Bioprocess and Biosystems Engineering (2023) 46:309–321
https://doi.org/10.1007/s00449-022-02715-x

CRITICAL REVIEW

Removing microplastics from wastewater using leading-edge treatment technologies: a solution to microplastic pollution—a review

Arunkumar Priya[1] · Gururajan Anusha[1] · Sundaram Thanigaivel[2] · Alagar Karthick[3] · Vinayagam Mohanavel[4] · Palanivel Velmurugan[4] · Balamuralikrishnan Balasubramanian[5] · Manickam Ravichandran[6,7] · Hesam Kamyab[8] · Irina Mikhailovna Kirpichnikova[9] · Shreeshivadasan Chelliapan[10]

Received: 27 December 2021 / Accepted: 23 February 2022 / Published online: 17 March 2022

Abstract

Microplastics (MPs) in environmental studies have revealed that public sewage treatment plants are a common pathway for microplastics to reach local surroundings. Microplastics are becoming more of a worry, posing a danger to both marine wildlife and humans. These plastic items not only contribute to the macrocosmic proliferation of plastics but also the scattering of microplastics and the concentration of other micropollutant-containing objects, increasing the number of pollutants identified. Microplastics' behavior, movement, transformation, and persistence mechanisms, as well as their mode of action in various wastewater effluent treatment procedures, are still unknown. They are making microplastics made from wastewater a big deal. We know that microplastics enter wastewater treatment facilities (WWTPs), that wastewater is released into the atmosphere, and that this wastewater has been considered to represent a threat to habitats and ground character based on our literature assessment. The basic methods of wastewater and sewage sludge, as well as the treatment procedure and early characterization, are covered throughout the dissection of the problematic scientific conceptualization.

✉ Arunkumar Priya
akpriy@gmail.com

✉ Alagar Karthick
karthick.power@gmail.com

✉ Hesam Kamyab
hesam_kamyab@yahoo.com; khesam2@Live.utm.my

Gururajan Anusha
anusha.g@kpriet.ac.in

Sundaram Thanigaivel
thanigaivel092@gmail.com

Vinayagam Mohanavel
mohanavel2k16@gmail.com

Palanivel Velmurugan
palanivelmurugan2008@gmail.com

Balamuralikrishnan Balasubramanian
bala.m.k@sejong.ac.kr

Manickam Ravichandran
smravichandran@hotmail.com

Irina Mikhailovna Kirpichnikova
kirpichnikovaim@susu.ru

Shreeshivadasan Chelliapan
shreeshivadasan.kl@utm.my

1 Department of Civil Engineering, KPR Institute of Engineering and Technology, Coimbatore, Tamil Nadu 641407, India

2 Saveetha School of Engineering, Department of Biotechnology, Saveetha Institute of Medical and Technical Sciences, Thandalam, Chennai, Tamil Nadu 602105, India

3 Renewable Energy lab, Department of Electrical and Electronics Engineering, KPR Institute of Engineering and Technology, Coimbatore, Tamil Nadu 641407, India

4 Centre for Materials Engineering and Regenerative Medicine, Bharath Institute of Higher Education and Research, Selaiyur, Chennai, Tamil Nadu 600073, India

5 Department of Food Science and Biotechnology, College of Life Science, Sejong University, Seoul 05006, South Korea

6 Department of Mechanical Engineering, K. Ramakrishnan College of Engineering, Tiruchirappalli, Tamil Nadu 621112, India

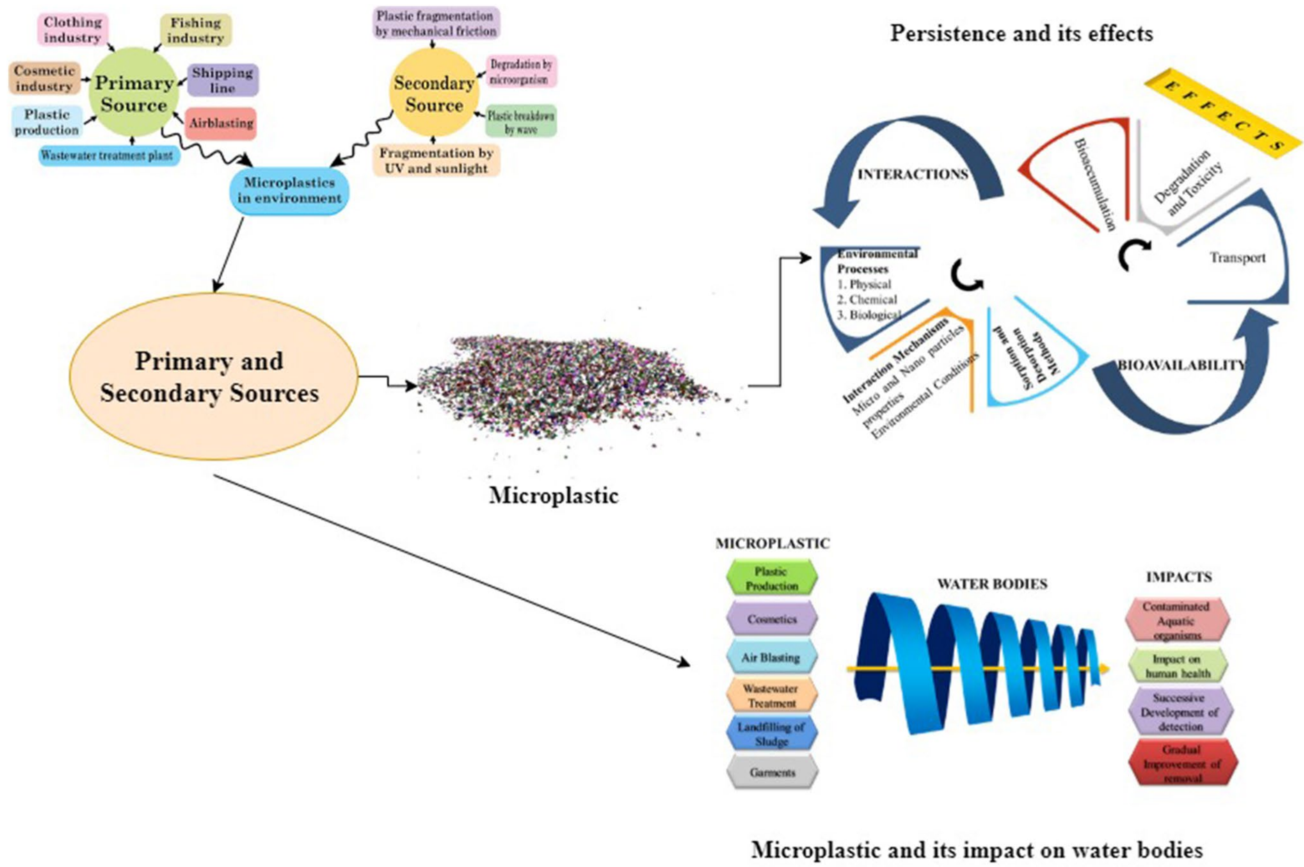
7 Department of Mechanical Engineering and University Centre for Research & Development, Chandigarh University, Mohali, Punjab 140413, India

