



# A Review on Microplastic- An Imposing Commination to the Aquatic Ecosystem and Its Removal Strategies in Waste Water Treatment Plants

Abdani R. Al – Rashid, Abdani D. Bandera, Louvill M. Oarraga, Buhary R. Macapanton, Alliah A. Abdullah – Pandapatan, Aleja Alyssa M. Macapodi, Jalila D. Dimapundug, and Mohammad Merhasshan G. Gubat

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Graduate Studies Department, College of Public Affairs, Mindanao State University, Marawi City, Philippines  
Email:alrashidabdani@gmail.com

## ABSTRACT

Plastic is broadly used for various human and there is an increasing concern about the risks for our surrounding environment and health. In particular, microplastics (MPs), both primary and secondary, occur in all environmental pockets and constitute a potential warning, since they easily enter into the food chain. Microplastics have the ability to absorb diverse pollutants, which thereby get accumulated inside human body via processes of bioaccumulation and biomagnification. Contamination of MPs in aquatic environment has presently been recorded as a transpiring environmental threat because of their fatalistic impact on the ecosystem. Their sources are numerous, but, undoubtedly, all are from synthetic matters. The sources of MPs are cosmetics and products of personal care, textile and tyre, abrasion processes of some other plastic products, bitumen and paints for road marking. Due to their low density and tiny particle size, MPs get easily extravasated into the wastewater drainage systems. Therefore, the municipal wastewater treatment plants (WWTPs) are designated to be the foremost recipients of MPs prior to getting excreted into the natural water reservoirs. The focus of this article is to put forward an all-inclusive review in order to preferably understand the channels of MPs into the environment, their characteristics in wastewater, and most importantly, the removal efficiency of MPs of the subsisting wastewater treatment technologies, as arrogated by the WWTPs. This review also encompasses the expansion of budding microplastics treatment technologies that have been investigated till date. Then, in the not-too-distant future, effective and standardized techniques for measuring MPs should be developed, as well as a greater understanding of sources and strategies for reducing microplastics contamination of treated effluent.

**Keywords :** Environmental Health; Plastic; Removal Efficiency; Waste Water Treatment Plants

## 1 INTRODUCTION

**C**ONTAMINATION via microplastics (MPs) in aquatic environment is an emerging environmental threat owing to the negative impact that they have on the ecosystem. Many sources of microplastics are there, but all are from synthetic components, like bitumen and road marking paints, cosmetics and personal care products, textile and tyre, abrasion or breakdown of other plastic products. Due to their small particle size and low density, they easily get discharged into wastewater drainage systems (Phuong Linh Ngoa, et al. 2019). Microplastics (MPs), the tiny plastic debris which is smaller than 5 mm in size (Eerkes-Medrano and Thompson, 2018; Lares et al., 2018; Zhang et al., 2018), have recently been documented as emerging dangerous contaminants. They are present in every type of environment worldwide from water to sediments (Van Cauwenberghe et al., 2013; Li et al., 2019), from urban to remote areas (Cole et al., 2011) and from continent to the ocean (Hirai et al., 2011; Cole et al., 2011; Jambeck et al., 2015).

Microplastic impacts have also been well identified in many environments including air (Liu et al., 2019a) soil (He et al., 2019; Li et al., 2019), ocean (Hidalgo-Ruz et al., 2012; Rochman et al., 2015; Clark et al., 2016; Hammer et al., 2016; Li, 2018) and freshwater (Lechner et al., 2014; Eerkes-Medrano et al., 2015). Microplastics can be ingested by aquatic animals which may cause choke or starvation because of pseudo satiety or physical harms such as abrasion and blockages (Clark et al., 2016). They can also poison aquatic biota by leaching out theirs contaminated monomers and toxins (Sussarellu et al., 2016). For example, MPs can transport various other toxic chemicals, namely poly-brominated diphenyl ethers, polycyclic aromatic hydrocarbons, and heavy metals which can poison aquatic species in many ways (Teuten et al., 2009; Wardrop et al., 2016; Hermabessiere et al., 2017; Li et al., 2019). The main sources of microplastic contaminants are the wastewater treatment plants (WWTPs), in aquatic environment, and an in-depth understanding of the behaviour of microplastics among the critical treatment technologies in WWTPs is urgently needed. (Weiyi Liu et al., 2021). Microplastics always cause chronic toxicity due to

their accumulation in organisms (Li et al., 2018).

WWTPs are the major recipients of terrestrial microplastics before entering natural aquatic systems (Sun et al., 2018), which convert primary microplastics into secondary microplastics. The microplastics that occur in municipal wastewater usually originate from day to day human activities. For example, polyester and polyamide components are commonly shed from clothing during the laundry process (Napper et al., 2016), and personal care products such as toothpaste, cleanser and shower gel enter WWTPs resulting from our daily use (Magni et al., 2019). Plastics in garbage are decomposed by microorganisms in the leachate and then are discharged into WWTPs (Durenkamp et al., 2016). In addition, the microplastics floating in the atmosphere, which have been emitted by plastics industries and vehicles, also converge in WWTPs via atmospheric deposition (Mintenig et al., 2017; Liu et al., 2019; Wright et al., 2020). It has been proven that untreated microplastics are commonly discharged from WWTPs, enter water bodies, and eventually accumulate in the environment (Carr et al., 2016). Therefore, it is urgent to study the performance of microplastic by different treatment technologies in WWTPs and understand the mechanism of removing microplastics to reduce the amount of microplastics entering the natural aquatic system. However, few pieces of research have been found to summarize the microplastics removal mechanisms of the critical treatment technologies in the WWTPs.

## 2 SOURCES OF MICROPLASTICS

The composition and sources of MP pollutants are different among various WWTPs due to the way they collect wastewater (Chang, 2015; Ziajahromi et al., 2017). Depending on the pattern of discharge set up, WWTPs may obtain only industrial sewage or domestic wastewater and also landfill leachate, provided distinct discharge systems have been applied. On the contrary, if integrated or intercepted discharge methods are utilized, municipal WWTPs may become recipient of contaminants coming from restricted industrial sewage, domestic wastewater, and storm water flow. However, irrespective of the type of wastewater runoff which delivers MPs, they have been categorized into two groups, namely, primary and secondary MPs.

