ethers, and polychlorinated biphenyls [23]. As a result, plastic waste has the potential to concentrate toxic toxins a million times more than the surrounding marine ecosystem. Plastics could also function as bacterial species' substrates, making them vectors for contaminants in marine environments. Microplastics affect animals on a variety of factors, including genetic structure and composition, metabolic activities (e.g. neuro, immune response, oxidative and energy-related enzyme activity), behavioral modifications (e.g. bathing, eating, olfactory senses, inflammatory reactions, and other normal behaviors), and life history characteristics (e.g. development, survival, reproduction, size, and weight), health inhibition (e.g. malformation, diseases)[6].

Humans eat seafood items, which absorb massive quantities of MPs. According to the "FAO (2016)" index, MPs were included in 11 out of over 25 species caught in global sea fishing. According to Browne et al. (2010), the amount of microplastics consumed by species in the coastal food web was higher than those consumed by organisms in offshore ecosystems. Due to prey object similarity in size and color, MPs may be readily eaten by low trophic fauna and marine invertebrates. MPs have been detected in the stomachs of fish, in the gut of lobster, in the gastrointestinal tract, liver, and gills of in seabreams, anchovies, sardines, finfish, and shellfish, demersal, and the gastrointestinal tract of shrimp[24].

According to the literature, some of the detrimental effects of MP accumulation and ingestion in aquatic animals include lessened generative fitness, reduced predator avoidance, a ruin of feeding efficiency, the potential transfer of hazardous toxicants from seawater, and eventually death (Gregory, 2009). Blockage of the digestive system can affect the aggregation of MPs in marine invertebrates (Wright et al., 2013). In one experiment, MPs accumulated in the digestive cavity, and tubules of bivalve mollusks that ate 20 m PS microspherules survived for up to 48 hours (Browne et al., 2008). Furthermore, owing to the external adsorption of MPs, which results in the physical blockage of light and oxygen, the algal species Chlorella and Scenedesmus have been prevented from photosynthesis (Bhattacharya et al., 2010). Nonetheless, since there are no enzymatic mechanisms in animals to break down plastic polymers, this illustrates the capacity of digestion or absorption MPs[25]. Table 1 presents the occurrence of MPs in some marine organisms.

Despite the fact that scientific research shows that MPs harm the aquatic food chain, there is no evidence to suggest that microplastics harm human health. MPs, on the other hand, have been found in a wide range of human foods, including canned sardines, carp, and sprats, salt, beer, seaweed, seafood, honey, and sugar. According to Karami et al. (2018), humans eat between 1 to 5 MPs particles each year from canned fish products. According to Peixoto et al. (2019), sea salt will contain up to 19,800 MPs particles per kg in different countries. MPs ranging from 243 to 684 particles per liter were also discovered in drinking water (Eerkes-Medrano et al., 2019) [26].

Scientists, on the other hand, believe that MP absorption is proportional to their duration. Smaller particles may be readily ingested and travel rapidly from the gut cavity to the lymphatic and circulatory systems, resulting in systemic exposure (Barboza et al., 2018). Nonetheless, it should be remembered that humans have the potential to quickly approach and absorb microplastic fibers from domestic dust operations, which is greater than mussel ingestion (Catarino et al., 2018; Prata, 2018). As a result, there are many obstacles to determining the true impact of MPs on the human body [27].

Table 1 Occurrence of MPs in some marine organisms [28]

Species	MPs load	MPs size	References
Mytilus edulis	0.36 ± 0.07 MP/g.w.w	> 5μm	Van Cauwenberghe and Janssen (2014)
Mytilus edulis	0.2 ± 0.3 MP/g.w.w	> 5μm	Van Cauwenberghe et al. (2015)
Carngon crangon	0.64 ± 0.53 MP/g.w.w	> 20μm	Devriese et al. (2015)
Nephrops norvegicus	0.83 MP/organism	<5 mm	Murray and Cowie (2011)
Tigriopus japonicus	2.1 × 105 MP /mL	0.05–6μm	Lee et al. (2013)
Centropages typicus	2000 MP/mL	0.4–30.6μm	Cole et al. (2013)
Calanus helgolandicus	37.5 MP/mL	20μm	Cole et al. (2015)
Parvocalanus crassirostris	5000 MP/mL	5–10μm	Heindler et al. (2017)
Echinodermata			
Tripneustes gratilla	100 MP/mL	10–45μm	Kaposi et al. (2014)
Paracentrtus lividus	500 MP/mL	–	Martínez-Gómez et al. (2017)
Chordata			
Lepas spp	33.5% of organisms	>0.5 mm	Goldstein and Goodwin (2013)
Scomber japonicus	0.27 ± 0.63 MP/fish	0.217–4.81 m m	Neves et al. (2015)

Microplastics may also have an effect on the terrestrial environment. For example, sacred cows in India died of starvation due to a blockage in their digestive system after ingesting plastics. If there are large numbers of plastics or microplastics in the atmosphere, livestock or wild animals which succumb to the same fate, and humans may lose access to healthy and useful animal food products or ecological resources offered by these animals (e.g., vegetation management by grazing). Although microplastics are unlikely to have such negative consequences for large livestock, they may have comparable consequences for smaller species that provide ecological services, such as detritivores. Changes in land materials, such as water permeability, or populations can also have an effect on primary development, with negative consequences for the ecosystem by raising the likelihood of desertification and, as a result, jeopardizing animal and human provisioning, posing a danger to food protection. For example, little is known about the effect of typical activities on microplastic concentrations in agricultural soils, such as the application of wastewater sludge, fertilizers, or grazing, but how these could impact soil permeability, soil communities, crop production and efficiency, food protection, or lead to the pollution of surrounding water bodies. Mulch films and synthetic ropes are two other farming activities that can lead to microplastics in soils. Only a multidisciplinary team composed of agronomists, health experts, veterinarians, scientists, and environmental engineering will address these concerns.

The future impacts of microplastics on ecosystem services, which humans depend on, are much more unpredictable. Anthropogenic stressors, such as the amount of a-chlorophyll in marine environments, are believed to impair habitat productivity (Johnston et al., 2015). The aftereffects of marine synthetic debris influencing the ecosystem services are generally far expected in fisheries and aquaculture, record (Beaumont et al., 2019). So far, the impact of aquatic plastic litter on environmental resources in fisheries and aquaculture, heritage, and recreation have been predicted (Beaumont et al., 2019). Ecosystem facilities, such as the supply of clean water or climate control, are inextricably linked to human wellbeing and survival (Coutts and Hahn, 2015). Human well-being is also supported by biodiversity conservation (Naeem that is al).

Another ecosystem-wide effect of microplastics may be the modulation of microalgae ecosystems, either by reduced nutrient uptake or shifts in predator species populations, possibly threatening the viability of these organisms responsible for 50% of primary net production, water quality maintenance, and multiple biogeochemical processes and significant $O2$ production (Barbosa, 2009). Similarly, microplastics interfering with light penetration and other processes in sea ice (Geilfus et al., 2019) may have harmful consequences for the local ecosystem and global atmosphere, impacting the atmosphere, human, and animal health. Plastic debris can influence dune systems in coastal ecosystems, including the effects of plastic leachates that may modify seed germination by mimicking phytohormones, possibly affecting complex dune formation (Menicagli et al., 2019). Due to the importance of dunes in preventing coastal degradation and floods

(Hanley et al., 2014), microplastic impacts may have far-reaching effects on the geomorphology, economy, and health of these areas. Again, biologists, chemists, geologists, atmospheric scientists, and others should be involved with all of these future effects, which have not been adequately discussed so far.

Microplastic pollution is an issue that affects not only the environment but also public health and social justice. Microplastics and litter accumulation may be a result of a community's broader environmental health issues, such as a shortage of waste and wastewater disposal facilities. Waste and wastewater are possible sources of infectious diseases, which, if not properly managed, will result in epidemics and the introduction of pathogens and toxins into environments (Hamer, 2003). Plastic litter will also have unanticipated health consequences and It's been proposed that abandoned containers collecting puddles of water may be used by disease vectors to multiply (e.g., malaria mosquitoes) or clog sewage and drainage pipes, causing floods (Clapp and Swanston, 2009). Floods have significant health consequences, especially in low-income countries, where they cause psychological trauma and infectious disease outbreaks (Hajat et al., 2003). Finally, a variety of factors affect fitness, including economic factors (Oliveira et al., 2019), and can be affected by microplastics in the United States, for example, a refundable tax credit (earned income tax credit) as a means of extra income was able to increase the household's self-reported wellbeing by 6.9% to 8.9%, mostly through increased food spending and greater access to health care (Lenhart, 2019). The approximate economic costs of decreased marine resources are expected to be between $33,000 and $2500 billion per tonne of marine plastic waste in 2011(Beaumont et al., 2019). Reduced tourism as a result of plastic litter could jeopardize the survival of many populations and, as a result, their welfare (Clapp and Swanston, 2009). For example, the Azores archipelago in the North-East Atlantic lost 710,698€ (0.02% of GDP) in 2016 due to adversities caused by marine debris, such as maintenance, lost production, and clean-up efforts (Rodrguez et al., 2020). Lost funds may be reallocated to social and environmental issues such as health and sustainability by avoiding the biological and economic effects of aquatic pollution, as well as the less well-known impacts of microplastics.

4. CONVENTIONAL WASTEWATER TREATMENT PROCESS

Classical wastewater treatment systems use a mix of physical, chemical, and biological processes and operations to isolate solids, organic matter, and nutrients from wastewater[29]. If you wish to increase the care level, the words preliminary, primary, secondary, and tertiary are used to define and enhance various treatments [30].

4.1 Preliminary treatment

The purpose of preliminary treatment solutions will be the elimination of coarse solids and also other materials that are largely contained in raw wastewater [31]. Preliminary treatment removes heavy solids that could be inorganic as sand and gravel as well as metal or glass [32].

4.2 Primary treatment

Primary treatment solutions are created to eliminate organic and solids that could be inorganic concerning the physical processes of flotation and sedimentation. Approximately 25-50% regarding the incoming oxygen this is actually biochemical (BODs), 50-70% associated with total suspended solids (SS), and 65% relating to grease and oil are removed during primary treatment. Some nitrogen or phosphorus this is actually organic and heavy metals pertaining to solids tend to be detached [30].

4.3 Secondary treatment

The purpose of secondary treatment is to get rid of the others organics and suspended solids. The distribution is approximately 30% suspended, 6% colloidal, and about 65% dissolved solids in connection with measurements in connection with solids.

The primary treatment utilizes clarifiers or tanks that could be settling which eliminate the settleable organics and settleable inorganic solids through the wastewater. The effluent from primary treatment, therefore, contains mainly colloidal and dissolved organic and solids that could be inorganic. Recent standards that could be effluent water quality standards require an elevated number of elimination of organics from wastewater than may be attained by primary treatment alone. Additional elimination of organics may be attained by secondary treatment.

The secondary treatment process is manufactured out from the biological fix for wastewater by using different varieties of microorganisms in a controlled environment. Several aerobic biological processes can be employed for secondary treatment. For secondary treatment, a variety of aerobic biological mechanisms are used, with the only differences being how oxygen is delivered to the microorganisms and how quickly the organisms metabolize the organic matter.

4.4 Microplastics

Although macroplastic waste has long been a source of environmental concern, tiny plastic particles, fibers, and granules, collectively known as "microplastics," have only been considered a pollutant in their own right since the turn of the century. Microplastics have been assigned particle debris size is typically less than 5 mm[33].

4.5 Primary MPs

Primary microplastics are plastics that are designed to be microscopic in dimension. These plastics are commonly used in facial cleansers and cosmetics, as well as air-blasting media, and their use in medicine as drug vectors is becoming more common. While their inclusion in this group has been criticized, virgin plastic output pellets (typically 2–5 mm in diameter) may be considered primary microplastics within the larger-scale concepts of a microplastic (Andrady, 2011; Costa et al., 2010).

Ground almonds, oatmeal, and pumice have been replaced by microplastic "scrubbers" in exfoliating hand cleansers and face scrubs (Derraik, 2002; Fendall and Sewell, 2009). Exfoliating cleansers containing plastics have been increasingly popular after the patenting of microplastic scrubbers in cosmetics in the 1980s (Fendall and Sewell, 2009; Zitko and Hanlon, 1991). These plastics are often referred to as "micro-beads" or "micro-exfoliates," and their form, texture, and structure vary depending on the substance (Fendall and Sewell, 2009). Gregory (1996), for example, found polyethylene and polypropylene granules (five millimeters in diameter) and polystyrene spheres (two millimeters in diameter) in one cosmetic product. Fendall and Sewell (2009) recently discovered an excess of irregularly formed microplastics in another cosmetic component, usually 0.5 mm in diameter with a mode scale of 0.1 mm.