8 Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, 54100 Kuala Lumpur, Malaysia

9 Electric Power Station, Network, and Supply System, South Ural State University, (National Research University), 76 Prospekt Lenina, 454080 Chelyabinsk, Russian Federation

10 Engineering Department, Razak Faculty of Technology and Informatics, Universiti Teknologi Malaysia, Jln Sultan Yahya Petra, 54100 Kuala Lumpur, Malaysia

Graphical abstract



Keywords Microplastic · Wastewater · Sludge · Pollution · Pretreatment · Habitat

Introduction

The manufacturing and demand-based production of plastic are now exceedingly more than 320 million metric tons [1]. With the rising production rate of plastic over the last half-century or so, it has become recognized as one of the top environmental concerns facing humankind [2]. Plastics have numerous benefits, but they are prone to cause harm to the environment when disposed of inappropriately. Plastic breaks down into different degradation classes that, over time, result in different types of fragmentation called microplastics [3]. Plastic contamination has been found in all marine environments globally, including the oceans, rivers, and freshwater bodies [4]. Various contaminants might reach the different water sources through runoff of stormwater, winds, and bulk discharge from sewage treatment plants [5]. The current state of microplastics and nano plastics is shown in Fig. 1.

Harmful microplastics are widely ranged from sizes less than 5 mm, and they are generally categorized as primary and secondary microplastics. The primary is commonly existing in many commercial goods and personal care items

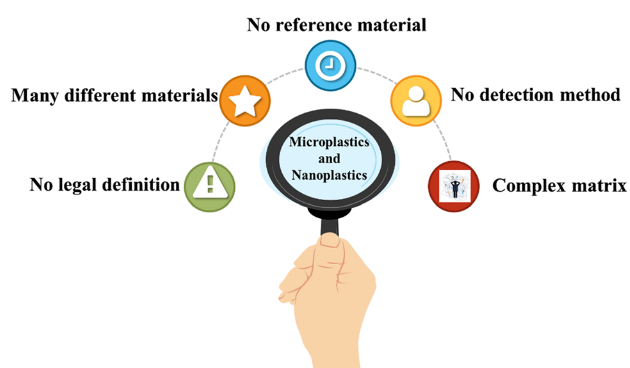


Fig. 1 Current state of microplastic and nano plastic

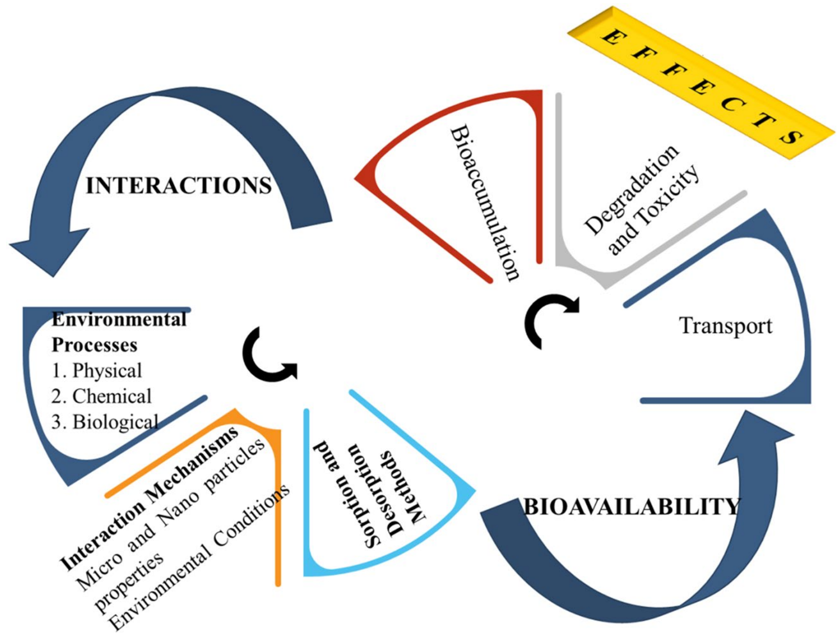


Fig. 2 Persistence and its effects

such as airtight media, considering that they are transformed into isolated microparticles of this scale [6]. Secondary microplastics are created by fragmenting more significant plastic pieces, washing synthetic textiles, and tearing tire wear and tear. Degraded microplastics are classified as used microplastics [7]. Critical microplastics materials such as plastic powders commercially used in molding, plastic nanoparticles used in many manufacturing processes were also found to impact environmental concerns negatively, and industrial 'scrubbers' were used to clean surfaces as a source to leach out microplastics [8]. The persistence of microplastic and its effects are shown in Fig. 2.

Given that some microplastics are used in some consumer goods, concerns are raised about leaks of microplastics into the atmosphere from wastewater treatment plants [9]. Those called personal care products for human needs, namely facial cleansers, body cleansers, cosmetics, toothpaste, and other pharmaceutical and daily needs, have a strong chance of contaminating the environment through microplastic releases through various runoffs. These contain plastic "micro-sized beads". They are likely to have the chance to pollute municipal wastewater [10]. Given the small size of these microbeads, some of these particles could escape from the wastewater treatment plant and end up in the aquatic environment [11]. Plastic from domestic and industrial drains passes through the drain system wastewater treatment facilities, where plastic particles can get concentrated in sludge and discharged into marine habitats as final effluents [12]. The specifics of microplastics allow them to stay in the atmosphere, broad travel distances and accumulate in bodies, and be dangerous to human health [13]. The persistent level of microplastics in different environmental and atmospheric conditions is discussed in Table 1. It represents the level of a persistent level of contaminants, and their half-life has been presented.

Different wastewater treatment plants (WWTPs) such as different industrial wastewater treatment plants are operated to remove enormous contaminants to purify the water by removing the debris, organic and inorganic pollutants [14]. These ultimately reach the higher-level food chain through various water resources, including the aquatic and marine environment. Conventional wastewater treatment with primary and secondary treatment methods will remove up to 99% of MP waste. Conventional WWTPs

Table 1 Persistence of contaminants and their effects

Type	Source	Persistency in days	Effects	References
Water	Marine	Greater than 60	Water contamination	[7]
Water	Fresh, estuarine	Greater than 40	Contamination	[7, 8]
Sediment	Marine	Greater than 180	Groundwater pollution affects organisms	[8, 9]
Sediment	Fresh, estuarine	Greater than 120	Biomagnification	[7, 9]
Ground	Soil	Greater than 120	Contamination	[7]