Microbeads and resin pellets are the primary MPs which are utilised to manufacture plastic products like, cosmetics and also personal care products such as toothpaste, facial cleansers, and body washes (Eriksen et al., 2013; Chang et al., 2015; Gouvia et al., 2018; Magni et al., 2019; Saxena & Srivastava, 2022). In personal care and cosmetic products, a relevant number of plastic microbeads that are generally irregular or spherical in shape are employed for cleansing or exfoliation purposes. It is estimated that a single face wash using one of these products could release around 94,500 microbeads to drainage system (Napper et al., 2016). Road dust associated MP particles is another major source coming from bitumen, tyres, and paints for road marking which spread throughout highways and roads. Rubber particles generated during abrasion from the wear and tear of tyres and road wear are recognized as MPs (Kole et al., 2017). It is argued that tyre and road wear particles account for about 42 percent of the total MPs transported by freshwater system to the ocean (Max Siegfried et al., 2017). It has been estimated that average number of MPs liberated by ablation of tyres each year in UK, Japan and Germany is about 63 kilotons, 240 kilotons, 120 kilotons, respectively (Max Siegfried et al., 2017). Tiny MP dust particles are present in significant amount in the air pollution (Max Siegfried et al., 2017) that are washed off from atmosphere by wet denudation processes like snow, rain, and dew condensation, what are further transported to the WWTPs through storm water runoff.

The incidental MPs which are considered as dominant type in water environment are generated from the breakdown or abrasion process of other plastic products such as packaging and textiles (Sun et al., 2019). The foremost secondary origin is plastic products that are discarded in landfills under extreme environmental situation like acid pH, high salinity, physical stress, gas generation, temperature fluctuation, and decomposition of microorganism particle into smaller pieces which are then would be carried away by the discharge of leachates to enter the WWTPs (Pramila et al., 2011; Zettler et al., 2013; He et al., 2019). Fibre loss from textiles during laundering and discharged into domestic wastewater pipe systems is also considered as a secondary MP pollutant in WWTPs (Manson et al., 2016; Hernandez et al., 2017). It has been estimated that a single wash of one set of synthetic fibre clothing can release more than 1900 fibre debris (Browne et al., 2011). However, these materials were not the main contributor to pollution due to a low percentage in the detected contaminants in inland water sources (Zhang et al., 2018). They are mostly retained in the sludge of WWTPs (Manson et al., 2011; Murphy et al., 2016). However, these synthetic fibre materials may have been detected in a small percentage of the tested samples in land water sources, but the samples tested may not be a complete representation of the overall scenario of the presence of MPs from synthetic fiber materials in the waterbodies.

### *Characteristics of Microplastics in WWTP*

Lehtiniemi M. et al., (2018) Defined Micro Plastic as a kind of polymer mixture having various sizes and shapes. Various sizes and shapes of microplastics showed different toxicity and physicochemical properties.

*Shape.* It is one of the chief classification factors for microplastics. The shape of microplastics affects their removal efficiency in WWTPs (McCormick, A. et al., 2014). Total nine shapes of microplastics have been perceived in effluent and influent of WWTPs namely Fibre, fragment, film, pellet, foam particle, ellipse, line, flakes. Fibres, pellets, fragments, and films were the most widely detected microplastics in wastewater, and their highest abundances were 91.32%, 70.38%, 65.43%, and 21.36%, respectively (Hidayaturrehman et al., 2019; Lehtiniemi, M. et al., 2018; Bayo et al., 2020).

*Size.* MPs can even end up in food chain, and size of these MPs rather than shape was a crucial factor influencing their performance and transformation in the WWTPs (Lehtiniemi, M. et al., 2018). Consequently, it is crucial to accentuate particle size of MPs. The profusion of MPs smaller than 1 mm is about 65.0–86.9% in influent and about 81.0–91.0% in effluent. With decreasing microplastic sizes, the primary microplastics were crushed (physical, chemical, and biological processes) into secondary microplastics (Magni et al., 2019). Those microplastic particles which are smaller were more probable to be ingested by plankton, filter-feeding organisms, and fishes, which can cause a series of toxicological effects in these organisms (Qiao et al., 2019). Accordingly, research regarding particle size of MPs, particularly smaller particle size (<1 mm) can be of guiding consequence for successive scrutiny of biological virulence and environmental transformation of microplastics.

*Type.* Twenty-nine kinds of polymers were detected in the influent and effluent of the WWTPs. Polyethylene (PE), polyamide (PA), polypropylene (PP), polystyrene (PS), polyester (PES) and polyethylene terephthalate (PET) were the 6 most extensively detected MPs in wastewater, and their topmost abundances were 64.07%, 32.92%, 10.34%, 75.36%, 24.17%, and 28.90%, respectively (Mintenig et al., 2017; Talvitie et al., 2017a; Ziajahromi, S. et al., 2017; Long et al., 2019).

The PE, PP, and PS microplastics originated from plastic products, including food packaging bags, plastic bottles, and plastic cutlery (Mintenig et al., 2017; Talvitie et al., 2017b; Lares et al., 2018). The PA, PET, and PES microplastics mainly originated from textiles and synthetic clothing, which are the main sources of household microplastics (Hernandez E. et al., 2017; Sun et al., 2019; Wei w. et al 2019). Moreover, mechanical compressing of plastic products, textile industries, the tire and rubber molecules in road dust were also identified as potentially important sources of the PE, PP, PS and PES microplastics (Talvitie et al., 2017a; Hidayaturrahman, H. et al., 2019; Wei w. et al. 2019). Additionally, polymer kinds mentioned above, distinct polymers also were recognized in WWTPs. For example, alkyds, which are widely used in industrial coatings, exhibited the highest abundance in a Glasgow WWTP (28.67%) (Murphy F et al., 2016). Therefore, research priority should be assigned to specific polymer types in addition to common polymers.

### 3 RISKS OF MICROPLASTICS

#### *Microplastics and their Chemical Components*

The constituents of MPs, like additives and monomers, may get released in course of usage and disposal of product, and some of these substances may be hazardous to the environment. Monomers are the basic units of plastic polymers, and the backbone structure derived from them is considered biochemically inert due to its large molecular size (Teuten et al., 2009).