Air blasting processing has also made use of primary microplastics (Derraik, 2002; Gregory, 1996). This method entails blasting rust and paints off of vehicles, engines, and boat hulls with acrylic, melamine, or polyester microplastic scrubbers at machinery (Browne et al., 2007; Derraik, 2002; Gregory, 1996). These scrubbers are also polluted with heavy metals (e.g. Cadmium, Chromium, Lead) as they are used repeatedly until their size diminishes and their cutting ability is lost (Derraik, 2002; Gregory, 1996)[34].

4.6 Secondary Mps

Microplastic particles derived from the breakdown of larger plastic waste, both at sea and on land, are referred to as secondary microplastics (Ryan et al., 2009; Thompson et al., 2004). Plastic debris may become fragmented as a result of a combination of physical, biochemical, and chemical processes over time (Browne et al., 2007)[13].

Plastic litter on beaches, on the other hand, has high oxygen availability and intense sunlight penetration, so it can decay quickly, becoming brittle, cracking, and "yellowing" over time (Andrady, 2011; Barnes et al., 2009; Moore, 2008). These plastics are more vulnerable to fragmentation due to abrasion, wave action, and vibration as their structural integrity deteriorates. This is a continuous operation, with pieces shrinking in size until they become microplastic. While the smallest micro-particle currently found in the oceans is 1.6 ml in diameter, it is thought that microplastics can degrade further to become nano plastics. Biodegradable plastics are often seen as a potential alternative to conventional plastics. Regrettably, biodegradable plastic decomposition is just a partial decomposition: although the bio-starch plastic's components will decompose, a large number of synthetic polymers will remain (Andrady, 2011; Roy et al., 2011; Thompson et al., 2004). Decomposition periods of even the degradable components of bio-plastics would be extended in the comparatively cold marine setting, in the absence of terrestrial microbes, raising the likelihood of the plastic being fouled and, as a result, decreasing UV permeation, which is essential for the degradation process (Andrady, 2011; Moore, 2008; O'Brine and Thompson, 2010). Microplastics can be introduced into the aquatic atmosphere after the decomposition process has been completed[33].

5. LITERATURE REVIEW OF MICROPLASTICS IN WWTPs, THEIR SAMPLING, CHARACTERISATION & REMOVAL METHODOLOGIES

5.1 Sampling Method

The WWTP samples were obtained in a variety of ways, as seen in table 2. Some scientists used a pump and cascade filtration through various size sieves (Dyachenko et al., 2017; Mason et al., 2016; Mintenig et al., 2017; Talvitie et al., 2015), while others used large volume samples (Ziajahromi et al., 2017) followed by cascade filtration through 500, 190, 100, and 25 m mesh sizes (Ziajahromi Another research (Carr et al., 2016) used a very high volume filtration method, which is unusual and necessitates a very complex configuration (Paper 5).

It's worth noting that the amount of samples gathered using an autosampler and bailers is mostly reduced to a few liters, raising the question of how reflective these samples are for a wastewater treatment plant with significant diurnal and seasonal fluctuations. The collection of samples with pumps is simple and allows for the collection of large volumes needed for effluent sampling with very low MP levels.

Skimming of very huge volumes with a specialized assembly similar to those used by Carr et al. (2016) has a design drawback in that it may only be installed in an open channel that can be polluted by atmospheric deposition and thus can only capture low density floating MPs.

With the exception of Mason et al. (2016) and Talvitie et al. (2017), who both collected a 24-hour consolidated sample, the representativeness of collected samples is a concern in most of these studies. Another factor to consider is sample filtration using various mesh sizes of sieves. None of the experiments used a sieve smaller than 20 m, implying that a fraction of MPs in the 1–20 m size range was absent from these sample sets.

Table 2 Various sampling methods used for microplastic collection in wastewater treatment plants[7]

Location	Matrix	Sampling
Sweden	Water	Water was sampled using Ruttner sampler.
	Sludge	25 g wet weight
Helsinki, Finland	Water	Pumped @1 ml/min and sieved through 200, 100and 20 µm sieves.
	Sediment	Used sediment corer with 30 mm top collected
	Water	Automated sampler collected sample from 1 m depth and size fractioned with 300, 100 and 20 µm sieves. Flow was measured using flowmeter.
	Sludge	Collected using metallic beaker and stored in pre-cleaned plastic container.
Saxony, Germany	Water	390–1000 l of water was pumped and filtered through 10 µm filter.
	Sludge	500 g of wet sludge were collected using shovel from each site and stored in dark at 4 °C.
Italy	Water	30 l wastewater collected with steel bucket, sieved through 5 mm, 2 mm, and 63 µm steel sieves.
	Sludge	50 ml sample collected in glass beaker.

5.2 Sample preparation

Microplastic determination in various environmental matrixes requires careful sample planning. It's especially important in sludge samples with a lot of organic and inorganic solids. For oxidizing organic matter, most experiments used 30 percent H2O2 and the Fenton reagent. The use of 30 percent H2O2 in greater quantities and with longer exposure times is likely to impact microplastic properties (Bessa et al., 2019). The National Oceanic and Atmospheric Administration (NOAA) recommends Fenton reagents for studying microplastics because they are an effective substitute for the digestion of organic material (Masura et al., 2015). Enzymatic digestion of organic matter was used in two of the studies mentioned in Table 3 (Lares et al., 2018; Mintenig et al., 2017), and it was quite effective in eliminating carbohydrates, lipids, and protein. Some staff used harsh acid treatment and high temperatures to speed up the reaction, resulting in MP damage; additionally, Carr et al. (2016) confirmed MP melting. The majority of experiments used a saturated NaCl solution (1.2 g cm3) to separate MP by density. Polycarbonate (PC), polyurethane (PU), alkyd, polyester, polyethylene terephthalate (PET), polyoxymethylene (POM), polyvinyl alcohol (PVA), and polytetrafluoroethylene (PTFE) are unable to float, resulting in a substantial underestimation of MP concentrations. The Australian study successfully used NaI solution with a density of 1.6–1.8 g cm3 for MP density separation (Ziajahromi et al., 2017), while the German study used $ZnCl_2$ solution with a density of 2.98–3.02 g cm3 for MP density separation (Ziajahromi et al., 2017). (Mintenig et al., 2017).

Table 3 Microplastic sample processing in wastewater treatment plant[7]

Location	Sample Type	Sample Preparation
Sydney, Australia	Wastewater effluent	Sampled material rinsed with 100 to 500 ml ultrapure water. All samples were concentrated to 100 ml by drying in an oven at 90 °C. 30% H_2O_2 used to digest the organic matter at 60 °C until H_2O_2 evaporated. Density separation using NaI solution (1.49 g/ml), was centrifuged for 5 min at 3500 ×g. Buoyant particles filtered using a 25 μm stainless steel mesh. Samples were stained by Rose Bengal and dried at 60 °C for 15 min.
Helsinki, Finland	Seawater and sediments	MP extracted using density separation with NaCl solution.
	Influent, effluent	MPs picked visually by micro tweezers.
	Reject water	10 g sample mixed with 1 l tap water, and MPs picked visually by micro tweezers
	Recess + raw sludge	1 g sample mixed with 1 l tap water and MPs picked visually by micro tweezers
	Dry sludge	0.2 g sample mixed with 1l tap water and MPs picked visually by micro tweezers
Saxony, Germany	Effluent	Multistep enzymatic maceration, H_2O_2 were used for digestion of organic material, samples incubated at 70 °C for 24 h and protease added to samples incubated at 50 °C for 48 h, followed by lipase and cellulose addition and further incubation for 96 h at 50 °C. Filters rinsed with Millipore water and ethanol. Filtered samples were treated with 35% H_2O_2 and density separated using $ZnCl_2$.
	Sludge	
Italy	Influent, effluent, and sludge	Samples added to glass bottles with 500 ml NaCl solution for density separation. Samples were stirred, decanted and filtered on 8 μm cellulose nitrate membrane filters using vacuum. The sample was digested with 15% H_2O_2 for 3 days at room temperature under a laminar flow hood.
Sweden	Water	Samples filtered through 300 μm mesh under vacuum.

5.3 Microplastic in wastewater

MP in wastewater results from the use of MP-containing materials and the fragmentation of plastics. More than 30 different forms of MPs have been found in wastewater, according to reports (Sun et al., 2019). As can be shown, research on MPs in wastewater is primarily concerned with their detection, quantification, particle size, pollution, transportation, and destination in wastewater and during wastewater treatment. Plastic debris, microbeads, and microfibers were found to be the most common MPs in wastewater. The findings are consistent with previous research, which found that MPs in wastewater are mostly plastic fragments (plastic debris), MPs from personal care products (microbeads), and fibers from laundry (microfibers) (Enfrin et al., 2019; Lares et al., 2018; Rezania et al., 2018; Sun et al., 2019). In addition, when the form of MPs in wastewater is summarized, it can be shown that fragment and fiber are the most commonly encountered MPs in wastewater, followed by microbeads and film, but the foam is very rarely detected (**Figure 3a**). It's because foam is tough to rupture and usually comes in huge sizes[5].

Figure 3b summarizes the different types of MPs used in wastewater. The most often found MPs in wastewater are polyethylene terephthalate (PET), polyethylene (PE), polypropylene (PP), and polystyrene (PS). That is due to human life practices and discharge sources since these materials are mostly used and consumed in the study. When polyester (PE/PES) and polyamide (PA) are detected as MPs in wastewater, they are usually in significant quantities. They are the most important factor of textiles. As wastewater is mostly drained from homes, it contains a lot of PE/PES and PA. MPs of polyurethane (PU/PUR) are rarely found in wastewater[35]. As PU/PUR is commonly used as a raw material in foam products, it results in the result shown in **Figure 3a.**

According to the analysis report, MPs with a size less than 0.05 mm dominated, whereas MPs with a size greater than 0.1 mm were insignificant (Sun et al., 2019). However, some researchers claimed that MPs with a size greater than 0.5 mm were substantially more numerous (Lares et al., 2018). The size distribution of MPs in wastewater is influenced by the wastewater source, the local economic structure, and the lifestyle of the inhabitants. Furthermore, the sample selection techniques have an impact on the study.

In accordance with the review study, it absolutely was observed that MPs with a size significantly less than 0.05mm were dominating, and likewise the particle size significantly more than 0.1 mm has reached a small portion (Sun et al., 2019). However, some researcher stated that the MPs with size over 0.5 mm was significantly high (Lares et al., 2018). The scale distribution of MPs in wastewater relates to the wastewater source, local structure, and people movement that is living there. Moreover, the sample collection methods have an impact on the analysis as well.

Microbeads of wastewater come from personal care goods, as previously said. They are primarily made of PE and PS and vary in size from 0.1 to 0.5 mm (Hintersteiner et al., 2015). Apart from microbeads, no correlation was found between MP size and MP form or composition. According to the currently available research, various sized MPs are spread at random (Ziajahromi et al., 2017). As a result, experiments have looked at the form, composition, and size of objects, but they haven't yet narrowed down to expose the relationship between shape, size, and composition[5].

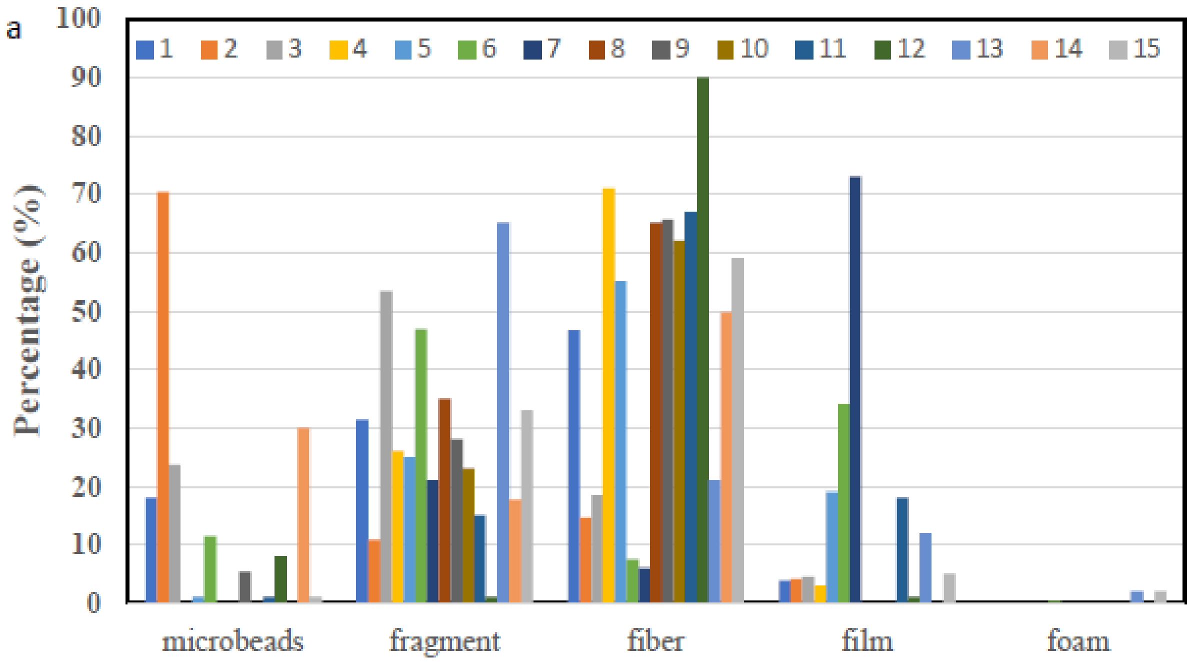


Figure 3a MPs Shapes in various treatment plants[5]