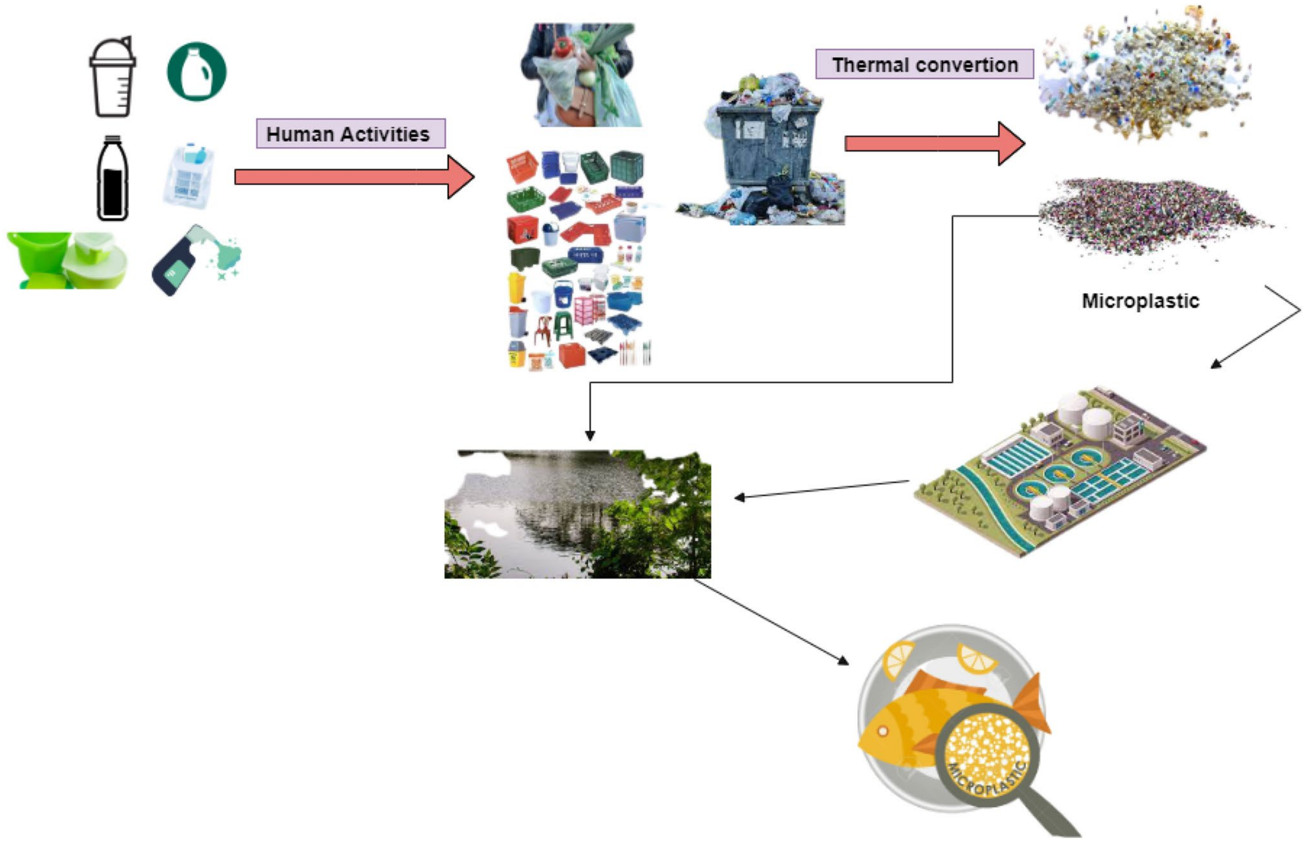


Fig. 3 Source and transport of microplastic

tend to be high POEMS sources because they discharge vast amounts of water. So far, it has been essential to keep up the standard of wastewater discharged from the urban area. However, it is not the right solution to eliminate MPs from wastewater due to inadequate treatment equipment [15]. This paper aims to examine MPs, their roots, multiple routes of action, and final destinations. The review also shows the different treatments for microplastic removal. Therefore, we conclude by suggesting managerial measures toward the efficient elimination of MPs in wastewater sources and highlighting potential research needs.

Source and origin of microplastics in wastewater treatment plants

Domestic greywater is an essential source of microfibers that migrate to wastewater treatment plants and are found in marine and terrestrial ecosystems [16]. As discussed, previous personal care products are such as polycarbonate, polyethylene, propylene, styrene-based reagents, and chemical additive-based products are contain granules, which act as a scrub agent and may be included in wastewater treatment plants. In 2009, 270,000 tons of microbeads were used individually in daily household assets. Microbeads are used in many face cleaners in the US, which release on average more than 15 mg per person per day. An exfoliating powder application releases 4500 to 94,500 particles. An application of toothpaste will have an average of more than 4000 plastic particles. Particles are small enough to move through the first sewage treatment plant (WTP), 6 mm. The release of sewage sludge into wastewater or biosolids into soil provides water and ground routes [17]. Agro waste and biowaste can be used to remove pollutants from wastewater. The source and transport of microplastic in the environment are shown in Fig. 3.

Features of microplastic and their emission sources

In cosmetics, natural exfoliating products like nutshells, pumice stone, and apricot core have recently been replaced with microplastics. Microbial cells are generally defined as the carrier of microplastics in different forms. According to the reports of the American Academy of Dermatology, microbeads are the main source of particles that are widely used in face cleansers because they are smooth and do not cause as much damage to the skin [15]. Personal care products with too many microplastics are easy to get rid of through the normal wastewater treatment process, and we do not notice them in the effluent [16]. Wastewater effluent contains high levels of plastic, microbead, and microfiber particles. Over the period, plastic particles from polyester, rayon, and nylon fabrics shed thousands of fibers, becoming a source for microparticle pollutants, so washing them will result in significant quantities of shed fibers [17]. A recent study found that over 50 million particulate matter could be released to wastewater treatment plant effluents regularly. Of the particles hit the books, the most popular form was MP fibers (59%), accompanied by fragments which took around 33%, films with 5%, foams range from 2% and pellets from1% are considered as the most of remnants of cosmetic microbeads [18]. Another study shows that about 8 billion microbeads enter American waters every day [19]. Microplastic, its distribution in water bodies, and its impacts on the environment are shown in Fig. 4.

While the amounts of MPs measured in this survey were relatively low, this would likely be a significant release considering the large amounts of effluent discharged to aquatic environments [20]. In the United Kingdom, a mean of one particle per gram of biosolids was recorded, but no data are available for PM loads in US biosolids or wastewater treatment plants in Australia [21].

Many researchers have recognized and characterized the microplastics of four commercially available face cleaners, ranging in size from 0.5 to < 1 mm [22]. In addition, all microplastics found in facial cleansers were primarily round and fragmented. The physical features of exfoliating cleaners include the scale, color, and concentration of microbeads. Industrial wastewater can release polypropylene, nylon-based, and PVA-based fibers from textile sources such as carpets, airbags, ropes, and fishing gear [23]. Some wastewater treatment plants in the United States have discharged 8.9 and 9 billion fibers per day [24]. Fibers were detected at the same site almost 15 years after sludge application and exhibited the same characteristics [14]. Polyethylene, polypropylene, polytetrafluoroethylene, nylon, polymethylmethacrylate, and Polyethylene terephthalate are the most commonly used polymer forms in sewage treatment plants [25].