However, studies have shown that some monomers have harmful effects. Lither et al. (2011) classified polymers depending on monomer threat categorizations and observed that the styrene monomer producing polystyrene possesses carcinogenic or mutagenic risk, so polystyrene is ranked as one of the most hazardous polymers and has been listed as a toxic substance by the US Environmental Protection Agency (Lithner, et al., 2011). Besides monomers, health hazards associated with additives must not be ignored. Some common plastic supplements include flame retardants, plasticizers, UV stabilizers and antioxidants. Many of these are recognized as hazardous, inclusive of brominated flame inhibitors (e.g., poly-brominated diphenyl ethers or PBDEs), lead heat stabilizers, and phthalate plasticizers (Halden, R.U., 2010; Lithner, et al., 2011). Bisphenol A, which is used in the production of polycarbonate, has endocrine-disrupting effects that can adversely affect human health (Halden, 2010). As a result, MPs and their chemical constituents pose health hazards.

#### *Effects of Microplastics on Marine Organisms*

Ingestion is the highest frequent interconnection between microplastics and marine organisms. It has been evaluated that about 690 species were contrived by marine plastic pollution in 2015, and at least 10% of those species had ingested microplastics (Gall et al., 2015). Moore observed that organisms might mistake microplastics for prey and ingest them directly. Moreover, plastic debris or microplastics have been identified in the guts or tissues of many marine organisms, including fish (Lusher, A. et al, 2013a; Neves D. et al., 2015), bivalves (Van Cauwenberghe et al., 2014), zooplankton (Frias, J. et al., 2014; Desforges et al., 2015), seabirds (Blight et al., 1997), turtles (Bugoni L et al., 2001), and whales (De Stephanis, R. et al., 2013). Ingestion of MPs by several aquatic organisms (bivalves, zooplankton, and fish) have been reported in the natural environment. The uptake of microplastics by marine organisms shows that the potential for physical and toxicological harm is an emerging topic. In terms of physical harm, plastic debris has direct mechanical effects on marine organisms through entanglement and ingestion (Derraik J.G. 2002). Specifically, plastic debris (mainly synthetic fibres) swallowed by marine organisms can lead to intestinal blockage, while hard microplastics with irregular shapes and sharp edges can penetrate the intestinal wall and damage the digestive system. All of these effects can reduce food intake, ultimately leading to starvation and death (Wright et al, 2013; Duis et al., 2016).

#### *Microplastic Removal Efficiency in Existing WWTPs*

Nonetheless, since MPs are a transpiring category of pollutants present in wastewater, currently, there are no WWTP dedicated to eradicate them. As for example, post preliminary, primary, secondary, then tertiary treatment procedures in UK, in a WWTP, the comprehensive

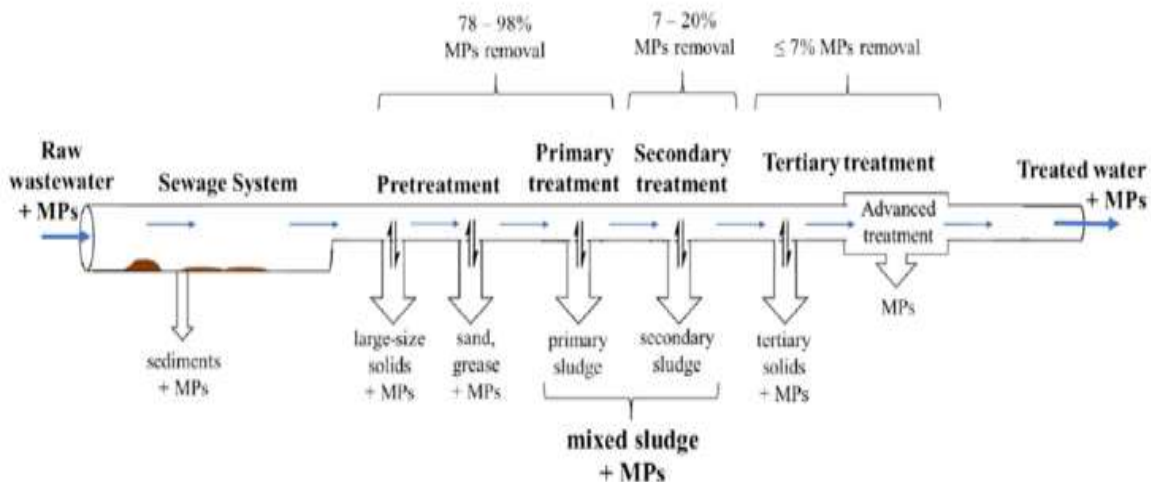
profusion got decreased by 6%, 68%, 92% and 96%, respectively (Blair et al., 2019). As a consequence, the removal rate of the contaminants in WWTPs is not efficient enough to prevent the MPs pollution of natural aquatic ecosystem and attained coherence of MP elution of each WWTP varies from around 60% to 99.9% worldwide, depending upon registered mechanics. WWTPs can remove overall 65% of MP in the wastewater influent such as WWTP in Wuhan, China (64.4%) (Liu X et al., 2019b) And in Sydney, Australia (66%) (Ziajahromi, et al., 2017). Whereas WWTP in Vancouver, Canada can reach to 91.7% (Gies et al., 2018) and with tertiary advanced treatment processes, WWTP in Finland can achieve 99.9% MP removal (Talvitie et al, 2017a).

*Primary Sedimentation and Floatation*

Primary as well as secondary treatment phases in sedimentation method brought a noteworthy contribution to MP eradication. Usually, sedimentation is a technique that extracts suspended solid fragments from liquid stream via gravitational settling, an indispensable ingredient in WWTP (Cheremisinoff, 2002). This technique may be applied for wastewater treatment procedure as either primary or secondary method, or also both. Besides showing a substantial effect in decreasing contaminants, it also imparts an optimal state for following methodologies like filtration, biological equipment, and disinfection due to an increased capacity of suspended material extraction. Analogously, air floatation technique is one of the favoured methods for removal of solids, fibrous material and oil. This technique is the outcome of air bubbles of microscopic range that enhance the natural proclivity of contaminants to float on the surface before being collected by mechanical skimming (Cheremisinoff, 2002). The air floatation procedure can extract grease, solid particles and oil, about up to 99%, hence, it has been one of the pivotal steps in domestic sewage, food processing and laundry wastewater treatments (Cheremisinoff, 2002).