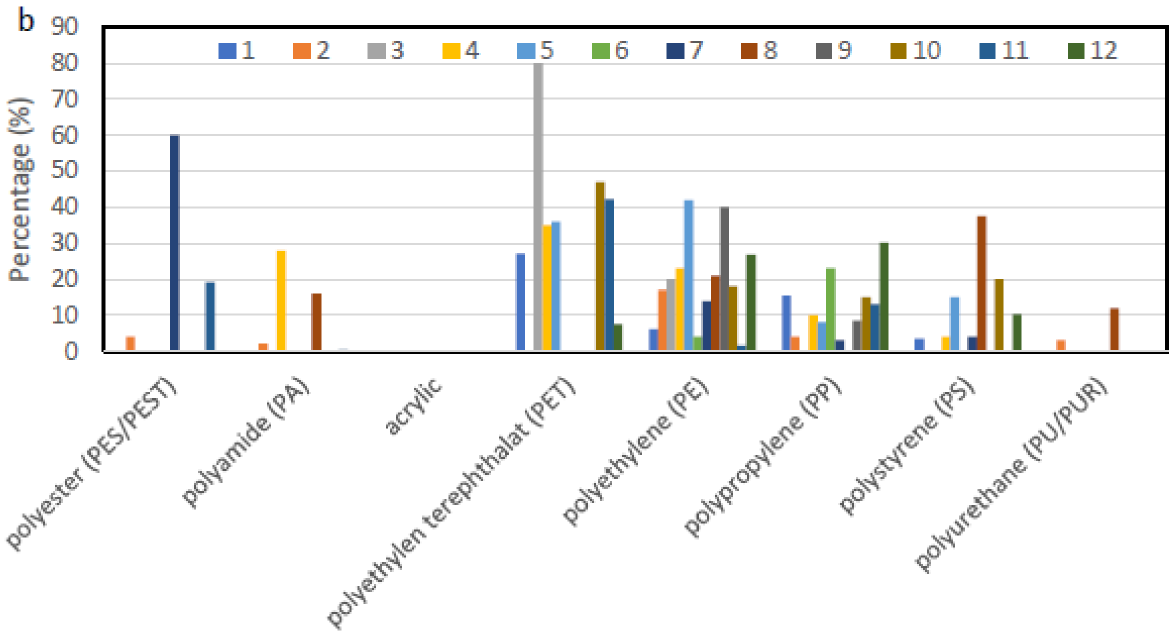


Figure 3b MPs in various treatment plants[5]

5.4 Characterisation of Microplastics in Wastewater

Table 4 Various MPs data of different location [1]

Designated Names	**Location**	**Dimensions (m3/day)**	**Residents**	**Treatment Methods**	**Source**
R1	Scotland, UK	166,422	1.8 × 105	Pri, Sec, Ter (Nitrification)	Municipal
R6	Wuhan, China	20,000	–	Pri, Sec (A2O), Ter (Chlorination)	Industrial, Agricultural, Municipal
R7(W1)	M-City, Korea	–	–	Pri, Sec (A2O)	Municipal
R7(W2)	Y-City, Korea	–	–	Sec (SBR)	Municipal
R7(W3)	S-City, Korea	–	–	Pri, Sec	Municipal
R16	Vancouver, Canada	493,271	1.3 × 106	Pri, Sec	Municipal

MPs are always present in the WWTPs due to the influent and effluent flows and vice versa. A few of the influent and effluents are shown in Table 4. The MPs in influent ranged 0.28 particle/litre to 3.14 [1]. Different WWTPs show different influent is due to the population or the area served and the difference may also be arise due to the sampling methodologies.

Any treatment plant's water contains MPs at all times. The amount of microplastic in the environment continuously reduced as the treatment progressed from primary to secondary. The first roadblock in eliminating microplastics from WWTPs was a critical treatment procedure that relied on physical processes. The most common type of primary treatment was the key settling tank. After primary care, biological treatment was the most appropriate technology in WWTPs [1]. Microplastic abundance declined further after tertiary treatment processes in most of the examined WWTPs (85.71 percent), whereas it rose in others treatment plants [1].

5.4.1 Shape and Particle Size

Microplastics are a polymer mixture that comes in a variety of shapes and sizes. Microplastics of various shapes and sizes had diverse physicochemical and toxicity properties (Lehtiniemi et al., 2018). As a result, the focus on the presence and elimination of microplastics in WWTPs of various forms, particle sizes, and polymer grades is somehow considered.

5.4.2 Shape

The outline of microplastics is an important criterion for classification. The microplastic form has an effect on their removal performance in WWTPs (McCormick et al., 2014). In the influent and effluent of the WWTPs, nine different types of microplastics were discovered. Table 5 depicts the little summary of the wide spreading of MPs shapes. The most often found microplastics in wastewater are fibers, pellets, particles, and films, with the largest abundances of 91.32 percent, 70.38 percent, 65.43 percent, and 21.36 percent, respectively [1].

Table 5 Shapes of MPs in Treatment Plants [1]

Shape	Influent (particles L^{-1})	Effluent (particles L^{-1})	Detection times
Fiber	0.22–4.60 × 103	nd-35.00	12
Fragment	0.25–3.40 × 103	nd-80.00	11
Film	0.06–1.30 × 103	nd-12.00	9
Pellet	0.01–2.21 × 104	nd-1.33 × 103	7
Foam	nd-2.33	nd	4
Particle	nd-2.91 × 102	nd-10.00	3
Ellipse	0.36	nd	1
Line	0.12	0.12	1
Flake	0.92	nd	1

In the WWTPs, the fiber, a filamentary microstructure, was the most common microplastic form. Domestic washings generated the microplastic fibers. As the amount of washing and textile consumption increased, fibers were detected more frequently (Cesa et al., 2017). Plastic packing bags became the source of microplastic films. Moreover, other shapes that could be microplastic for example foams, particles, ellipses, lines, and flakes, were also detected as soon as you go through the wastewater treatment plants.

5.4.3 Particle size

Microplastics have the potential to enter the food chain due to their particulate size, so as a result, the particle size of microplastics must be highlighted. Figure 4 depicts the MPs particle size distribution. The abundance of microplastics smaller than 1 mm in the influent ranged from 65.0–86.9% to 81.0–91.0 percent in the effluent and they can be converted to secondary MPs from primary due to the shrinkage of their sizes [1].

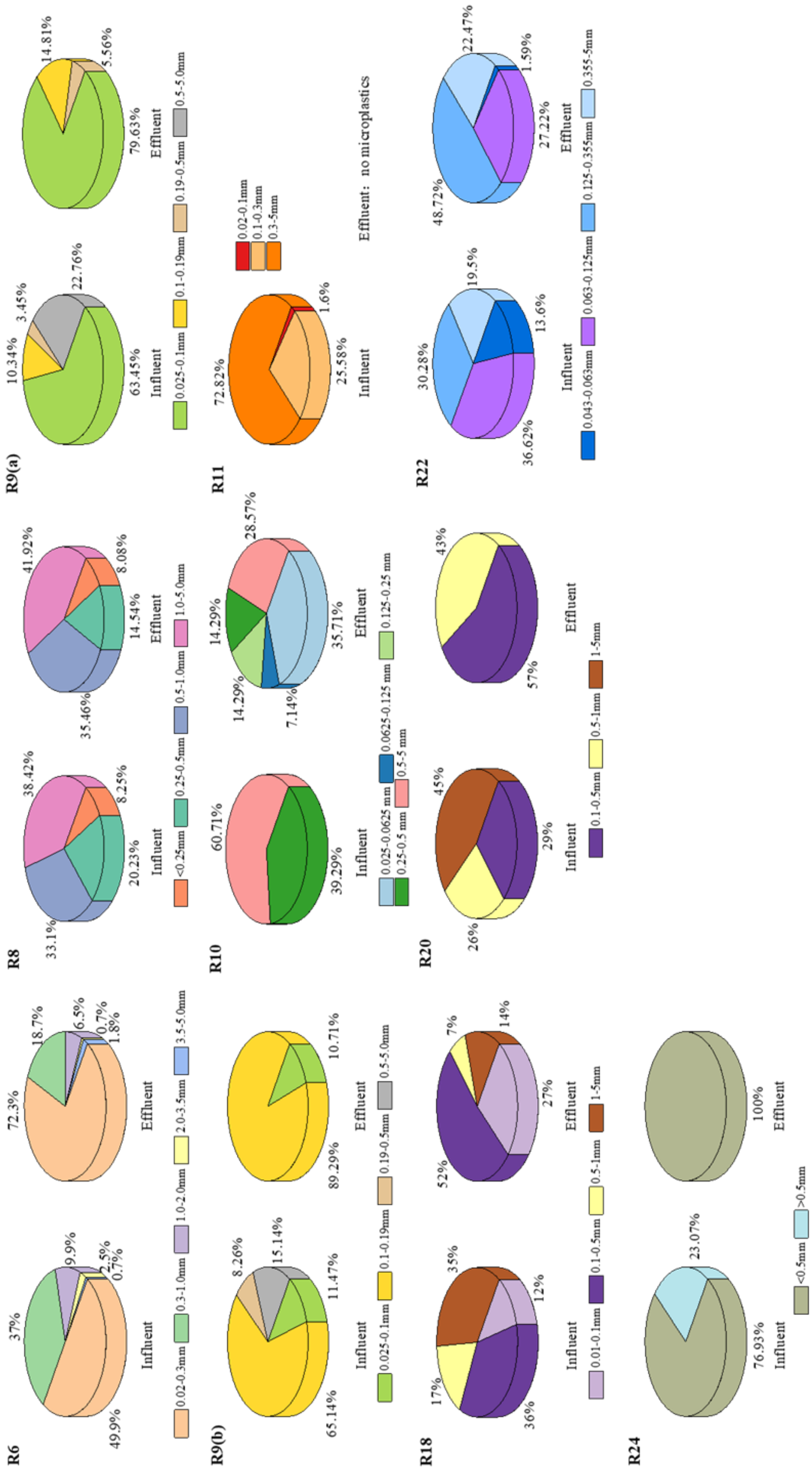


Figure 4 Distribution of Particles [1]

5.4.4 Polymer type

In this section, Table 6, shows the abundances of various microplastic polymer groups in the influent and effluent. In the influent and effluent of the WWTPs, twenty-nine different polymers were included. The top six most commonly found microplastics in wastewater were PE, PP, PA, PES, PS, and PE, with 64.07 percent, 32.92 percent, 10.34 percent, 75.36 percent, 24.17 percent, and 28.90 percent, respectively (Long et al., 2019, Mintenig et al., 2017, Talvitie et al., 2017a, Ziajahromi et al., 2017).

Table 6 The abundance of different polymer types of microplastics in WWTPs [1]

Polymer	Abbreviation	Influent (particles L−1)	Effluent (particles L−1)	Detection times
Polyethene	PE	0.03–1.05	0.00–0.67	9
Polypropylene	PP	0.02–1.42	0.00–0.22	8
Polyamide	PA	0.06–0.71	0.00–0.06	6
Polyester	PES	0.22–6.31	0.07–1.33	6
Polystyrene	PS	0.00–0.41	0.00–0.08	5
Polyethene terephthalate	PET	0.01–0.63	0.00–0.16	5
Polyurethane	PUR / PU	0.07–1.40	0.00–0.02	4
Polyvinyl chloride	PVC	0.12–1.65	0	3
Polyvinyl acetate	PVA	0.26–0.50	0.00–0.01	2

Unique polymers were discovered in the WWTPs in addition to the polymer groups described above. As a result, in addition to standard polymers, various polymer forms should be given research priority.

5.4.5 Microplastics in the sludge

The sludge contains the majority of the microplastics and the amount is higher as compared to the wastewater. Table 7 shows the rate of microplastic abundance in sludge treated with various treatment methods.

Table 7 The abundance of microplastics in the sludge of different wastewater treatment processes[1]

Location	Treatment Process	Abundance (Particles kg−1)
R6	Primary clarifier + A2O + Secondary clarifier	2.40 × 105
R7(a)	Primary settling tank + A2O + Secondary settling tank	1.49 × 104
R7(b)	SBR	9.65 × 103
R7(c)	Primary settling tank + Secondary settling tank	1.32 × 104
R16	Primary settling	1.49 × 104
R16	Secondary clarifiers	4.40 × 103

In recent years, sludge use has gained a lot of coverage. The sludge from WWTPs was mostly used for agricultural purposes in Norway (82 percent), Ireland (63 percent), the United States (55 percent), China (45 percent), and Sweden (36 percent), and it was incinerated in the Netherlands (99 percent), Korea (55 percent), and Canada (47 percent), while it was used as soil fertilizer (Figure 5) [1]. Pyroplastics are a new class of pollutants generated when microplastics are burned informally or in a controlled manner. Pyroplastics are released into the atmosphere during sludge incineration, posing significant risks (Turner et al., 2019). In China, landfills now account for 35% of the sludge from WWTPs. Microplastics are then transported into the soil and groundwater through leachate (Chen et al., 2012, Rolsky et al., 2020). Overall, soil pollution with microplastics is a little-known problem, and it's, therefore, one of the most pressing issues associated with microplastics [1].