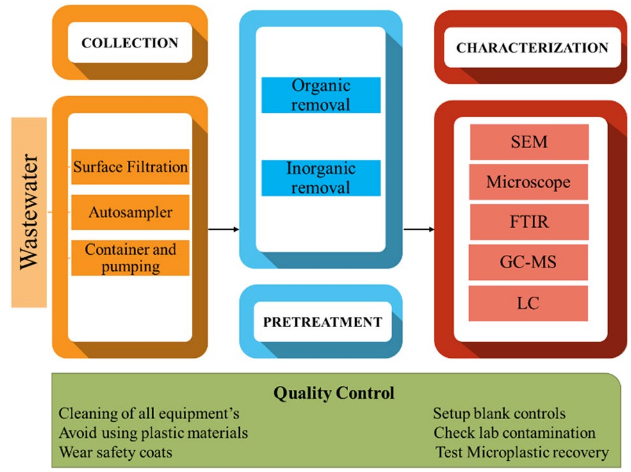


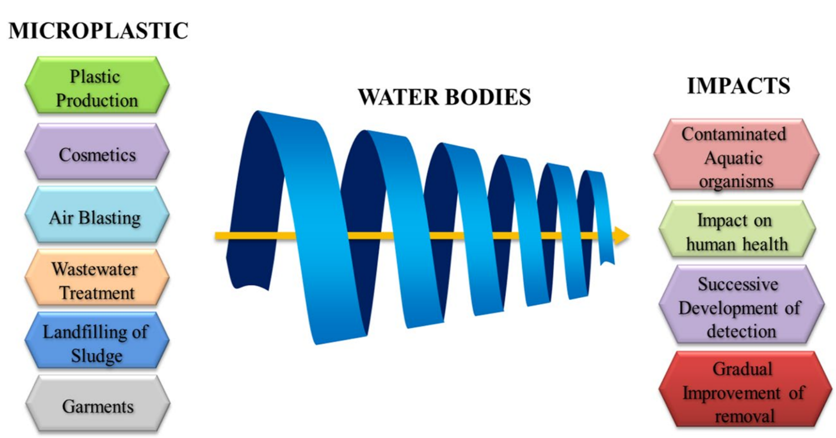
Fig. 5 Flow chart for microplastic detection in WWTPs

Microplastic detection techniques in WWTPs

The detection of microplastics at wastewater treatment plants generally involves three steps: sampling, pretreatment of samples, and characterization/quantification of microplastics, summarized in Fig. 5.

Each organism that carries pollutants in the form of micro or nano plastics needs to be examined through a digital optical microscope to make sure it exists. The high-resolution power of up to 50 × magnification allows the microorganism to be seen, and the sections that could be filled with microplastics have been targeted and examined [26]. Both collected particles are put under secondary examination to

Fig. 4 Microplastic and its impact on water bodies



analyze and photograph all the available nano-sized plastics and micro-sized particles with the most significant dimension using the built-in ZEN 2.3 program [27]. The particles were divided into distinct categories of plastics and fibers after a thorough analysis; approximately 54 classes were created based on the helicity of the fibers and cross-section forms [28]. Further, uniquely selected particles were planted on an optical microscope with 1000 × magnification, followed by Fourier transform infrared spectroscopy/ Raman spectroscopy analysis were performed to identify the functional elements in the mixture of samples [29].

FTIR microscopy and Raman analysis represent the samples of most of the groups mentioned above were analyzed by FTIR and micro-Raman spectroscopy to determine the functional groups in society to validate their credit card- or non-plastic existence [30]. The method is derived more accurately than an analytical process. To reduce the potential for microplastic errors, all particles and fibers were confirmed using spectroscopy methods [31]. Only particles, made explicitly of various organic compounds or other non-plastics-based materials, such as plant-based algae, sand, and glass, were omitted for the scanning electron microscope (SEM) and Raman spectroscopy (RS) studies [32]. Therefore, on average, from 2 to 3 biological particles or fibers were examined with a Fourier transform infrared (FTIR) microscope and a micro-Raman spectrometer for each grade, respectively, which accounted for 1.3 and 1.4% of all collected biological particles and fibers [33].

Generally, the process of micro-Raman analysis was calibrated using a laser-green (514 nm), using the software LabSpec 5, with a spectral range of 200–3000 cm^{-1}. FTIR and Raman spectra libraries have been collected from various sources for comparison and have proven useful [34].

Technologies to eliminate microplastics

Removal of microplastics from wastewater treatment facilities

The total amount of microplastics extracted from the system was estimated based on their previous presence [35]. The removal efficiency of wastewater treatment plants without secondary treatment was more than 88%, and this range is significantly increased with more than 97% of wastewater treatment plants using the secondary treatment process [36]. The lowest rate of removal and their efficiency was calculated for 2 L of wastewater was probably due to the flow rate attained only up to 2 L of sewage to detect the microplastics contaminations [37]. Many other studies have also suggested the use of more wastewater for analysis [38]. However, it is usually triggered by the reduced production of certain nuclear reactors, such as the nuclear membrane reactor [39]. The approximate concentration of microplastics in wastewater is based on the ranges of values documented in the literature, showing how microplastics are well extracted during the various stages of treatment [40]. Different types of WWTPs have been tested for the microplastics removal process concerning the membrane pore size, shape, properties along many influencing parameters which will undergo for the efficient removal of microplastics have been described in Table 2 for the better understanding of the global scenario toward the effective percentage of microplastic removal [41]. Schematic of overall residue removal and their influence in the aquatic environment were screened to better remove micro and nano plastic contaminants from the wastewater through a series of schematics given in Fig. 6.