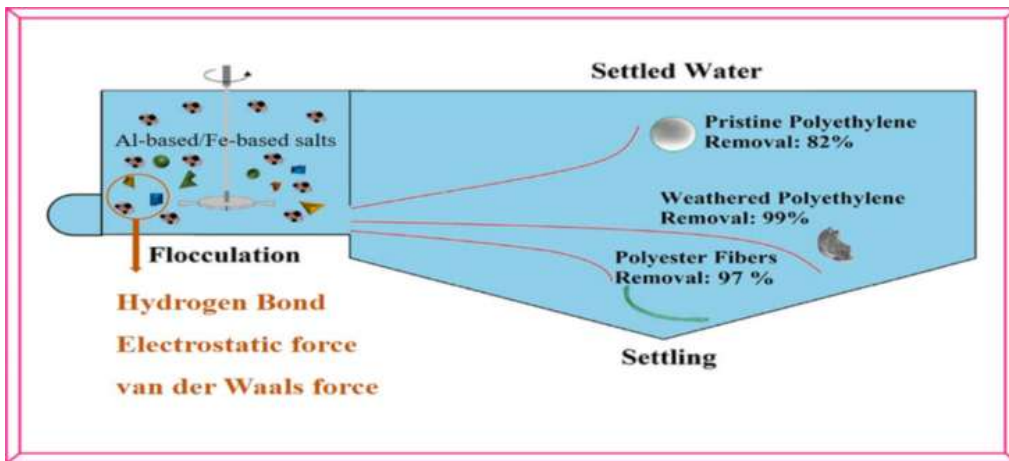
*Activated Sludge and Sedimentation*

Initialized sludge is a favoured technology pertained in municipal WWTPs post or aerated grit bower, sedimentation tank or diffused air flotation. In the aerobic panzer, sludge floccules or extracellular polymers of bacteria during the growth stage are competent of fostering the accumulation of the MP contaminants in sewage which then would get eliminated in the sedimentation process. The plastic debris may also be held into sludge flocs by the ingestion of microorganisms (Scherer et al 2018). Nevertheless, there is uncertainty yet regarding how exactly plastic debris associate with microorganisms and to what magnitude the procedure could pin down MPs. Ziajahromi et al. (2017) encountered the MP removal grade of activated sludge about at 66.7%, whereas A2O which is the combination of anaerobic, anoxic and aerobic (activated sludge) eliminated only 28.1% in WWTP in Wuhan, China (Rummel et al., 2017) and 54.47% in WWTP in Beijing, China (Yang, L. et al 2019). The outcomes from these reports manifested an unsteady MP rate of removal of this technology. The influencing factors that could affect the MP removal rate of the activated sludge process are the retention time (Carr et al., 2016) and nutrient level in wastewater (Rummel et al., 2017). Longer the contact period, higher are the probabilities of surface biofilm overlay on plastic debris that modifies the surface, size and relative densities of the contaminants (Carr et al., 2016). These changes may cause a noteworthy impact on the nonchalantly buoyant MPs to escalate the probability for extracting them by settling or skimming techniques, which then upgrade the removal frequency of the technique. Hence, the contact time and nutrient level in sewage need further investigation to enhance the MP removal efficiency of the technology.



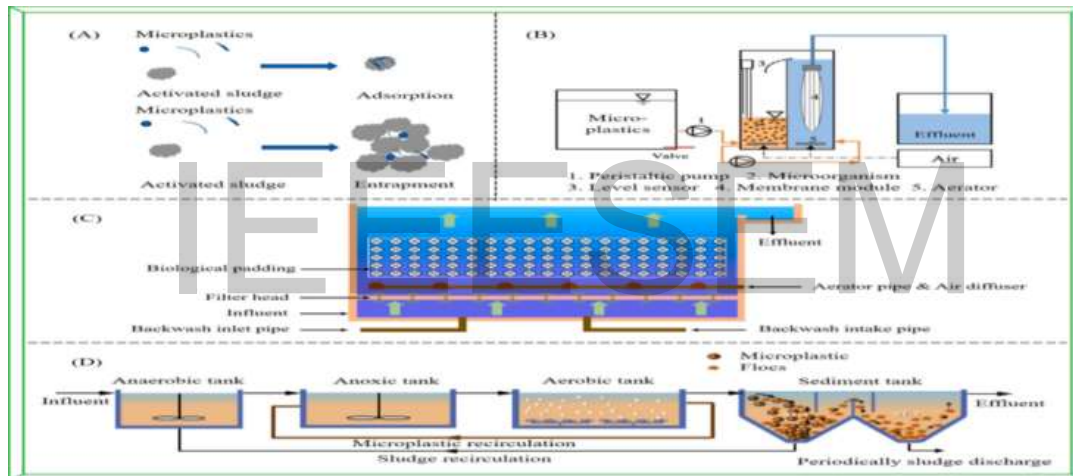
**Figure 1:**

A Schematic Representation of WWTP processes and percentages of MPs removal during processing (Paula Masia et al., 2020)



**Figure 2:**

The schematics of primary settling with flocculation technologies in microplastics removal (Lapointe et al., 2020)



**Figure 3:**

The schematics of the bioreactor system in microplastics removal. (a) Activated sludge process (Zhang, et al., 2020); (b) MBR (Li et al., 2018); (c) Biofilter; (d) A2O (Liu et al., 2020)

#### 4 CONCLUSION

Microplastic-directed treatment methodologies are incessantly needed in order to avoid discharge into soil and aquatic environments. The potential effect of successive exertion of sludge on soil habitats should be scrutinized in future. Currently, no standard protocol or international rules for monitoring MPs in treated wastewater are available for professionals to follow, making it difficult to compare results. Concurrently, further study should highlight the inquiry of specific MPs, particularly those in industrial areas. The regulating components of ministrations in eliminating MPs in WWTPs also needs in-depth study, like salinity, hydraulic retention time, and dissolved organic matter.