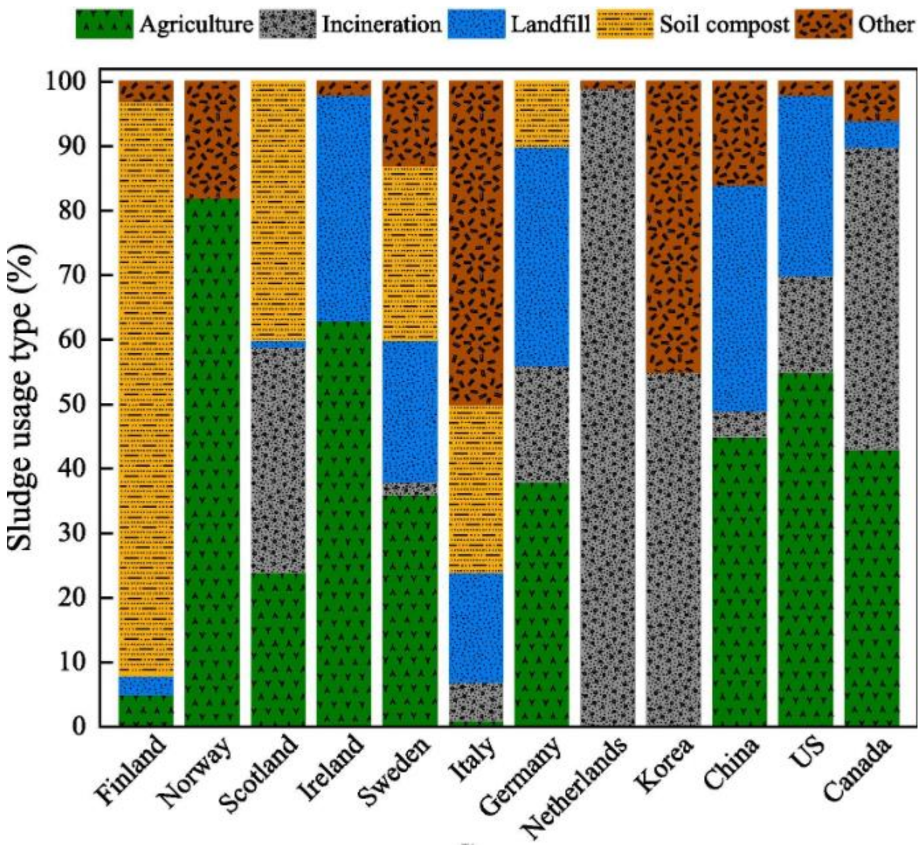


Figure 5 Ratios of various types of sludge use in 12 countries[1]

6 REMOVAL TECHNOLOGIES OF MICROPLASTICS IN WWTPs - EXAMPLES

WWTPs have been shown in recent researches to efficiently isolate MPs from sewage by main, secondary, and tertiary treatment systems. According to Talvitie et al. (2017a), the removal rate of MPs by Kenkaveronniemi WWTP (Mikkeli, Finland) was up to 99.9%, despite the fact that the removal efficiency of different WWTPs differs greatly. The removal rate of MPs by some WWTPs has been estimated to be less than 50%, as seen in **table 8**, and several reports have reported that the removal rate of MPs by WWTPs is based on the sewage treatment process used. WWTPs that use membrane bioreactor (MBR) and rapid sand filtration technologies, in general, have the highest MPs removal performance, usually exceeding 90%. (Xu et al., 2019). It's worth noting that WWTPs that use tertiary treatment processes remove more MP than those that only use primary or secondary treatment processes. This phenomenon may be attributed to the widespread use of tertiary treatment processes such as MBR, rapid sand filtration, and reverse osmosis, which essentially restricts the discharge of MPs into natural water sources by filtration. To efficiently minimize MPs discharge, a thorough understanding of the MPs removal impact and process at each WWTP level is needed.

Table 8 Influent and effluent concentrations of MPs, with the removal effectiveness of WWTPs applying different treatment processes worldwide[2]

Location	Daily processing capacity (m3/d)	Technologies	MPs removal (%)	Sampling method	Analytical method	Influent (MPs/L)	Effluent (MPs/L)
Paris, France	2.4 × 105	Sedimentation, biofilter	88.1	Autosampler	Visual	260–320	14–50
Mikkeli, Finland	1.0 × 104	Grit separation, activated sludge, membrane bioreactor	99.3	Steel bucket	Visual/FTIR/Raman	45.2–70.0	0.3–0.5
Sydney, Australia		Reverse Osmosis	98.25	Sieving	Visual/FTIR/Raman	12	0.28
Northern Italy	4.0 × 106	sedimentation, Sand filter treatment and disinfection	84	Steel bucket	Visual/FTIR/ATR	2.5	0.4
Finland	2.7 × 106	Activated sludge process, biologically active filter	99.9	Pump	Visual/FTIR	597.9–675.5	0.4–1.6

6.4 Pre-Treatment

About the fact that current WWTP processes are not intended to directly eliminate MPs, all previous experiments have shown that MP concentrations decrease dramatically after each treatment level. The majority of MPs are stated to be effectively removed from wastewater using provisional and primary treatment methods (pre-treatment). 35.1e58.6% of MPs are eliminated after provisional treatment (Michielssen et al., 2016), while 56.8e98.3% are removed during primary treatment (Michielssen et al., 2016) and can be seen in Table 9.

Table 9 The removal rates of microplastics by each specific treatment unit in sewage treatment plants in different countries worldwide [2]

	1	2	3	4	5	6	7
Location	Glasgow, Scotland, United Kingdom	Detroit, United States	Northfield, United States	Mikkeli, Finland	Sydney, Australia	Helsinki, Finland	Vancouver, Canada
Screening and grit removal	44.6	58.6	35.1				
Sedimentation	78.3	84.1	88.4	98.3	87.5		91.6
Activated sludge	98.4	93.8	89.8		96		98.4
Coagulation							
Ozone							
Discfilter						40~98.5	
Rapid sand filtration			97.2			97	
Membrane bioreactor				99.3		99.9	
Reverse Osmosis					98.3		
Dissolved air flotation						95	

Screening, grit removal, sedimentation, and flotation are all typical pre-treatment processes used in WWTPs, with main sedimentation tanks and floatation tanks being especially effective at removing MPs. Gravity has a considerable impact on MP removal during the settling period, and table 10 shows the influent abundance (Liu et al., 2021), density (Sun et al., 2019), and source (Ngo et al., 2019) of typical MPs in WWTPs. Physical sedimentation effectively removes MPs of a greater density than drainages, such as polybutylene terephthalate (PBT), polyethylene (PET), and polyvinyl chloride (PVC) from the sewage river. Low-density polyamide (PA), polyethylene (PE), and polypropylene (PP) accounted for 86.5 percent of the cumulative MPs in the influent of a sewage treatment plant in Wuhan (China) (Liu et al., 2019). High-density PET, on the other hand, accounted for 42.3 percent of the gross MPs in the influent of a sewage treatment plant in Beijing (China) (Yang et al., 2019). Despite the use of sedimentation processes at both the Wuhan and Beijing WWTPs, the removal rates of MPs after primary wastewater treatment were 40.7 percent (Liu et al., 2019) and 58.8 percent (Yang et al., 2019), respectively. Overall, after the sedimentation treatment process, the concentration of low-density MPs in wastewater increases, while the total density of MPs decreases. Air flotation technology, in comparison to sedimentation, has shown a strong removal effect for low-density MPs (such as PE and PP) and moderate-density MPs (such as PS and PA) (Ngo et al., 2019). Electro-flotation, diffuse air flotation, and dissolved air flotation are the most typical air flotation processes used in WWTPs (Rubio et al., 2002). Air flotation is a technique that uses highly scattered micro-bubbles as carriers to bind to suspended matter in wastewater, causing the suspended matter to rise to the surface against gravity and form a floating foam, separating the matter from suspension in water (Rubio et al., 2002). Figure 6 depicts a possible mechanism for MP removal via air flotation. Through electrolysis, aeration, and adjusting ambient pressure to release supersaturated air within wastewater, WWTPs produce an explosion of tiny air bubbles in wastewater. These microbubbles cling to suspended MPs in wastewater, creating a 'bubble-MPs' complex with a lower average density than water. These compounds collide with other air bubbles and suspended particles as they rise to the water level, flocculating to create a solid scum that rises to the surface, preventing MPs from suspension in wastewater. Both heavy and medium MPs may be separated using a combination of primary sedimentation and air flotation processes, resulting in successful total MP elimination. However, the occurrence of tar, grease, surfactants and other pollutants in wastewater should be closely monitored because they can change the surface physicochemical properties of MPs and thereby impair their removal performance in WWTPs.

Table 10 Common MP polymers detected in WWTPs and their corresponding densities, influent abundance and potential sources[2]

Polymer	Abbreviation	Influent abundance (%)	Density g/cm3	Sources
Polyethylene terephthalate	PET	4%–47%	0.96–1.45	Synthetic textile fibres.
Polyamide(nylon)	PA	0.5%–30%	1.02–1.16	
Polyethylene	PE	4%–64%	0.89–0.98	Personal care products (such as body and facial scrubs), food packaging films and water bottles.
Polypropylene	PP	2%–35%	0.83–0.92	Synthetic textile fibres, water pipes, food and drug packaging.
Polystyrene	PS	0.5%–24%	1.04–1.1	Disposable plastic tableware, hollow floor sound insulation material.
Polyurethane	PU/PUR	0.5%–6%	1.2	Synthetic leather, coatings, elastic fibre, shoulder pads, bra sponge, cotton pad.
Polyvinyl chloride	PVC	1%–29%	1.16–1.58	Synthetic leather, pipes, wires and cables, packaging films, foam materials.
Polycarbonate	PC	1%–1.5%	1.2–1.22	Water bottles, medicine packaging, surgical instruments

6.5 Secondary Treatment

The most commonly used biological approach for urban sewage treatment is activated sludge systems, including derived and modified processes. Enabled sludge adsorption can efficiently strip dissolved and colloidal biodegradable organic matter, as well as suspended solids, including MPs, from sewage. According to Hidayaturrahman and Lee (2019), activated sludge treatment greatly decreased the concentration of MPs in sewage after pre-treatment, with a further decrease of 18.2e27.5 percent. Extracellular polymeric substances (EPS), a central component of granular sludge, play important roles in granule structure maintenance, protection against external toxic substances, and MP elimination. Summers et al. (2018) exposed MPs to the bacterial glycoprotein EPS and discovered that due to entanglement in the EPS polymer chains, MPs formed agglomerates with the associated microbial population. EPS acts as a wetting agent, covering MPs and modifying the surface properties of hydrophobic fragments or changing the relative density of particles, causing them to be sedimented out of wastewater (Schmitt-jansen, 2017). Low

EPS concentrations (0.01e1 mg/mL) help MPs disperse by reducing their hydrophobic properties while not creating enough entanglements to allow agglomeration (Summers et al., 2018). It's worth noting that additives in plastic materials and other chemicals adsorbed in wastewater will alter the surface chemistry of MPs, impacting their agglomeration/dispersion behavior.

MPs, on the other hand, have been shown to block EPS secretion in sludge, resulting in lower levels of EPS proteins, humic acids, and fatty acids (Zhang et al., 2020). The oxygen in wastewater, in particular, interacts with a large number of active sites on the surface of MPs, producing active oxygen through disproportionation and Fenton reactions (Editor and Mossman, 2003), resulting in sludge particle degradation. Zhang et al. (2020) investigated how PET-MPs affected the exposure-response of anaerobic granular sludge. However, the PET-MP concentrations from 75 to 300 MP/L resulted in a 17.4e30.4 percent decrease in COD removal efficiency and a 17.2e28.4 percent decrease in methane yields, respectively, as well as a 119.4e227.8 percent rise in short-chain fatty acid accumulation. Polyethersulfone resin (PES)-MPs (Li et al., 2020) and polyethersulfone resin (PA)-MPs (Zhao et al., 2020) both inhibit nitrification and denitrification reactions to varying degrees, lowering bioreactor wastewater treatment performance and residual sludge output. As a result, improving MP elimination in the pre-treatment stage would greatly increase wastewater secondary treatment quality.