Table 2 Membrane-mediated microplastics removal processes by different WWTPs in global concern

S. no	Type of treatment process	Influencing factors	Processing parameter	Removal percentage of microplastics	Origin of WWTPs	References
1	First and second-order process	Pore size, thickness, surface properties	Flux velocity, membrane pressure	99%	Sweden	[15, 41]
2	Biofilters (Primary and secondary)	Membrane material, thickness	Polarizing concentration	Up to 88%	France	[15, 16, 42]
3	First and second-order process	Pore size, thickness, surface properties	Flux velocity, membrane pressure	99	United States	[15, 43]
4	First and second-order process	Pore size, thickness, surface properties	Flux velocity, membrane pressure	98	Scotland	[16, 44]
5	First and second-order process	Pore size, thickness, surface properties	Flux velocity, membrane pressure	Up to 94	Netherlands	[17, 43]
6	First and second-order process	Pore size, thickness, surface properties	Flux velocity, membrane pressure	96	United States	[15, 45]
7	First and second-order process	Pore size, thickness, surface properties	Flux velocity, membrane pressure	98	Finland	[17]

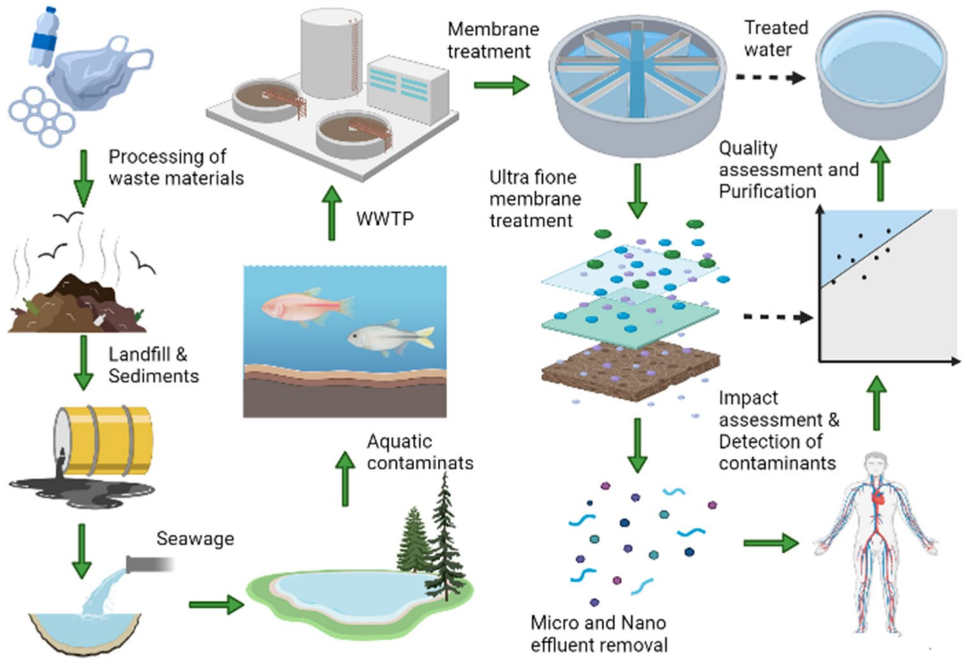


Fig. 6 The removal process of microplastics from wastewater

Pre-processing and primary processing

Preliminary and primary treatment resulted in significant reductions in the concentrations of microplastics in wastewater. About 35 ~ 59% of the microplastics were removed during pretreatment, and about 50–98% of the micro-sized plastics were filtered after the primary treatment process [46]. Microplastics that are generated in sewage systems during the process of mechanical separation in the static settling are removed via the process of speed-filtering process and the fewer weight microplastics in the floating conditions during the grease skimming process in first stage filtrations as well for process of sedimentation of the heavy microplastics that are imprisoned in solids-based floc mixture during the process of removal through the gravitational process of separation [47]. Regardless of the precautions taken, the most significant impact was the size of the microplastics, which could be readily eliminated [48]. The percentage of coarse elements in water declined by 87% after the first procedure and 92% after the second [49]. Pretreatment of microplastics before wastewater treatment was more effective in removing fibers than fragments, with the relative abundance of fibers decreasing after treatment [50]. This can be attributed to the fact that fibers are more easily imprisoned in agglutinating particles [51]. Studies have found that microbeads were efficiently extracted by skimming due to the bulk size of these microbeads being made of polyethylene, which are positively buoyant, which implies that they can swim on top of the urine and could be quickly skipped off [52]. A similar finding has been found in other studies, demonstrating that microbeads are not present in wastewater treatment plant effluents. In comparison, a study conducted in New York using wastewater treatment plants were found that 4 out of 10 wastewater treatment plants still emit microbeads [53]. The difference could be achieved since the vast quantities of greases and mixture of oils were present in the wastewater sediments, and components may be considered as positive parameters which influence the process for being microplastics, efficient effluent removal from wastewater was processed as per the schematic given in Fig. 7.

Secondary process for waste treatment

It typically consists of various biological and chemical clarifications-based treatments, which are managed further to subside the level of microplastics and their associated contents in the wastewater is 14%, the second part of that regulation was insane, the trace amounts are nanograms per liter [54]. Owing to this, in which a plastic particle after the filtration or flocculation is not entirely removed, the remainder of the credit card that would then be resolved in the clarification tank would not be taken away in case it did not heal [55].

In addition, microplastics may become trapped inside the tissue flocs produced by the ingestion of protozoa or metazoan. Filter bags, which are widely used in the wastewater

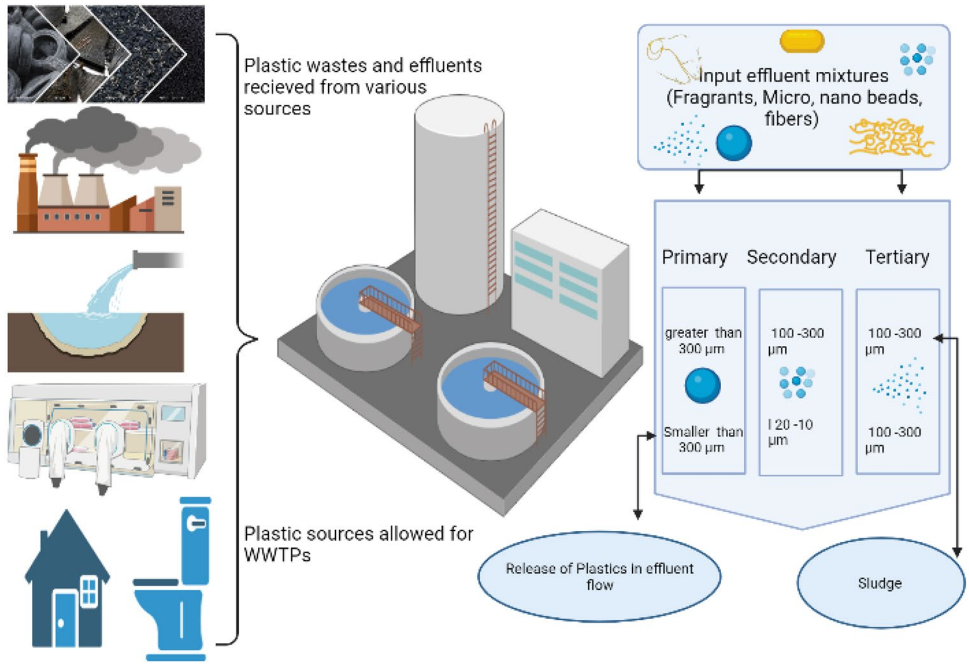


Fig. 7 Efficient plastic waste removal process using WWTPs

treatment process, are renowned for preserving solids and fluids [56]. It is possible that filter bags, when reused in the reverse procedure, can degrade or change their functionality in the system by concentrating other kinds of microscopic solids [57]. On the other hand, microplastics are being drawn to the microbial or chemical flux and what percentage of GFP-microplastics are being attracted to due to microplastics to how much it can support microplastics removal is unknown until now [58]. Likewise, tiny molecules of plastic can be gathered by the UAS and then redistributed with the tending of the glass and be to settle with the aqueous process and become squared up less effectively [59]. Another explanation can be due to the change in the amount of water in the UAS and make the settling of the flocs more disordered [60].