#### REFERENCES

- [1] Bayo, J., Olmos, S., L'opez-Castellanos, J., (2020). Microplastics in an urban wastewater treatment plant: The influence of physicochemical parameters and environmental factors. *Chemosphere*, 238, 124593. <https://doi.org/10.1016/j.chemosphere.2019.124593>.
- [2] Blair, R.M., Waldron, S., Gauchotte-Lindsay, C., (2019). Average daily flow of microplastics through a tertiary wastewater treatment plant

- over a ten-month period. *Water Research*, 163. <https://doi.org/10.1016/j.watres.2019.114909>.
- [3] Blight, L.K., Burger, A.E., (1997). Occurrence of plastic particles in seabirds from the eastern North Pacific. *Marine Pollution Bulletin*, 34, 323-325. [https://doi.org/10.1016/S0025-326X\(96\)00095-1](https://doi.org/10.1016/S0025-326X(96)00095-1)
- [4] Browne, M.A., Crump, P., Niven, S.J., Teuten, E., Tonkin, A., Galloway, T., Thompson, R. (2011). Accumulation of microplastic on shorelines worldwide: sources and sinks. *Environmental Science and Technology*, 45, 9175-9179. <https://doi.org/10.1021/es201811s>
- [5] Bugoni, L., Krause, L.g., Petry, M.V.n., (2001). Marine debris and human impacts on sea turtles in southern Brazil. *Marine Pollution Bulletin*, 607 42, 1330-1334. [https://doi.org/10.1016/S0025-326X\(01\)00147-3](https://doi.org/10.1016/S0025-326X(01)00147-3)
- [6] Carr, S.A., Liu, J., Tesoro, A.G., (2016). Transport and fate of microplastic particles in wastewater treatment plants. *Water Research*, 91, 174-182. <https://doi.org/10.1016/j.watres.2016.01.002>.
- [7] Chang, M., (2015). Reducing microplastics from facial exfoliating cleansers in wastewater through treatment versus consumer product decisions. *Marine Pollution Bulletin*, 101, 330-333. <https://doi.org/10.1016/j.marpolbul.2015.10.074>
- [8] Cheremisinoff, N.P. (2002). Sedimentation, clarification, flotation, and coalescence, in NP Cheremisinoff (ed.), *Handbook of Water and Wastewater Treatment Technologies*, Butterworth-Heinemann, Woburn, 268-334. <https://doi.org/10.1016/B978-075067498-0/50011-5>.
- [9] Clark, J.R., Cole, M., Lindeque, P.K., Fileman, E., Blackford, J., Lewis, C., Lenton, T.M., Galloway, T.S., (2016). Marine microplastic debris: a targeted plan for understanding and quantifying interactions with marine life. *Frontiers in Ecology and the Environment*, 14, 317-324. <https://doi.org/10.1002/fee.1297>
- [10] Cole, M., Lindeque, P., Halsband, C., Galloway, T.S. (2011). Microplastics as contaminants in the marine environment: a review. *Marine Pollution Bulletin*, 62, 2588-2597. <https://doi.org/10.1016/j.marpolbul.2011.09.025>
- [11] De Stephanis, R., Giménez, J., Carpinelli, E., Gutierrez-Exposito, C., Cañadas, A., (2013). As main meal for sperm whales: Plastics debris. *Maine Pollution Bulletin*, 69, 206-214. <https://doi.org/10.1016/j.marpolbul.2013.01.033>
- [12] Derraik, J.G., (2002). The pollution of the marine environment by plastic debris: a review. *Marine Pollution Bulletin* 44, 842-852. [https://doi.org/10.1016/S0025-326X\(02\)00220-5](https://doi.org/10.1016/S0025-326X(02)00220-5)
- [13] Desforges, J.-P.W., Galbraith, M., Ross, P.S., (2015). Ingestion of microplastics by zooplankton in the Northeast Pacific Ocean. *Archive of Environmental Contamination and Toxicology*, 69, 320-330. <https://doi.org/10.1007/s00244-015-0172-5>.
- [14] Duis, K., Coors, A., (2016). Microplastics in the aquatic and terrestrial environment: sources (with a specific focus on personal care products), fate and effects. *Environmental Sciences Europe*, 28, 2. <https://doi.org/10.1186/s12302-015-0069-y>
- [15] Durenkamp, M., Pawlett, M., Ritz, K., Harris, J.A., Neal, A.L., McGrath, S.P., (2016). Nanoparticles within WWTP sludges have minimal impact on leachate quality and soil microbial community structure and function. *Environmental Pollution*, 211, 399-405. <https://doi.org/10.1016/j.envpol.2015.12.063>.
- [16] Dyachenko, A., Mitchell, J., Arsem, N., (2017). Extraction and identification of microplastic particles from secondary wastewater treatment plant (WWTP) effluent. *Analytical Methods*, 9, 1412-1418. <https://doi.org/10.1039/C6AY02397E>
- [17] Eerkes-Medrano, D., and Thompson, R., (2018). Occurrence, fate, and effect of microplastics in freshwater systems'. *Microplastic Contamination in Aquatic Environments*, 95-132. <https://doi.org/10.1016/B978-0-12-813747-5.00004-7>.
- [18] Eriksen, M., Mason, S., Wilson, S., Box, C., Zellers, A., Edwards, W., Farley, H., Amato, S., (2013). Microplastic pollution in the surface waters of the Laurentian Great Lakes. *Marine Pollution Bulletin* 77, 177-182. <https://doi.org/10.1016/j.marpolbul.2013.10.007>
- [19] Frias, J., Otero, V., Sobral, P., (2014). Evidence of microplastics in samples of zooplankton from Portuguese coastal waters. *Marine Environmental Research*, 95, 89-95. <https://doi.org/10.1016/j.marenvres.2014.01.001>
- [20] Gall, S.C., Thompson, R.C., (2015). The impact of debris on marine life. *Marine Pollution Bulletin*, 92, 170-179. <https://doi.org/10.1016/j.marpolbul.2014.12.041>
- [21] Gies, E.A., LeNoble, J.L., Noël, M., Etemadifar, A., Bishay, F., Hall, E.R., Ross, P.S., (2018). Retention of microplastics in a major