Fibers, particles, and films are the most typical MP forms left in the effluent after activated sludge treatment (Conley et al., 2019). Surprisingly, the activated sludge mechanism is better at removing small MPs than it is at removing larger ones. Bayo et al. (2020b) investigated a WWTP in Spain and discovered that wastewater treated by activated sludge processes had a higher concentration of MPs with particle sizes larger than 400 mm. Furthermore, an analysis conducted by Long et al. (2019) on seven secondary WWTPs in Xiamen (China) found that the MPs removal rate improved with declining particle size, with the average removal rate of large MPs (>355 mm) being just 78.5 percent, while the average removal rate of small MPs (43e63 mm) being 95.5 percent. Smaller MPs can be more readily swallowed by protozoans and metazoans and therefore entrapped in sludge flocs, but the cause of this effect is unknown. Unfortunately, small MPs have a higher potential to consume and desorb toxic chemicals due to their wide specific surface area (Song et al., 2015), resulting in increased biofilm toxicity. Exploring the combined mechanisms of action of MPs with various morphological and surface physio-chemical properties, as well as sludge flocs, is therefore critical for optimizing activated sludge processes and maximizing MP removal effects.

In addition to activated sludge, oxidation demand (OD) and anaerobic-anoxic-oxic (A2O) biological treatment systems are often commonly used in WWTPs. OD and A2O, on the other hand, have a poorer removal potential for MPs in wastewater than the activated sludge process and are more quickly influenced by MP density and morphology. For example, A2O was used as a secondary wastewater treatment process at both the Wuhan and Beijing WWTPs, with removal rates of MPs of 54.47 percent (Yang et al., 2019) and 28.1 percent (Liu et al., 2019) respectively. The physical properties of the treated MPs in these two experiments, however, were vastly different. Yang et al. (2019) found that fibrous MPs made up 85.92 percent of total MPs in a Beijing WWTP, while high-density PET and PES made up 42.25 percent and 19.09 percent of total MPs, respectively. However, according to Liu et al. (2019), the content of MP fragments in Wuhan WWTPs ranged from 33.5 percent to 56.7 percent, while fibrous MPs content ranged from 30.4 percent to 45.6 percent, and low-density PA, PE, and PP accounted for 54.8 percent, 12.5 percent, and 9.2 percent of MPs, respectively. These results indicate that the combined effects of MP density and morphology influence the removal rate of MPs by the A2O process, resulting in a higher average removal rate for fibrous MPs and high-density MPs by the A2O process. Furthermore, the MP removal rate is determined by more than just the morphology and density of MPs, according to HidayaturRahman and Lee (2019), with hydraulic retention time being another significant aspect. As a result, the short hydraulic residence periods in A2O and OD may help MPs combine with bacterial micelles or flocs in sewage, inhibiting the development of biofilms on MPs' surfaces and restricting MPs' ability to settle and accumulate in sludge.

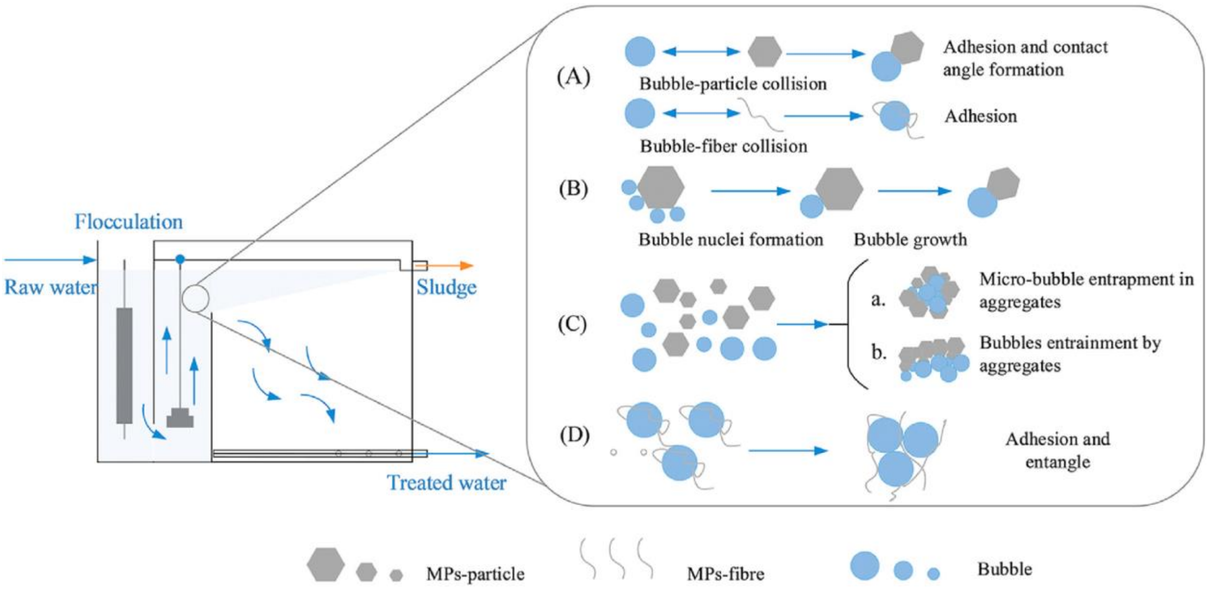


Figure 6 Rremoval of MPs by air flotation[2]

6.3 Tertiary Treatment

Tertiary treatment systems of WWTPs can be very good at removing MPs from wastewater, with studies showing that after tertiary treatment, MP concentrations of wastewater are decreased to between 0.1 percent and 7.8 percent of influent concentrations. Membrane bioreactors, rapid sand filtration, disc-filtration, and coagulation are some of the more common tertiary treatment methods, with membrane bioreactors, rapid sand filtration, disc-filtration, and coagulation being the most common. Membrane-related technologies have been found to have the best MP removal efficiency, with MPs remaining mostly in the form of microbeads and fibres in the tertiary treatment effluent (Ziajahromi et al., 2017). The smallest sizes fraction (20e190 mm) MPs were found to be the most prevalent after tertiary treatment (Ziajahromi et al., 2017). Since tertiary treatment is the last line of defence against MPs accessing natural water sources, future studies on tertiary treatment approaches should concentrate on the elimination of small MPs with structures similar to microbeads and fibres.

6.3.1 Membrane Bioreactor System

Many biofilm-based treatment types, such as the fluidized bed reactor, revolving biological contactor, and MBR systems, are gaining popularity for wastewater treatment at the moment (Yi et al., 2020). MBR, a comparatively recent treatment method that incorporates membrane isolation and biological treatment, is one of these developments (Luo et al., 2014). MBR filters have narrower pore sizes (pore sizes of 0.01e5 mm) than most widely used wastewater treatment filters, stopping most MPs from getting through (Meng et al., 2017). Lv et al. (2019) found that using MBR decreased MP concentration of wastewater treated by secondary sedimentation from 0.28 0.02 MP/L to 0.05 0.01 MP/L, essentially eliminating 82.1 percent of MPs from the secondary treatment effluent and achieving a final cumulative MP elimination rate of 99.5 percent. Lares et al. (2018) announced that MBR was used in a sewage treatment plant in Finland to extract 60.0 percent of MPs from traditional activated sludge effluent water, resulting in a total MP removal rate of 98.3 percent [2].

The vast majority of MPs are reportedly extracted through mechanical and chemical pre-treatment processes (Talvitie et al., 2017b),this are solid skimming, and sludge settling, according to most previous studies (Carr et al., 2016). However, in a study by Talvitie et al. (2017a), MBR was used directly to treat the primary effluent, with an MP removal rate of 99.9%, which was higher than most observed secondary treatment methods. As a result, as a secondary or tertiary treatment procedure, MBR could be the most effective method for removing MPs from wastewater among the common wastewater treatment technologies.

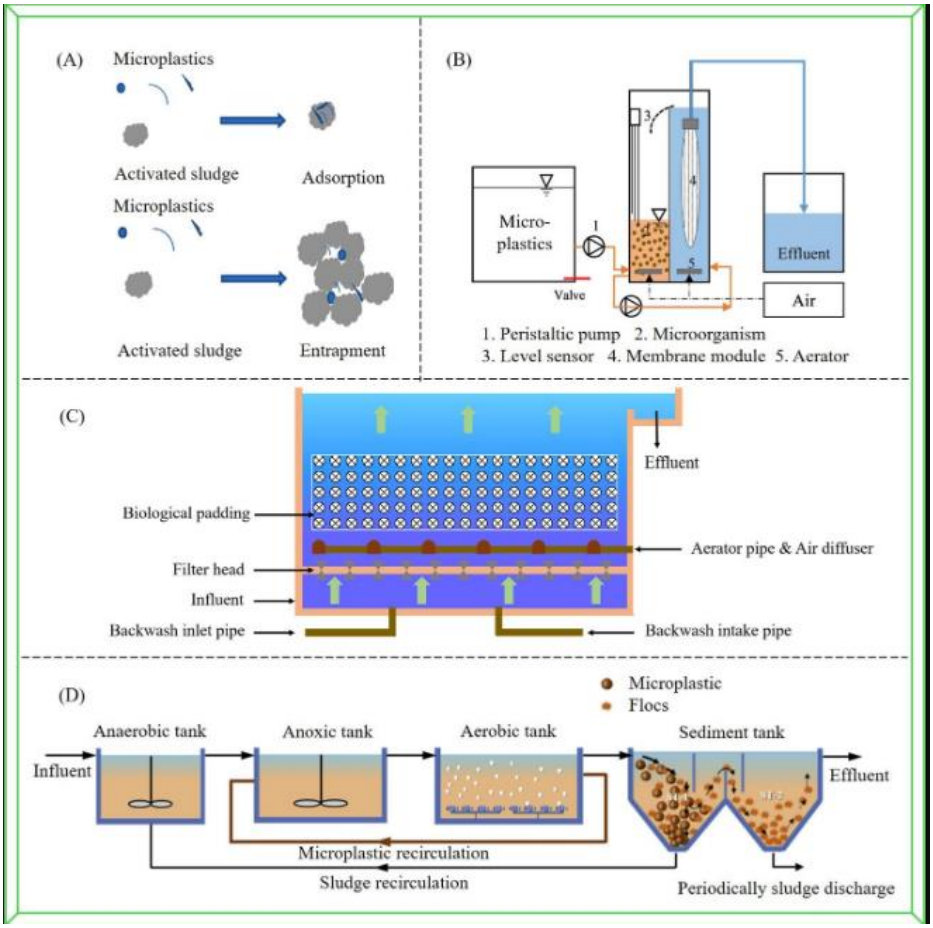


Figure 7 The bioreactor system in microplastics removal

6.3.2 Rapid sand filtration

RSF is a water treatment technology that uses natural quartz sand and anthracite as filter products, resulting in lower building, operation, and repair costs than MBR. RSF is widely used in specialized wastewater treatment to remove dissolved inorganic and organic particles, as well as plankton, bacteria, and floating or emulsified oils from water. RSF has been shown to strip 97 percent of MPs from wastewater (Talvitie et al., 2017a), with the hydrophilic interactions between MPs and sand particles (Fig. 8(a)) playing a key role. Despite the fact that the surface of the filter material in RSF is under oligotrophic conditions and is subjected to constant washing, a considerable number of microorganisms live on it

(Gülay et al., 2016). MPs can form aggregates (Fig. 8(b)) with EPS polymer glycoproteins secreted by these microorganisms, which are easily captured within the sand levels.

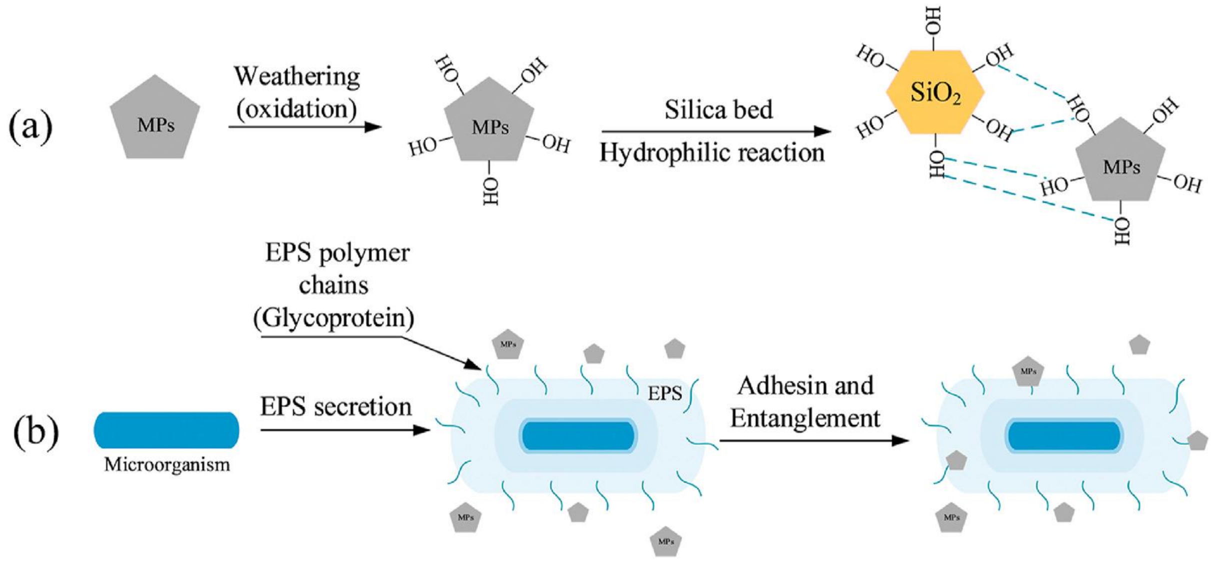


Figure 8 MP adsorption mechanisms in the rapid sand filtration process

Because of machine clogging and variations in the density, amount, and particle size of MPs in various seasons and areas, the removal rate of MPs is greatly decreased when RSF is used for a long time. Furthermore, MPs are adsorbed by silica grains by a hydrophilic relationship with hydroxyl groups on the surface of MPs, rendering reverse adsorption impossible. As a result, after a long period of activity, the adsorption sites on the surface of silica particles become saturated, and MPs in the filtered water cannot be adsorbed on the surface of silica particles by hydrophilic interactions, reducing RSF performance. Therefore, system clogging is a challenge to effective use of RSF being a final wastewater treatment method and additional researches are necessary to enhance methods to separate and heal MPs adsorbed in the area of silica particles.