Another factor that played a decisive role in excluding microplastics from secondary releases was the interval during which the interaction took place on wastewater [61]. A longer contact time (time of contact between seamen and seawater) was related to a higher potential for the surface biofilm coatings around microplastics [62]. These biological coatings can also reduce the property of surface morphology of microplastics, promptly allowing them to slide out of the water, thus improving the efficiency of removing water bodies [63]. Such advances could be relatively more efficient in removal efficiency for nano plastics; they generally exist in the neutral form of buoyant particles that are more probable to be free-floating and thus get away from both skimming and deposition processes [64]. On top of other concerns, if we look at the number of contacts aqueous Contact Time has four films developed on microplastics, or how these interactions rely on nutrient levels in our wastewater, the time-dependent contact interactions may be worthwhile to research [65]. In the investigation on film-forming bacterial formation on microplastics will cause the impact in the organisms through particle transport in the freshwater and marine environment, experimental methods and mathematical models were used, cited as references are strong references to taking out such studies in wastewater system [64].

Larger sized microplastics are excluded from the treatment during the secondary stage of waste treatment, which is turned into a reduced profusion of microplastics accumulation during the treatment secondary effluent process than in standard wastewater treatment [63, 65]. Although 500 mm microplastics were rarely present in secondary effluents, studies have shown that they are virtually absent. The microparticles greater than 300 mm only account for 8% of the volume of microparticles collected during secondary care treatment. In comparison, the number of MPs that measure between 500 and 1000 mm still account for 43% after secondary care [65]. The age of death was unknown. This examines the impact that different secondary treatment methods have on microplastics removal. This would be considered the point to be focused on shortly for advancing this type of treatment process [51].

Tertiary process of waste treatment

About tertiary care, additional polishing can be substantial. The technologies taken to extract microplastics vary, with the membrane-related devices proving to be the well-known method. Many studied the comparison of the efficacy of various secondary treatment procedures, i.e., sand filtration (RSF), disc filter (DF), dissolved air flotation (DAF), and membrane-based bioreactor systems (MBR) have well known for the primary effluent treating process. Then the process of MBR had found the highest percentage of removal efficiency up to 99.9%, followed by DAF and RSF which yield around 97 and 95%, with an average of exclusion efficiency is about 97% was observed and an overall exclusion of efficiency of 95% [66]. The elimination rate of DF ranged from 40 to 98.5%. In the New York analysis, we found that two advancements with filter membrane did not emit micro-sized beads, whereas the other four types have advantages over other filters (i.e. one rapid sand filter, one continuous counter-wash filter, and two unspecified filters) [54]. The ultrafiltration and reverse osmosis decreased microplastics pollutant concentrations [67]. It was also concluded that the advanced granular filtration system does not minimize the release of plastic from sewage treatment plants. The effect of the active biological filter (BAF) and maturing pond on the microplastics of wastewater treatment plants did not significantly change the flow rate. It's worth remembering that the microplastics content in the tertiary treatment unit's influent and effluent might be quite bad, and can give false zero findings if the sample is only a few letters long. To assess the reliability of tertiary treatment processes when removing microplastics, the required sample volume is higher than that of pretreatment and secondary treatment processes [68].

Microplastics-targeted treatment technology

Some of the ways microplastics are separated from wastewater in a treatment facility, but none of these is explicitly designed to eliminate microplastics. Owing to a large number of microplastics in wastewater treatment systems, they will possibly avoid being processed and join the receiving water system [57]. Microplastics in WWTPs are retained in sludge, which means smaller bits could find their way into the atmosphere by sludge land application. But no microplastic treatment method has yet been developed or implemented in a wastewater treatment plant, and the advancement of microplastic treatment technology is still in its early stages [69]. A device manufactured with gravitational force to remove Mp particles through the secondary stage of wastewater treatments effluents process. The machine serves as a filtration device to filter microplastics from water or as a counter-rinse unit for washing microplastics with wastewater. The effects of filtration materials, water pressure, and microplastics in terms of flow rate and recovery were tested with a three-dimensional filter, and they have lower pressure water with around (0.68 kPa) showing the best execution. However, such a device has only been analyzed with one form of MPs, and its effectiveness in the extraction of

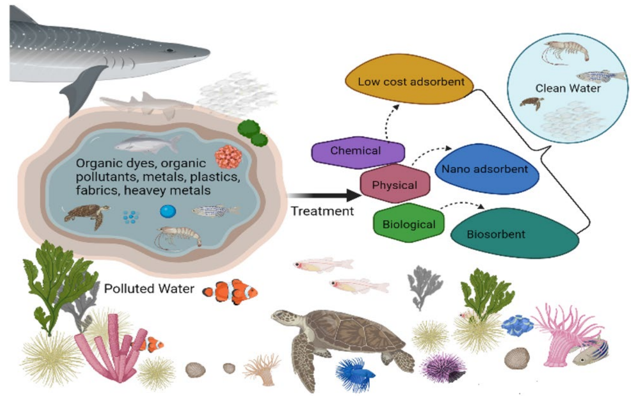


Fig. 8 Polluted water treatment process

biodegradable waste has not been tested [70]. The feasibility of eliminating microplastics with dynamic membranes and suggested further advances in this technology to efficiently extract microplastics. However, design, protection, and costs associated with operations are to be fully assessed upon using an additional unit operation for microplastic removal. One way to remove microplastics from wastewater is to enhance the operability of wastewater treatment processes to extract microplastics more effectively. The present skimming process and sedimentation units have well proved their enhancement in the process to remove MPs at a certain point, it's noteworthy looking into the differential outcome of different operating conditions, such as movement retention time for the MPs removal process and its performance [71]. The properties of various filter and membrane systems with their properties and the number of microplastics extracted are worth evaluating. Clarification of the role of flocculation/coagulation in the elimination of microplastics is also promoted. Artificial intelligence-based coagulants were found to be more efficient at removing microplastics than Fe-based coagulants, and a pluggable authentication module was able to improve efficiency in the removal of microplastics. These findings suggest that enhancing wastewater treatment by optimizing flocculation/coagulation processes is feasible, given that additional research is performed [72].

The process for treatment of microplastics in wastes of sludge can occur in vastly diverse forms, as attempting to distinguish microplastics from sludge can be difficult. One means of avoiding microplastics entering the waste sludge is to enhance grease recovery and to treat the grease separately to avoid microplastics from being laundered into the waste sludge [56]. The process of thermal, catalytic pyrolysis, and microwave-assisted processes have been used to treat plastic-based contamination, which can break down long-chain polymers into oligomers. Since the heat content of plastics was close to that of hydrocarbons and fossil fuels, this process can transform plastics into fuels in an inexpensive and environmental-friendly manner [68]. This approach has only been applied to large volumes of plastic waste to date. However, the use of pyrolysis with biomass can help to treat microplastic-containing wastewater.