- secondary wastewater treatment plant in Vancouver, Canada. *Marine Pollution Bulletin*, 133, 553-561  
<https://doi.org/10.1016/j.marpolbul.2018.06.006>
- [22] Gouveia, R., Antunes, J., Sobral, P., Amaral, L., (2018). Microplastics from wastewater treatment plants- preliminary data. *Proceedings of the International Conference on Microplastic Pollution in the Mediterranean Sea*, 53-57. [https://doi.org/10.1007/978-3-319-71279-6\\_8](https://doi.org/10.1007/978-3-319-71279-6_8)
- [23] Halden, R.U., (2010). Plastics and health risks. *Annual Review of Public Health*, 31, 179-194.  
<https://doi.org/10.1146/annurev.publhealth.012809.103714>
- [24] Hammer, S., Nager, R., Johnson, P., Furness, R., Provencher, J., (2016). Plastic debris in great skua (*Stercorarius skua*) pellets corresponds to seabird prey species. *Marine Pollution Bulletin*, 103, 206-210. <https://doi.org/10.1016/j.marpolbul.2015.12.018>
- [25] He, P., Chen, L., Shao, L., Zhang, H., Lü, F., (2019). Municipal solid waste (MSW) landfill: A source of microplastics?-Evidence of microplastics in landfill leachate. *Water Research*, 159, 38-45. <https://doi.org/10.1016/j.watres.2019.04.060>
- [26] Hermabessiere, L., Dehaut, A., Paul-Pont, I., Lacroix, C., Jezequel, R., Soudant, P., Duflos, G., (2017). Occurrence and effects of plastic additives on marine environments and organisms: a review. *Chemosphere*, 182,781-793.  
<https://doi.org/10.1016/j.chemosphere.2017.05.096>.
- [27] Hernandez, E., Nowack, B., Mitrano, D.M., (2017). Polyester textiles as a source of microplastics from households: a mechanistic study to understand microfiber release during washing. *Environmental Science and Technology*, 51, 7036-7046  
<https://doi.org/10.1021/acs.est.7b01750>
- [28] Hidalgo-Ruz, V., Gutow, L., Thompson, R.C., Thiel, M., (2012). Microplastics in the marine environment: a review of the methods used for identification and quantification. *Environmental Science and Technology*,46,3060-3075. <https://doi.org/10.1021/es2031505>
- [29] Hidayaturrehman, H., Lee, T.G., (2019). A study on characteristics of microplastic in wastewater of South Korea: Identification, quantification, and fate of microplastics during treatment process. *Marine Pollution Bulletin*, 146, 696-702. <https://doi.org/10.1016/j.marpolbul.2019.06.071>.
- [30] Hirai, H., Takada, H., Ogata, Y., Yamashita, R., Mizukawa, K., Saha, M., Kwan, C., Moore, C., Gray, H., Laursen, D., (2011). Organic micropollutants in marine plastics debris from the open ocean and remote and urban beaches. *Marine Pollution Bulletin*, 62,1683-1692.  
<https://doi.org/10.1016/j.marpolbul.2011.06.004>
- [31] Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., Law, K.L., (2015). Plastic waste inputs from land into the ocean. *Science*,347,768571. <https://doi.org/10.1126/science.1260352>
- [32] Kole, P.J., Löhr, A.J., Van Belleghem, F., Ragas, A., (2017). Wear and tear of tyres: a stealthy source of microplastics in the environment. *International Journal of Environmental Research and Public Health*,14,1265. <https://doi.org/10.3390/ijerph14101265>
- [33] Lapointe, M., Farner, J.M., Hernandez, L.M., Tufenkji, N., (2020). Understanding and improving microplastics removal during water treatment: Impact of coagulation and flocculation. *Environmental Science and Technology*, 54, 14, 8719-8727.  
<https://doi.org/10.1021/acs.est.0c00712>.
- [34] Lares, M., Ncibi, M.C., Sillanpää, M., Sillanpää, M., (2018). Occurrence, identification and removal of microplastic particles and fibers in conventional activated sludge process and advanced MBR technology. *Water Research*, 133, 236-246.  
<https://doi.org/10.1016/j.watres.2018.01.049>
- [35] Lechner, A., Keckeis, H., Lumesberger-Loisl, F., Zens, B., Krusch, R., Tritthart, M., Glas, M., Schludermann, E., (2014). The Danube so colourful: a potpourri of plastic litter outnumbers fish larvae in Europe's second largest river. *Environment and Pollution*, 188, 177-181.  
<https://doi.org/10.1016/j.envpol.2014.02.006>
- [36] Lehtiniemi, M., Hartikainen, S., N'akki, P., Engström, J., Koistinen, A., Setälä, O., (2018). Size matters more than shape: Ingestion of primary and secondary microplastics by small predators. *Food Webs*, 17, e00097. <https://doi.org/10.1016/j.fooweb.2018.e00097>.
- [37] Li, J.Y., Liu, H.H., Paul Chen, J.P. (2018). Microplastics in freshwater systems: A review on occurrence, environmental effects, and methods for microplastics detection. *Water Research*, 137, 362-374. <https://doi.org/10.1016/j.watres.2017.12.056>.
- [38] Li, X., Mei, Q., Chen, L., Zhang, H., Dong, B., Dai, X., He, C., Zhou, J. (2019). Enhancement in adsorption potential of microplastics in sewage sludge for metal pollutants after the wastewater treatment process. *Water Research*, 157, 228-237.