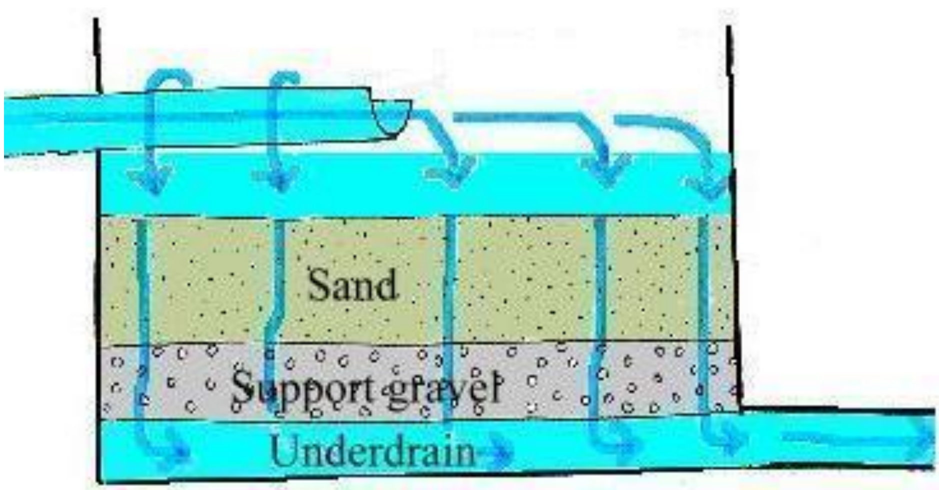


Figure 9 Rapid sand filtration[36]

6.3.3 Disc-filtration

The disc-filter (DF) method is a new form of liquid filter device that removes minor impurities from wastewater by layering several layers of alternating filter screen plates and flange rings. MP concentrations in the final effluent of WWTPs using a DF method for tertiary treatment have been confirmed to be less than 0.3 MP/L. Direct DF treatment of raw wastewater will remove MPs to the tune of 89.7%. (Simon et al., 2019). Curiously, a significant amount of MP particles with particle sizes larger than the pore size of the disk filter will stay in the effluent, meaning that these particles will bypass or move through the filter panel, decreasing the filter's efficiency and output (Simon et al., 2019). The use of DF systems reduced MP concentrations from 0.5 (0.2) MPs/L to 0.3 (0.1) MPs/L with a 10 mm pore size filter and from 2.0 (1.3) MPs/L to 0.03 (0.01) MPs/L with a 20 mm pore size filter, according to Talvitie et al. (2017a). Despite the fact that smaller pore size filters could be more effective at removing MPs, Talvitie et al. (2017a) observed that 10 mm pore size filters were less effective at removing MPs than 20 mm pore size filters, with the gap between the two classes exceeding 48.5 percent. The cause of this phenomenon is unknown. As a result, further research is needed to ascertain the impact of factors like disc filter pore size and physico-chemical MP properties on MP removal.

6.3.4 Coagulation

Coagulation is a wastewater treatment process in which colloidal compounds are dissolved, flocculated, and gradually isolated by adding a coagulant to the wastewater. Coagulation is caused by the incorporation of electrolytes, which destabilize colloidal particle agglomerates through reducing or eliminating the electromotive force of colloidal particles by compression or neutralization. Polymer materials adsorb through bridging or sediment trapping mechanisms, resulting in agglomeration of MP particles. Polymer materials adsorb through bridging or sediment trapping mechanisms, resulting in agglomeration of MP particles. According to Hidayaturrahman and Lee (2019), the efficiency of coagulation for the elimination of MPs from wastewater is between 47.1 and 81.6 percent, while Wang et al. (2020) found that the MP removal efficiency of coagulation combined with sedimentation is between 40.5 and 54.5 percent. The plastic microsphere removal effect of the coagulation process was found to be important as compared to the use of MBR, RSF, and DF systems, decreasing the concentration of plastic microspheres in secondary effluent by more than 80%. According to study, the use of aluminum salt coagulants has the best impact in promoting MP removal (Ma et al., 2019), and future research should concentrate on improving coagulants or successfully mixing coagulation with other processes to facilitate MP remova[2].

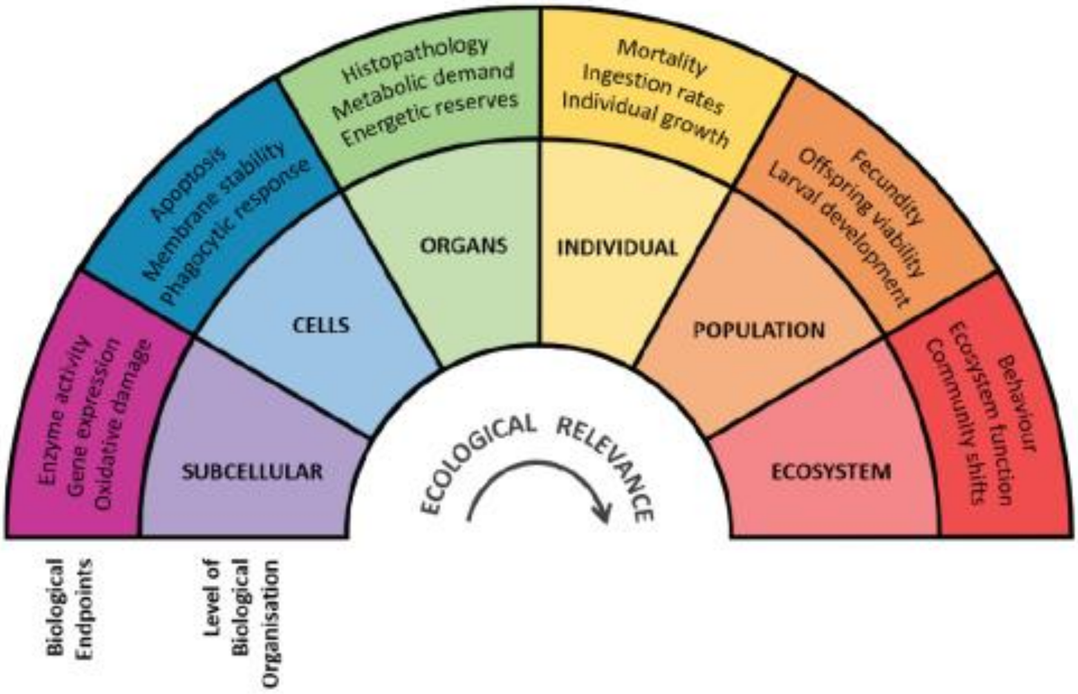
7 THE COMPLEXITIES IN MINIMIZING MICROPLASTIC CONTAMINATION

There are many obstacles to overcome in the investigation of microplastic waste control [8]. While the scientific community's interest in this topic is growing, and the number of published studies is increased but the lack of a clear understanding of what constitutes microplastic makes it difficult to compare the findings of various studies. Furthermore, the methodologies used in the experiments vary, so the findings are not always similar. One of the difficulties in preventing microplastic contamination of water sources is the absence of equipment that successfully retains this kind of substance at wastewater treatment facilities [18]. However, even though large levels of reduction were achieved, minor amounts would be dumped into water sources, continuing to affect the ecosystem. There are technologies that can efficiently eliminate microplastics during wastewater treatment, according to Beljanski et al., but they are costly, difficult to implement in current facilities, and only used where high-quality requirements are needed. Membrane bioreactors, for example, use cross-flow filtration to diffuse only water and small particles after primary and secondary application. A further disadvantage of this technology is the high electricity requirement, which results in higher operating costs. Beljanski et al. explored the construction of a low-cost, energy-efficient device with fast retro filtration in a report published in 2016. The clogging, retro filtration capability, and short-term longevity of two separate filter media were investigated[20]. Many facilities in Canada use membrane technology during the treatment process, although it is not clear if this is primarily for the removal of microplastics. Few older membrane process has showed that it can minimize the volume of MPs in the effluent water, but the high cost of implementation raises many concerns about its economic viability. Michielssen et al. compared the efficacy of various unit processes at three WWTPs in eliminating tiny anthropogenic little particles in 2016. (SAL). At the final stage, the facilities may either use secondary or tertiary treatment, in addition to membrane bioreactor device that finishes treatment with microfiltration. The membrane bioreactor plant was found to maintain a higher percentage of SAL (99.4 percent) [31].

7.1 The case for microplastic-pollution prevention

The four pillars connected with the 2018 European Plastics method (European Commission, 2018) are generally reuse and recycling, curbing waste, attaining complete circularity through development and financial investment, and motivating global activities[37]. The Strategy's microplastics activities come under the pillar of waste reduction, which specifies that targeted emission control strategies should be implemented for various sources. The Strategy recognizes that there is already a lack of information about the causes and effects of microplastic. The scientific basis of regulations relating to plastic and microplastic waste are scarce, according to Chapter 4 of the SAPEA Evidence Review Report that underpins this Opinion (SAPEA, 2019: Chapter 4). As a result, in light of current and possible future policy implementation directed at microplastics, it is worthwhile to re-examine the theoretical logic driving current and potential future policy development. Overall, SAPEA (2019) demonstrates that the current scientific understanding of microplastic waste and its consequences is a blend of consensus, disputed knowledge, educated extrapolation, speculation, and many unknowns. This represents the field's immaturity as well as its inherent uncertainty. Microplastic emission research in the psychological and behavioral sciences is also in its infancy. Since social science research is more transferable than natural science research, it includes important studies from other fields of study (SAPEA, 2019: Chapter 3). The emerging literature explains popular awareness of microplastics (SAPEA, 2019: 3.2), as well as moral opposition to microplastics, focused on indignation and anger, especially when it comes to it entering the food chain (SAPEA, 2019: 3.3). On the whole, the literature supports the need to respond, with no evidence to deniers of plastic waste (SAPEA, 2019: 3.6). Natural sciences are more sophisticated than social sciences, but they are also in their infancy. Even though important findings are emerging, they do not yet offer an accurate description of baseline microplastic stocks and flows, let alone of their impacts. The reported negative effects of acute workplace exposure to microplastics, animal studies, and what is understood about possible risks are both causes for concern and a need for further definitive studies. Some microplastics research has concentrated on determining their existence, destiny, and scale-, composition-, or concentration-dependent differences in their behavior in the setting. There is evidence of microplastic pollution's rising size and global presence, as well as its long-term existence (Barnes et al, 2009). Microplastics have also been shown to make their way into the food chain and all environmental compartments (SAPEA, 2019: Chapter 2)[38].

Many others investigated how microplastics bind with biota and other compounds in the laboratory (**see figure 10**), such as inducing discomfort in animals when consumed, carrying persistent organic contaminants (POPs), and leaching toxic additives. Biochemically, plastics are generally thought to be sterile. Synthetic polymers, on the other hand, can contain up to 4% unreacted residual monomers, as polymerization reactions are rarely complete (Matlack, 2010)[39]. Material additives and monomer precursors used in plastic manufacturing may have the highest chemical hazard rating 23 (see Lithner,



Larsson, & Dave, 2004). Catalysts and polymerization solvents, as well as a variety of chemicals (plasticisers, flame retardants, catalysts, stabilisers, pigments, and so on) that

Figure 10 Impacts of nano and microplastics on biota [28]

may move from plastics to air, water, or other touch media, like food, are all potentially dangerous components of microplastics [40].