Furthermore, because a large portion of microplastics comes from our everyday life, future research needs to be focused on developing household-scale microplastics treatment technologies that could assist in preventing microplastics contamination at its source. Washing machine effluents include a high volume of microplastics that require fibers. Techniques could be introduced to minimize the release of fibers from washing machines, and fibers in wastewater could be isolated at homes, which would reduce microplastics in the wastewater [73]. Implementing legislation banning plastic microbeads will serve as an essential complementary intervention to avoid sources of contamination in the environment shown in Fig. 8.

Microplastics as a pollutant transport vector in wastewater treatment plants

From the source to the treatment plant, wastewater transports a wide spectrum of chemical pollutants. Flame retardants, fluorinated and sulfonated organic compounds, methyl tert-butyl ether, phthalates, nonylphenols, and other chemicals found in personal care and household cleaning products, pharmaceuticals, sunscreen agents, estrogens, antibiotics, pesticides, and party drugs are examples of such chemicals [74]. Hydrophobic organic chemicals with high hydrophobicity and lipophilicity bind to nonpolar phases of sediment particles and suspended organic matter on density-based particles, which can be visible on the surface of wastewater and in sludge during treatment. Heavy metals can be absorbed by MPs from the surrounding environment [75]. When employed for agriculture or landfilling, the significant metal load in sludge poses an environmental hazard. Weathering at WWTPs can take several forms, one of which is biodegradation. In anaerobic sludge conditions, for example, the PP biodegradation rate constant was insignificant, despite no significant differences in other polymers [76]. In the various wastewater treatment phases, biofouling can change the density of a particle, diminish its buoyancy, allow it to sink further, or enhance the surface area or characteristics of the particle. In anaerobic sludge conditions, for example, the PP biodegradation rate constant was insignificant, despite no significant differences in other polymers. For example, it has been suggested that microbial breakdown of MPs in aerobic environments may be used as a WWTP process remediation technique. Because the amounts of

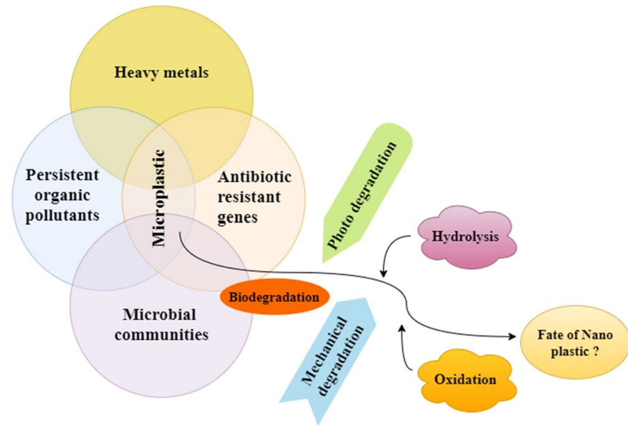


Fig. 9 Relevant environmental threats and degrading consequences of microplastics in wastewater

sorbed chemicals are dependent on the place where they are left, studies of pollutant compound interactions with MPs are urgently needed. Inhaled microplastic fibers can cause lung tumors in humans, whereas dispersive colors found in polyester and acrylic fibers can cause dermatitis, endocrine disturbance, and hormone disruption [77]. Furthermore, higher concentrations of the above-mentioned heavy metals and organic compounds produce acute and chronic toxicity, which can lead to impairments, cancer, and death. The environmental threats and degradation consequences of microplastics are shown in Fig. 9. Microplastic with heavy metals, organic pollutants, microbial communities was undergoing biodegradation and photodegradation, get converted into nano plastic, and exist in the environment.

Conclusions and further prospects

Water treatment plants (WWTPs) are used as a pathway for entering the natural world with plastic waste. In this report, the role of microscopic plastic particles in wastewater treatment plants is studied. The key points are:

(1) MPs particles in WWT plants can be detected using a variety of specimen samples and detection methods. These procedures vary from study to study, resulting in a lack of comparability. Using a single bottle pump and an intermittent method, a complex sample was collected. Micro-RFI/ Raman spectroscopy techniques may provide the best options for examining materials at this time, as they provide detailed information on the particle being studied, including its chemical composition.

(2) MPs are widely found in various contaminated aquatic environments which are to be processed with wastewater treatment plants, with recorded influent concentrations ranging between 0 and 1047 molecules per 10,000cc. Popular polymeric materials have been detected in effluent treatment plants mainly used with polyesters, ethylene, terephthalate, polyamides, and fibers representing the largest proportion of microplastics observed. Cumulative microplastic discharge from wastewater treatment plants, but the median value is still 2X. 106 particles/day, averaging an efflux of 5X per year.
(3) Microplastics are easily eliminated in wastewater treatment systems. During the process of grease, a huge number of materials were removed, which can be improved by potentially avoiding large amounts of MPs in waste sludge if fat is treated separately. Membrane filtration technology works best to reduce microplastics in final wastewater.
(4) Microplastics taken by the screen shall be recovered from the final waste sludge. It may be an effective environmental pathway for the release of pollutants as the application activities are implemented. The wastewater sludge burned can prevent microplastics from entering the atmosphere.

Based on existing knowledge, it would be necessary to focus on these areas in the future to understand better and reduce the presence of microplastics in WWTPs.

(1) Since the sampling methods of microplastics and their quantification and detection methods are distinct, it is best to harmonize them. The approach will identify the main types of plastics found in wastewater and speak about all types of plastics.
(2) Most studies focus on microplastics less than 20 mm in wastewater treatment plants. However, research suggests that smaller microplastics may be more prevalent in aquatic environments, which is not inherently beneficial to aquatic organisms. As a result, it is worth using very small microplastics (<5mm) in potential studies. Raman spectroscopy and thermographic analysis techniques could help detect microplastic particles.
(3) Although most of the microplastics in sewage sludge end up in the atmosphere, future studies should evaluate the potential effects on the environment of sewage sludge application.
(4) There need to be strategies developed for minimizing the number of microplastics in wastewater treatment plants and sludge.

Source monitoring requires microplastics to be collected to avoid contamination. Future endeavors may be based on separating microplastics from wastewater in the household and controlling plastic.

Acknowledgements The authors gratefully acknowledge support from the Universiti Teknologi Malaysia and Post-Doctoral fellow (Teaching and Learning) Scheme under MJIIT-UTM and are thankful to the South Ural State University for extending support for research collaboration and invitation as visiting senior researcher.

Declarations

Conflict of interest No conflict interest.