<https://doi.org/10.1016/j.watres.2019.03.069>

- [39] Lithner, D., Larsson, A., Dave, G. (2011). Environmental and health hazard ranking and assessment of plastic polymers based on chemical composition. *Science of the Total Environment*, 409, 3309-3324. <https://doi.org/10.1016/j.scitotenv.2011.04.038>
- [40] Liu, K., Wang, X., Fang, T., Xu, P., Zhu, L. & Li, D. (2019a). Source and potential risk assessment of suspended atmospheric microplastics in Shanghai. *Science of the Total Environment*, 675, 462-471. <https://doi.org/10.1016/j.scitotenv.2019.04.110>
- [41] Liu, K., Wang, X.H., Fang, T., Xu, P., Zhu, L.X., Li, D.J. (2019c). Source and potential risk assessment of suspended atmospheric microplastics in Shanghai. *Science of the Total Environment*, 675, 462-471. <https://doi.org/10.1016/j.scitotenv.2019.04.110>.
- [42] Liu, W.L., Wu, Y., Zhang, S.J., Gao, Y.Q., Jiang, Y., Horn, H., Li, J. (2020b). Successful granulation and microbial differentiation of activated sludge in anaerobic/anoxic/aerobic (A2O) reactor with two-zone sedimentation tank treating municipal sewage. *Water Research*, 178, 115825 <https://doi.org/10.1016/j.watres.2020.115825>.
- [43] Liu, X., Yuan, W., Di, M., Li, Z., Wang, J., (2019b). Transfer and fate of microplastics during the conventional activated sludge process in one wastewater treatment plant of China. *Chemical Engineering Journal*, 362, 176-182 <https://doi.org/10.1016/j.cej.2019.01.033>
- [44] Long, Z.X., Pan, Z., Wang, W.L., Ren, J.Y., Yu, X.G., Lin, L.Y., Lin, H., Chen, H.Z., Jin, X. L. (2019). Microplastic abundance, characteristics, and removal in wastewater treatment plants in a coastal city of China. *Water Research*, 155, 255-265. <https://doi.org/10.1016/j.watres.2019.02.028>.
- [45] Lusher, A., Mchugh, M., Thompson, R. (2013a). Occurrence of microplastics in the gastrointestinal tract of pelagic and demersal fish from the English Channel. *Marine Pollution Bulletin*, 67, 94-99. <https://doi.org/10.1016/j.marpolbul.2012.11.028>
- [46] Magni, S., Binelli, A., Pittura, L., Avio, C.G., Della Torre, C., Parenti, C.C., Gorbi, S., Regoli, F. (2019). The fate of microplastics in an Italian Wastewater Treatment Plant. *Science of the Total Environment*, 652,602-610. <https://doi.org/10.1016/j.scitotenv.2018.10.269>.
- [47] Mason, S.A., Garneau, D., Sutton, R., Chu, Y., Ehmann, K., Barnes, J., Fink, P., Papazissimos, D., Rogers, D.L., (2016). Microplastic pollution is widely detected in US municipal wastewater treatment plant effluent. *Environmental Pollution*, 218,1045-1054. <https://doi.org/10.1016/j.envpol.2016.08.056>
- [48] Max, S., Albert A.K., Ellen, B., Carolien, K., (2017). Export of microplastics from land to sea. A modelling approach. *Water Research*, 127, 15, 249-257. <https://doi.org/10.1016/j.watres.2017.10.011>
- [49] McCormick, A., Hoellein, T.J., Mason, S.A., Schlupe, J., Kelly, J.J. (2014). Microplastic is an abundant and distinct microbial habitat in an urban river. *Environmental Science Technology*, 48, 11863-11871. <https://doi.org/10.1021/es503610r>
- [50] Mintenig, S.M., Int-Veen, I., L'oder, M.G.J., Primpke, S., Gerdt, G. (2017). Identification of microplastic in effluents of waste water treatment plants using focal plane array-based micro-Fourier-transform infrared imaging. *Water Research*, 108, 365-372. <https://doi.org/10.1016/j.watres.2016.11.015>
- [51] Murphy F., Ewins, C., Carbonnier, F., Quinn, B. (2016). Wastewater treatment works (WwTW) as a source of microplastics in the aquatic environment. *Environmental Science and Technology*,50,5800-5808. <https://doi.org/10.1021/acs.est.5b05416>
- [52] Napper, I.E., Thompson, R.C. (2016). Release of synthetic microplastic plastic fibres from domestic washing machines: Effects of fabric type and washing conditions. *Marine Pollution Bulletin*, 112, 39-45. <https://doi.org/10.1016/j.marpolbul.2016.09.025>
- [53] Neves, D., Sobral, P., Ferreira, J.L., Pereira, T. (2015). Ingestion of microplastics by commercial fish off the Portuguese coast. *Marine Pollution Bulletin*, 871 101, 119-126. <https://doi.org/10.1016/j.marpolbul.2015.11.008>
- [54] Ngo, P.L., Pramanik, B.K., Shah, K., Roychand, R., (2019). Pathway, classification and removal efficiency efficiency of microplastics in wastewater treatment plants. *Environmental Pollution*, <https://doi.org/10.1016/j.envpol.2019.113326>
- [55] Nizzetto, L., Futter, M., Langaas, S. (2016). Are agricultural soils dumps for microplastics of urban origin? *Environmental Science and Technology*, 50, 10777-10779. <https://doi.org/10.1021/acs.est.6b04140>.
- [56] Paula M., Daniel S., Alba A., Amanda L., Yaisel J. B., Eduardo, D., Adriana,L., Gonzalo M.S., Mario, D. & Vazquez, E. (2020). Bioremediation as a promising strategy for microplastics removal in waste water treatment plants. *Marine Pollution Bulletin*, 156, 111252 <https://doi.org/10.1016/j.marpolbul.2020.111252>