It's vital to understand the essence of these consequences and whether there's a significant risk that they'll have a detrimental impact on biota and wildlife, as well as human wellbeing when microplastics join the body (via inhalation, food ingestion, or through the skin). This type of study, which focuses on the presence or absence of harmful effects in particular controlled situations and field trials, is becoming more common[28]. Many animals, from large mammals, birds, and fish to tiny zooplankton, eat plastic and die as a result (de Sá, Oliveira, Ribeiro, Rocha, & Futter, 2018). Microplastics have been shown in laboratory studies to have a variety of mechanical, chemical, and biological effects on biota, resulting in injury, dysfunction, and physiological disturbances. They show that inflammation and stress have negative effects on food intake, development, reproduction, and survival in a variety of species SAPEA (2019: 2.5.1). Although such effects are observed at microplastic concentrations greater than those present in nature, the latter could be overlooked in the absence of improved sampling and measurement techniques (SAPEA, 2019: 2.5.2). Many studies have been published in the literature, such as (Jovanovi et al., 2018; Rist, Carney Almroth, Hartmann, & Karlsson, 2018), demonstrating that simplistic generalizations should be avoided. SAPEA (2019: 2.5.5) also reports a number of human health conditions linked to environmental exposure to acrylic, polyester, nylon, and polyurethane dust, some of which date back to the 1970s. However, no population-based trials of human health impacts exist. As a result, what little is learned about ecological or health threats is shrouded in mystery. Environmental threats can still occur in certain marine waters and sediment locations, according to SAPEA (Bergmann et al., 2017; Fischer, Elsner, Brenke, Schwabe, & Brandt, 2015; Kanhai et al., 2019). However, the general research conclusion is that microplastic waste does not pose a significant danger at this time (SAPEA, 2019). SAPEA also concludes that, if microplastic emission is not addressed, impact concentration limits will be met in the near future, and widespread risk will emerge within a century if business as normal continues. Furthermore, scientists believe that the data requires sincere interest and vigilance. To summarize, growing empirical research on the risks of unregulated microplastic emissions, along with its long-term prevalence and irreversibility, shows that rational and proportional measures should be taken to avoid the release of microplastics into the atmosphere and their formation from a macroplastic break-up(SAPEA, 2019: 2.8). These efforts should try to: a. reduce excessive plastic use; b. restrict deliberate microplastic use; c. eliminate or attenuate microplastic formation over the life cycle of plastics and plastic-containing products; d. minimize release into the atmosphere as close to the source as possible, and e. alleviate and monitor at crucial points in waterways from source to sink[28].

7.2 European Union (EU) activity in the field of microplastics

The European Commission introduced new EU-wide regulations in 2018 to target the ten most commonly found one-time plastic-related things (goods) on Europe's beaches and seas[41]. These products together account for 70% of all aquatic debris.

The EU Plastic Strategy outlines a holistic strategy for minimizing microplastics emissions from all sources [42].

Within the European Green Deal, coping with emissions from microplastics is going to be one of the many Commission's priorities.

The Commission envisions targeted measures to reduce microplastic emissions from the use of goods like tires and textiles, as well as from primary plastic processing.

Microplastics deliberately applied to consumer or technical materials, such as cosmetics, paints, or detergents, are still under consideration by the Commission.

The recent Drinking Water Directive gives the Commission the authority to create a technique for measuring microplastics in order to add them to the watch list.

This commission will look at the possibilities to compute microplastics in the influent and effluent of wastewater treatment services and also that how eliminating the microplastics from wastewater raises the accumulation of microplastics in the sludge, as a continuation to the Evaluation of the Urban Waste Water Treatment Directive[42].

7.2.1 The Europeans Chemicals Agency proposed restrictions

In 2017, the European Commission asked European Chemicals Agency (ECHA) to examine the empirical evidence in order to take legal action on microplastics that are purposefully applied to goods at the EU level (i.e. substances and mixtures).[43]

ECHA suggested a broad ban on microplastics in goods imposed on the EU/EEA market in January 2019 in order to prevent or limit their release into the atmosphere. From March to September 2019, a public consultation on the proposed restriction was held[44]. 477 individual comments were issued by ECHA. The consultation's information, including non-confidential comments, can be found on ECHA's website.[43]

For the next 20 years, the plan is intended to prohibit the release of 500 000 tonnes of microplastics[45]

The Commission is considering other strategies for eliminating unwittingly shaped microplastics in the marine ecosystem as part of its Plastics Strategy and the current circular economy action plan[46].

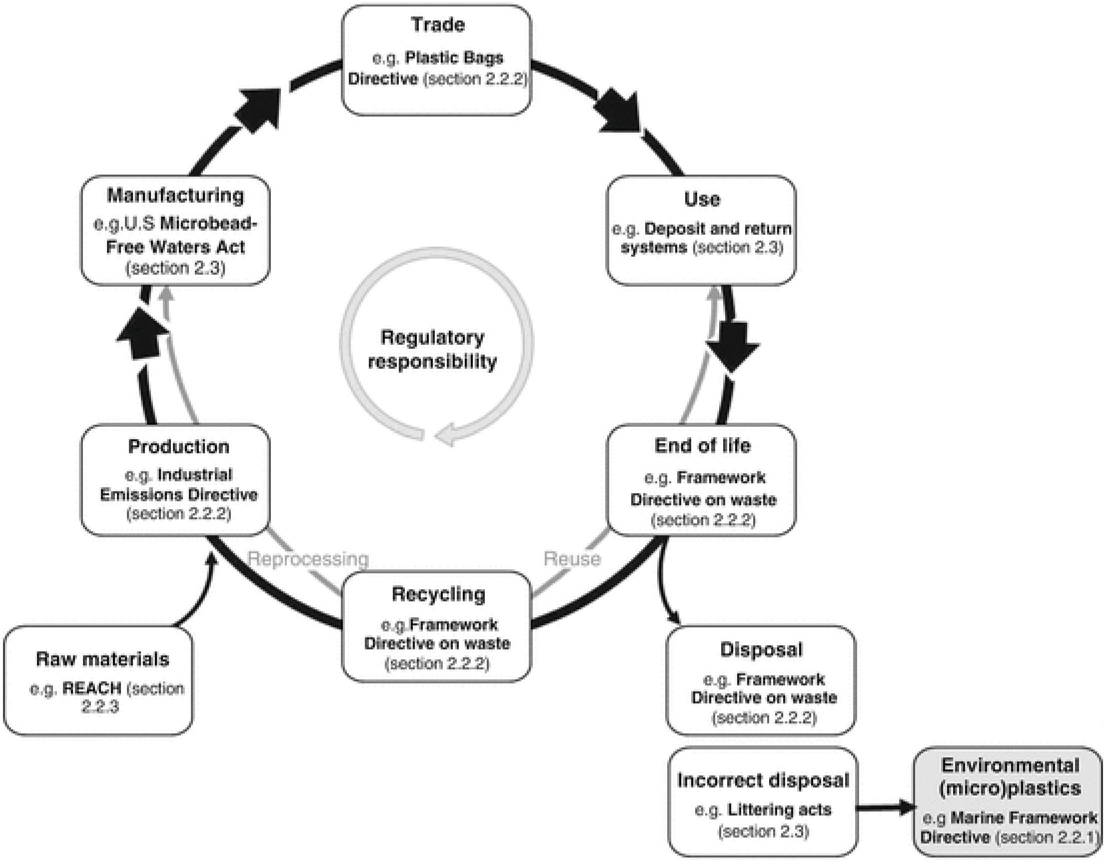


Figure 11 Main stations in the life cycle of plastic products[46]

7.2.2 ECHA Committee opinions

In June 2020, the ECHA's Risk Assessment Committee (RAC) issued its opinion. It backed the plan while proposing more rigorous conditions for derogating biodegradable polymers, as well as a moratorium on microplastics used as infill content on artificial turf fields following a six-year implementation span. The lower limit size of 100 nanometres (nm) suggested by ECHA for limiting microplastics is not appropriate for compliance, according to RAC, and no lower limit size is recommended[47].

In December 2020, the Committee for Socioeconomic Analysis (SEAC) issued its opinion. It backed ECHA's plan but offered several suggestions for the European Commission to consider during the decision-making process[48].

SEAC suggested a lower size limit for microplastics of 1 nm, among other aspects. It was also suggested that a provisional lower size limit of 100 nm be implemented to ensure that the ban can be enforced by the detection of microplastics in materials.

SEAC did not favor any of the risk management solutions suggested by ECHA over the others for controlling the release of infill content from artificial turf pitches into the environment. The committee indicated that the final decision would be based on policy goals, especially in terms of emissions reduction.

7.2.3 Decision by EU States

Following ECHA's report and the committees' joint view, the Commission is required to prepare its recommendation. The EU Member States will vote in the REACH Committee on the Commission's plan to change the list of substances prohibited under Annex XVII of REACH. The European Parliament and the Council must also approve the ban before it can be implemented [49].

8. CONCLUSION

The average MP removal rates found in the samples do not exceed the previously recorded averages of 99 percent, with some studies reporting removal rates as low as 30%. The substrate, morphology, scale, and density of MPs, as well as the wastewater treatment process used in WWTPs, all have an impact on their removal effect. There are several variations in the facility configuration and operational specifications of each WWTP for the same wastewater treatment operation, which can lead to the reported differences in removal performance.

In existing researches for these microplastics in WWTPs, particular dilemmas must certainly be fixed in future studies. The fate from the microplastics in WWTPs or some other ecological news, the additional analysis should pay attention to the rise of standard sampling and evaluation practices to raised measure. Simultaneously, an additional analysis should concentrate on the analysis of particular microplastics, specifically in manufacturing areas. The influencing facets for the treatment procedures in enabling rid of microplastics into the WWTPs also require study.

Plastics manufacturing and use are on the rise, posing increased health and environmental threats. A greater understanding of the technology to remove microplastics (MPs) is important and has been addressed in this work to some extent, in addition to the plan to minimize plastic waste and find alternative sources.

Increased amounts of microplastics have been shown to have a detrimental effect on drainage and sludge disposal. On triggered sludge flocs, microplastics have a strong inhibitory effect. Microplastics can stop methane from being produced in sludge, as well as impact key enzymes and metabolic intermediates. Microplastics often limit the complexity of biological communities as well as the abundance of important microorganisms. Microplastics' effect on wastewater and sludge disposal is complicated by the adsorption of environmental micropollutants and the exudation of additives.

9. SUMMARY

Microplastics can be found in a variety of places, from the atmosphere, soil, seas, freshwater, and also the sediment of an Arctic freshwater lake. Because of their limited volume (particle debris size is typically less than 5 mm) and large specific surface region, they can adsorb contaminants such as polycyclic aromatic hydrocarbons, heavy metals, polybrominated diphenyl ethers, pharmaceutical, and personal care materials from environmental media. Microplastics, as a result of their aggregation in cells, often cause persistent toxicity. The key beneficiaries of terrestrial microplastics before they reach natural marine environments are wastewater treatment plants, which transform primary microplastics into secondary microplastics. Microplastics found in urban wastewater are often the product of everyday human activities.

The literature search made for this review used the different databanks for the characterization and removal of microplastics from global wastewater treatment plants i.e. SpringerLink (http://link.springer.com), ACS Publications (http://pubs.acs.org), and RSC Publishing (http://pubs.rsc.org). The keywords used in the search were: microplastic, wastewater, wastewater treatment plants, plastic fragments, micro debris, and plastic waste. For sampling, characterization, and removal techniques, three different research papers were taken into account. For characterization of MPs Paper 1 is analyzed, removal of MPs Paper 2 is taken into consideration and for sampling Paper 6 is discussed.

The microplastic loads in the primary, secondary, and tertiary treatment processes and effluent are presented in Table1 from Paper 1. From primary to secondary treatment the quantity of MPs becomes less. The first obstacle to remove the MPs in WWTPs is the primary treatment methodology.

MPs have dissimilar shapes and include a suite of chemical and biological components. Microplastics can enter the human body through ingestion and inhalation where they may be taken up in several organs and might affect health, for example, through destructing cells or bringing inflammatory and immune reactions. It has been warned of MP's pervasive dissemination and the potential for negative effects on human health and the environment. MPs entered the atmosphere through a variety of pathways, including direct human dumping, the garment industry, and wastewater treatment plants. MP elimination from wastewater treatment plants has received a lot of coverage recently.

Removal of MPs in wastewater treatment plant used the same technique like it firstly it went through primary, secondary and tertiary processes and 99.9% MP removal has resulted but at some WWTPs the removal efficiency was just up to 50% as metioned in (Paper 2). In general, the majority of MPs are removed during the pre-treatment stage, with subsequent treatment processes showing relatively low MP removal rates. This lower efficiency cannot be attributed solely to poor removal effects; rather, it should be investigated whether differences in the initial concentration, or methods of sampling and identification of MPs in different treatment stages, obstruct experimental MP quantification. To mitigate or prevent the leakage of MPs into natural water sources, the MP removal processes of particular treatment units should be thoroughly investigated. MPs' form (shape), density, and scale, in addition to the effects of various treatment processes, will have an impact on their elimination. As a result, it's important to keep in mind that the existing data on MP removal rates by particle size may contain significant errors.