- [57] Pramila, R., Ramesh, K.V., (2011). Biodegradation of low density polyethylene (LDPE) by fungi isolated from municipal landfill area. *Journal Microbiological Biotechnological. Research* 1, 131-136. <https://doi.org/10.5897/JBR12.003>
- [58] Qiao, R.X., Deng, Y.F., Zhang, S.H., Wolosker, M.B., Zhu, Q.D., Ren, H.Q., Zhang, Y., (2019). Accumulation of different shapes of microplastics initiates intestinal injury and gut microbiota dysbiosis in the gut of zebrafish. *Chemosphere*, 236, 124334. <https://doi.org/10.1016/j.chemosphere.2019.07.065>
- [59] Rochman, C., Tahir, A., and Williams, S. et al. (2015). Anthropogenic debris in seafood: Plastic debris and fibers from textiles in fish and bivalves sold for human consumption. *Scientific Reports*, 5, 14340. <https://doi.org/10.1038/srep14340>
- [60] Rummel, C.D., Jahnke, A., Gorokhova, E., Kühnel, D., Schmitt-Jansen, M. (2017). Impacts of biofilm formation on the fate and potential effects of microplastic in the aquatic environment. *Environmental Science and Technological Letter*, 4, 258-267. <https://doi.org/10.1021/acs.estlett.7b00164>
- [61] Saxena, A., & Srivastava, A. (2022). Industry Application of Green Manufacturing: A Critical Review. *Journal of Sustainability and Environmental Management*, 1(1), 32-45. <https://doi.org/10.5281/zenodo.6207141>
- [62] Scherer C., Weber A., Lambert S., Wagner M. (2018). Interactions of microplastics with freshwater Biota. *The Handbook of Environmental Chemistry*, 58. [https://doi.org/10.1007/978-3-319-61615-5\\_8](https://doi.org/10.1007/978-3-319-61615-5_8)
- [63] Seow, T.W., Lim, C.K., Nor, M., Mubarak, M., Lam C.Y., Yahya, A., Ibrahim, Z. (2016). Review on wastewater treatment technologies. *International Journal of Applied Environmental Science*, 11, 111-126. <https://doi.org/10.1371/journal.pgen.1006493>
- [64] Sun, J., Dai, X.H., Wang, Q.L., van Loosdrecht, M.C.M., Ni, B.J., (2019). Microplastics in wastewater treatment plants: Detection, occurrence and removal. *Water Research*, 152, 21–37. <https://doi.org/10.1016/j.watres.2018.12.050>.
- [65] Sussarellu, R., Suquet, M., Thomas, Y., Lambert, C., Fabioux, C., Pernet, M.E.J., Le Goïc, N., Quillien, V., Mingant, C., Epelboin, Y., (2016). Oyster reproduction is affected by exposure to polystyrene microplastics. *Proceedings of the National Academy of Science*, 113, 2430-2435. <https://doi.org/10.1073/pnas.1519019113>
- [66] Talvitie, J., Mikola, A., Koistinen, A., Setälä, O., (2017a). Solutions to microplastic pollution - Removal of microplastics from wastewater effluent with advanced wastewater treatment technologies. *Water Research*, 123, 401–407. <https://doi.org/10.1016/j.watres.2017.07.005>.
- [67] Talvitie, J., Mikola, A., Setälä, O., Heinonen, M., Koistinen, A., (2017b). How well is microlitter purified from wastewater? A detailed study on the stepwise removal of microlitter in a tertiary level wastewater treatment plant. *Water Research*, 109, 164–172. <https://doi.org/10.1016/j.watres.2016.11.046>.
- [68] Teuten, E.L., Saquing, J.M., Knappe, D.R., Barlaz, M.A., Jonsson, S., Björn, A., Rowland, S.J., Thompson, R.C., Galloway, T.S., Yamashita, R., (2009). Transport and release of chemicals from plastics to the environment and to wildlife. *Biological Science*, 364,2027-2045. <https://doi.org/10.1098/rstb.2008.0284>
- [69] Van Cauwenberghe, L., Janssen, C.R., (2014). Microplastics in bivalves cultured for human consumption. *Environmental Pollution*, 193, 65-70. <https://doi.org/10.1016/j.envpol.2014.06.010>
- [70] Van Cauwenberghe, L., Vanreusel, A., Mees, J., Janssen, C.R., (2013). Microplastic pollution in deep-sea sediments. *Environmental Pollution*, 182, 495-499. <https://doi.org/10.1016/j.envpol.2013.08.013>
- [71] Wardrop, P., Shimeta, J., Nuggeoda, D., Morrison, P.D., Miranda, A., Tang, M., Clarke, B.O. (2016). Chemical pollutants sorbed to ingested microbeads from personal care products accumulate in fish. *Environmental Science and Technology*, 50, 4037-4044. <https://doi.org/10.1021/acs.est.5b06280>
- [72] Wei, W., Huang, Q.S., Sun, J., Wang, J.Y., Wu, S.L., Ni, B.J. (2019). Polyvinyl chloride microplastics affect methane production from the anaerobic digestion of waste activated sludge through leaching toxic Bisphenol-A. *Environmental Science and Technology*, 53,2509–2517. <https://doi.org/10.1021/acs.est.8b07069>.
- [73] Weiyi L., Jinlan Z., Hang, L., Xiaonan, G., Xiyue, Z., Xiaolong, Y., Zhiguo, C., Tingting, Z. (2021). A review of the removal of microplastics in global wastewater treatment plants: Characteristics and mechanisms. *Environment International*, 146,106277. <https://doi.org/10.1016/j.envint.2020.106277>

- [74] Wright, S.L., Rowe, D., Thompson, R.C., Galloway, T.S., (2013). Microplastic ingestion decreases energy reserves in marine worms. *Current Biology*, 23. <https://doi.org/10.1016/j.cub.2013.10.068>
- [75] Wright, S.L., Ulke, J., Font, A., Chan, K.L.A., Kelly, F.J. (2020). Atmospheric microplastic deposition in an urban environment and an evaluation of transport. *Environment International* 136. <https://doi.org/10.1016/j.envint.2019.105411>.
- [76] Yang, L., Li, K., Cui, S., Kang, Y., An, L., Lei, K. (2019). Removal of microplastics in municipal sewage from China's largest water reclamation plant. *Water Research*, 155,175-181. <https://doi.org/10.1016/j.watres.2019.02.046>
- [77] Zettler, E.R., Mincer, T.J., Amaral-Zettler, L.A. (2013). Life in the “plastisphere”: microbial communities on plastic marine debris. *Environmental Science and Technology*,47,7137-7146. <https://doi.org/10.1021/es401288x>
- [78] Zhang, K., Shi, H., Peng, J., Wang, Y., Xiong, X., Wu, C., Lam, P.K.S. (2018). Microplastic pollution in China's inland water systems: A review of findings, methods, characteristics, effects, and management. *Science of the Total Environment*, 630, 1641-1653. <https://doi.org/10.1016/j.scitotenv.2018.02.300>
- [79] Zhang, X.L., Chen, J.X., Li, J. (2020). The removal of microplastics in the waste water treatment process and their potential impact on anaerobic digestion due to pollutants association. *Chemosphere*, 251, 126360. <https://doi.org/10.1016/j.chemosphere.2020.126360>.
- [80] Ziajahromi, S., Neale, P.A., Rintoul, L., Leusch, F.D.L. (2017). Wastewater treatment plants as a pathway for microplastics: Development of a new approach to sample wastewater-based microplastics. *Water Research*, 112, 93–99. <https://doi.org/10.1016/j.watres.2017.01.042>

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