Frequent readings have stated that the removal rate of MPs by means of WWTPs is dependent on the sewage treatment process employed. Overall, WWTPs using membrane bioreactor (MBR) and rapid sand filtration technologies exhibit the highest MPs removal efficiency as mentioned in Paper 2. Point to be considered, that WWTPs utilizing tertiary treatment processes exhibit a higher MP removal rate than those utilizing primary or secondary treatment processes only. This sensation may be due to MBR, rapid sand filtration, and reverse osmosis processes being widely used as tertiary treatment processes, effectively restricting the discharge of MPs into natural water bodies through filtration. Consequently, an in-depth sympathetic (understanding) of the MPs removal effect and mechanism at each WWTP stage is required to effectively reduce the discharge of MPs.

10. References

[1] W. Liu *et al.*, "A review of the removal of microplastics in global wastewater treatment plants: Characteristics and mechanisms," *Environ. Int.*, vol. 146, p. 106277, 2021, doi: 10.1016/j.envint.2020.106277.

[2] Z. Xu, X. Bai, and Z. Ye, "Removal and generation of microplastics in wastewater treatment plants: A review," *J. Clean. Prod.*, vol. 291, p. 125982, 2021, doi: 10.1016/j.jclepro.2021.125982.

[3] M. S. Bank and S. V. Hansson, "The Plastic Cycle: A Novel and Holistic Paradigm for the Anthropocene," *Environ. Sci. Technol.*, vol. 53, no. 13, pp. 7177–7179, 2019, doi: 10.1021/acs.est.9b02942.

[4] Z. Zhang and Y. Chen, "Effects of microplastics on wastewater and sewage sludge treatment and their removal: A review," *Chem. Eng. J.*, vol. 382, no. July 2019, p. 122955, 2020, doi: 10.1016/j.cej.2019.122955.

[5] X. Zhang, J. Chen, and J. Li, "The removal of microplastics in the wastewater treatment process and their potential impact on anaerobic digestion due to pollutants association," *Chemosphere*, vol. 251, 2020, doi: 10.1016/j.chemosphere.2020.126360.

[6] X. T. Bui, T. D. H. Vo, P. T. Nguyen, V. T. Nguyen, T. S. Dao, and P. D. Nguyen, "Microplastics pollution in wastewater: Characteristics, occurrence and removal technologies," *Environ. Technol. Innov.*, vol. 19, p. 101013, 2020, doi: 10.1016/j.eti.2020.101013.

[7] S. Uddin, S. W. Fowler, and M. Behbehani, "An assessment of microplastic inputs into the aquatic environment from wastewater streams," *Mar. Pollut. Bull.*, vol. 160, no. June, p. 111538, 2020, doi: 10.1016/j.marpolbul.2020.111538.

[8] H. Westphalen and A. Abdelrasoul, "Challenges and Treatment of Microplastics in Water," *Water Challenges an Urban. World*, 2018, doi: 10.5772/intechopen.71494.

[9] "Plastic pollution facts and information." https://www.nationalgeographic.com/environment/article/plastic-pollution (accessed Mar. 30, 2021).

[10] J. Soares, I. Miguel, C. Venâncio, I. Lopes, and M. Oliveira, "Perspectives on micro(Nano)plastics in the marine environment: Biological and societal considerations," *Water (Switzerland)*, vol. 12, no. 11, pp. 1–16, 2020, doi: 10.3390/w12113208.

[11] "Impacts on Marine Animals | PLASTICS IN OCEANS." https://blogs.ntu.edu.sg/hp331-2015-14/impacts/impacts-on-health/ (accessed Mar. 30, 2021).

[12] F. Galgani *et al.*, "Impacts of Marine Plastic Pollution From Continental Coasts to Subtropical Gyres-Fish, Seabirds, and Other Vertebrates in the SE Pacific," *Front. Mar. Sci. | www.frontiersin.org*, vol. 1, p. 238, 2018, doi: 10.3389/fmars.2018.00238.

[13] M. Cole, P. Lindeque, C. Halsband, and T. S. Galloway, "Microplastics as contaminants in the marine environment: A review," *Marine Pollution Bulletin*, vol. 62, no. 12. pp. 2588–2597, Dec. 2011, doi: 10.1016/j.marpolbul.2011.09.025.

[14] N. Ajith, S. Arumugam, S. Parthasarathy, S. Manupoori, and S. Janakiraman, "Global distribution of microplastics and its impact on marine environment—a review," *Environmental Science and Pollution Research*, vol. 27, no. 21. Springer, pp. 25970–25986, Jul. 01, 2020, doi: 10.1007/s11356-020-09015-5.

[15] C. O. Egbeocha, S. Malek, C. U. Emenike, and P. Milow, "Feasting on microplastics: Ingestion by and effects on marine organisms," *Aquatic Biology*, vol. 27. Inter-Research, pp. 93–106, 2018, doi: 10.3354/ab00701.

[16] M. Carbery, W. Andrew O'connor, T. Palanisami, W. O'connor, and P. Thavamani, "Trophic transfer of microplastics and mixed contaminants in the marine food web and implications for human health The resilience of marine bivalves to anthropogenic change View project An understanding of biomineralisation pathways is key to predict clima," 2018, [Online]. Available: https://doi.org/10.1016/j.envint.2018.03.007.

[17] S. Sharma and S. Chatterjee, "Microplastic pollution, a threat to marine ecosystem and human health: a short review," *Environ. Sci. Pollut. Res.*, vol. 24, no. 27, pp. 21530–21547, Sep. 2017, doi: 10.1007/s11356-017-9910-8.

[18] S. Beer, A. Garm, B. Huwer, J. Dierking, and T. G. Nielsen, "No increase in marine microplastic concentration over the last three decades – A case study from the Baltic Sea," *Sci. Total Environ.*, vol. 621, pp. 1272–1279, Apr. 2018, doi: 10.1016/j.scitotenv.2017.10.101.

[19] C. Campanale, C. Massarelli, I. Savino, V. Locaputo, and V. F. Uricchio, "A detailed review study on potential effects of microplastics and additives of concern on human health," *International Journal of Environmental Research and Public Health*, vol. 17, no. 4. MDPI AG, Feb. 02, 2020, doi: 10.3390/ijerph17041212.

[20] P. S. Ross and C. Morales-Caselles, "Out of sight, but no longer out of mind: Microplastics as a global pollutant," *Integr. Environ. Assess. Manag.*, vol. 11, no. 4, pp. 721–722, Oct. 2015, doi: 10.1002/ieam.1681.

[21] G. G. N. Thushari and J. D. M. Senevirathna, "Plastic pollution in the marine environment," *Heliyon*, vol. 6, no. 8. Elsevier Ltd, p. e04709, Aug. 01, 2020, doi: 10.1016/j.heliyon.2020.e04709.

[22] A. A. Koelmans, E. Besseling, and E. M. Foekema, "Leaching of plastic additives to marine organisms," *Environ. Pollut.*, vol. 187, pp. 49–54, Apr. 2014, doi: 10.1016/j.envpol.2013.12.013.

[23] "Analysis of Nanoplastics and Microplastics in Food - Google Books." https://books.google.ee/books?id=I14JEAAAQBAJ&pg=PA190&lpg=PA190&dq=Microplastics+are+hydrophobic+and+have+large+surface+areas,+allowing+them+to+accumulate+organic+pollutants+such+as+polycyclic+aromatic+hydrocarbons,+polybrominated+diphenylethers,+polychl (accessed Mar. 30, 2021).

[24] L. G. A. Barboza, A. Dick Vethaak, B. R. B. O. Lavorante, A. K. Lundebye, and L. Guilhermino, "Marine microplastic debris: An emerging issue for food security, food safety and human health," *Marine Pollution Bulletin*, vol. 133. Elsevier Ltd, pp. 336–348, Aug. 01, 2018, doi: 10.1016/j.marpolbul.2018.05.047.

[25] S. L. Wright, R. C. Thompson, and T. S. Galloway, "The physical impacts of microplastics on marine organisms: A review," 2013, doi: 10.1016/j.envpol.2013.02.031.

[26] A. Karami, A. Golieskardi, C. K. Choo, V. Larat, S. Karbalaei, and B. Salamatinia, "Microplastic and mesoplastic contamination in canned sardines and sprats," *Sci. Total Environ.*, vol. 612, pp. 1380–1386, Jan. 2018, doi: 10.1016/j.scitotenv.2017.09.005.

[27] B. Fadeel *et al.*, "Safety Assessment of Graphene-Based Materials: Focus on Human Health and the Environment," *ACS Nano*, vol. 12, no. 11. American Chemical Society, pp. 10582–10620, Nov. 27, 2018, doi: 10.1021/acsnano.8b04758.

[28] European Commission's Group of Chief Scientific Advisors, *Environmental and Health risks of Microplastic pollution*, no. 6. 2019.

[29] "3. Wastewater treatment." http://www.fao.org/3/t0551e/t0551e05.htm (accessed May 15, 2021).

[30] "3. Wastewater treatment." http://www.fao.org/3/t0551e/t0551e05.htm

(accessed Mar. 20, 2021).

[31] "Preliminary Treatment." http://web.deu.edu.tr/atiksu/ana52/yeni001.html (accessed Mar. 23, 2021).

[32] "Preliminary Treatment." http://web.deu.edu.tr/atiksu/ana52/yeni001.html (accessed May 15, 2021).

[33] M. Cole, P. Lindeque, C. Halsband, and T. S. Galloway, "Microplastics as contaminants in the marine environment: A review," *Mar. Pollut. Bull.*, vol. 62, no. 12, pp. 2588–2597, 2011, doi: 10.1016/j.marpolbul.2011.09.025.

[34] "(PDF) Microplastics as contaminants in the marine environment: A review." https://www.researchgate.net/publication/51719107_Microplastics_as_contaminants_in_the_marine_environment_A_review (accessed Mar. 20, 2021).

[35] B. Gewert, M. M. Plassmann, and M. Macleod, "Pathways for degradation of plastic polymers floating in the marine environment," *Environmental Sciences: Processes and Impacts*, vol. 17, no. 9. Royal Society of Chemistry, pp. 1513–1521, Sep. 01, 2015, doi: 10.1039/c5em00207a.

[36] "Rapid Sand Filters | Water Treatment | Waste Water Treatment | Water Treatment Process & Plant Design." http://www.thewatertreatments.com/water-treatment-filtration/rapid-sand-filters/ (accessed May 08, 2021).

[37] European Commission, "A European Strategy for Plastics," *Eur. Com.*, no. July, p. 24, 2018, doi: 10.1021/acs.est.7b02368.

[38] Q. T. Birch, P. M. Potter, P. X. Pinto, D. D. Dionysiou, and S. R. Al-Abed, "Sources, transport, measurement and impact of nano and microplastics in urban watersheds," *Reviews in Environmental Science and Biotechnology*, vol. 19, no. 2. Springer, pp. 275–336, Jun. 01, 2020, doi: 10.1007/s11157-020-09529-x.

[39] N. Prinz and Š. Korez, "Understanding How Microplastics Affect Marine Biota on the Cellular Level Is Important for Assessing Ecosystem Function: A Review," in *YOUMARES 9 - The Oceans: Our Research, Our Future*, Springer International Publishing, 2020, pp. 101–120.

[40] H. S. Auta, C. U. Emenike, and S. H. Fauziah, "Distribution and importance of microplastics in the marine environmentA review of the sources, fate, effects, and potential solutions," *Environment International*, vol. 102. Elsevier Ltd, pp. 165–176, 2017, doi: 10.1016/j.envint.2017.02.013.

[41] P. Alexy *et al.*, "Managing the analytical challenges related to micro- and

nanoplastics in the environment and food: filling the knowledge gaps," *Food Addit. Contam. - Part A Chem. Anal. Control. Expo. Risk Assess.*, vol. 37, no. 1, pp. 1–10, Jan. 2020, doi: 10.1080/19440049.2019.1673905.

[42] "Finding the right methods for measuring microplastics in water | EU Science Hub." https://ec.europa.eu/jrc/en/news/finding-right-methods-measuring-microplastics-water (accessed Apr. 03, 2021).

[43] "Microplastics - ECHA." https://echa.europa.eu/hot-topics/microplastics (accessed Apr. 03, 2021).

[44] "Microplastics - ECHA." https://echa.europa.eu/hot-topics/microplastics (accessed May 16, 2021).

[45] "Presence of microplastics and nanoplastics in food, with particular focus on seafood," *EFSA J.*, vol. 14, no. 6, Sep. 2016, doi: 10.2903/j.efsa.2016.4501.

[46] N. Brennholt, M. Heß, and G. Reifferscheid, "Freshwater Microplastics: Challenges for Regulation and Management," in *Freshwater Microplastics : Emerging Environmental Contaminants?*, M. Wagner and S. Lambert, Eds. Cham: Springer International Publishing, 2018, pp. 239–272.

[47] "Annex to news 1 (6) Annex to a news release."

[48] P. Reach, "Annex to a news release," vol. 1, no. September, pp. 1–6, 2020.

[49] "ECHA's scientific committees support restricting PAHs in granules and mulches - All news - ECHA." https://echa.europa.eu/-/echa-s-scientific-committees-support-restricting-pahs-in-granules-and-mulches (accessed Apr. 03, 2021).