References

1. Eerkes-Medrano D, Thompson RC, Aldridge DC (2015) Microplastics in freshwater systems: a review of the emerging threats, identification of knowledge gaps and prioritization of research needs. Water Res 75:63–82
2. Arthur C, Baker JE, Bamford HA (2009) Proceedings of the International Research Workshop on the Occurrence, Effects, and Fate of Microplastic Marine Debris, September 9–11, 2008, University of Washington Tacoma, Tacoma, WA, USA
3. Dris R, Gasperi J, Rocher V et al (2015) Microplastic contamination in an urban area: a case study in greater Paris. Environ Chem 12:592–599
4. Yonkos LT, Friedel EA, Perez-Reyes AC et al (2014) Microplastics in four estuarine rivers in the Chesapeake Bay, USA. Environ Sci Technol 48:14195–14202
5. Yogeshwaran V, Priya AK (2019) Removal of heavy metals using nanoparticles–a review. Indian J Environ Prot 39:17–21
6. Dyachenko A, Lash M, Arsem N (2019) Microplastics in Water and Wastewater. Method development for microplastic analysis in wastewater. IWA Publishing, London, UK. https://doi.org/10.2166/9781789060034_0063
7. Gouin T (2020) Toward an improved understanding of the ingestion and trophic transfer of microplastic particles: critical review and implications for future research. Environ Toxicol Chem 39(6):1119–1137
8. Hadibarata Tony, Sathishkumar Palanivel, Prasetia Hafiizh, Pusfitasari Eka Dian, Tasfiyati Aprilia Nur, Muzdalifah Dian, Waluyo Joko et al (2021) Microplastic contamination in the skipjack tuna (Euthynnus affinis) collected from Southern coast of Java, Indonesia. Chemosphere 276:130185
9. Browne MA, Crump P, Niven SJ et al (2011) Accumulation of microplastic on shorelines woldwide: sources and sinks. Environ Sci Technol 45:9175–9179
10. Mason SA, Garneau D, Sutton R, Chu Y, Ehmann K, Barnes J, Rogers DL (2016) Microplastic pollution is widely detected in US municipal wastewater treatment plant effluent. Environ Pollut 218:1045–1054
11. Barcelo D, Pico Y (2020) Case studies of macro- and microplastics pollution in coastal waters and rivers: is there a solution with new removal technologies and policy actions. Case Stud Chem Environ Eng. https://doi.org/10.1016/j.cscee.2020.100019
12. Leslie HA, Brandsma SH, Van Velzen MJM, Vethaak AD (2017) Microplastics en route: field measurements in the Dutch river delta and Amsterdam canals, wastewater treatment plants, North Sea sediments and biota. Environ Int 101:133–142
13. Silva AB, Bastos AS, Justino CI, da Costa JP, Duarte AC, Rocha-Santos TA (2018) Microplastics in the environment: challenges in analytical chemistry-a review. Anal Chim Acta 1017:1–19

14. Sun J, Dai X, Wang Q, van Loosdrecht MC, Ni BJ (2019) Microplastics in wastewater treatment plants: detection, occurrence and removal. Water Res 152:21–37
15. Talvitie J, Mikola A, Koistinen A, Setälä O (2017) Solutions to microplastic pollution–removal of microplastics from wastewater effluent with advanced wastewater treatment technologies. Water Res 123:401–407
16. Wang F, Wong CS, Chen D, Lu X, Wang F, Zeng EY (2018) Interaction of toxic chemicals with microplastics: a critical review. Water Res 139:208–219
17. Murphy F, Ewins C, Carbonnier F, Quinn B (2016) Wastewater treatment works (WwTW) as a source of microplastics in the aquatic environment. Environ Sci Technol 50:5800–5808
18. Priya AK (2018) Utilization of waste materials as adsorbents for color removal from textile effluents-a review. Biomed J 2:3
19. Carr SA, Liu J, Tesoro AG (2016) Transport and fate of microplastic particles in wastewater treatment plants. Water Res 91:174–182
20. Rochman CM (2015) The complex mixture, fate and toxicity of chemicals associated with plastic debris in the marine environment. Marine anthropogenic litter. Springer, Cham, pp 117–140
21. Schneiderman ET (2015) Discharging microbeads to our waters: an examination of wastewater treatment plants in New York. New York State Office of the Attorney General, pp 1–11
22. Ziajahromi S, Neale PA, Rintoul L, Leusch FDL (2017) Wastewater treatment plants as a pathway for microplastics: development of a new approach to sample wastewater-based microplastics. Water Res 112:93–99
23. An L, Liu Q, Deng Y, Wu W, Gao Y, Ling W (2020) Sources of microplastic in the environment. Microplastics Terr. Environ. Emerg. Contam. Major Challenges, Springer, Cham
24. Ma B, Xue W, Hu C et al (2019) Characteristics of microplastic removal via coagulation and ultrafiltration during drinking water treatment. Chem Eng J 359:159–167
25. Cheung PK, Fok L (2017) Characterization of plastic microbeads in facial scrubs and their estimated emissions in Mainland China. Water Res 122:53–61
26. Eriksen M, Lebreton LCM, Carson HS et al (2014) Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. PLoS One 9:e111913
27. Dubaish F, Liebezeit G (2013) Suspended microplastics and black carbon particles in the Jade system, southern North Sea. Water, Air, Soil Pollut 224:1352
28. Aju S, Carbery M, Kuttykattil A et al (2018) Transport and fate of microplastics in wastewater treatment plants: implications to environmental health. Rev Environ Sci Biotechnol 17:637–653
29. Eriksen M, Mason S, Wilson S et al (2013) Microplastic pollution in the surface waters of the laurentian great lakes. Mar Pollut Bull 77:177–182
30. McCormick A, Hoellein TJ, Mason SA et al (2014) Microplastic is an abundant and distinct microbial habitat in an urban river. Environ Sci Technol 48:11863–11871
31. Mintenig SM, Int-Veen I, Löder MGJ et al (2017) Identification of microplastic in effluents of waste water treatment plants using focal plane array-based micro-Fourier-transform infrared imaging. Water Res 108:365–372
32. Wu W-M, Yang J, Criddle CS (2017) Microplastics pollution and reduction strategies. Front Environ Sci Eng 11:1–4
33. Gouin T, Roche N, Lohmann R, Hodges G (2011) A thermodynamic approach for assessing the environmental exposure of chemicals absorbed to microplastic. Environ Sci Technol 45:1466–1472
34. Chang M (2015) Reducing microplastics from facial exfoliating cleansers in wastewater through treatment versus consumer product decisions. Mar Pollut Bull 101:330–333
35. Kalčíková G, Alič B, Skalar T et al (2017) Wastewater treatment plant effluents as source of cosmetic polyethylene microbeads to freshwater. Chemosphere 188:25–31
36. Napper IE, Bakir A, Rowland SJ, Thompson RC (2015) Characterization, quantity and sorptive properties of microplastics extracted from cosmetics. Mar Pollut Bull 99:178–185
37. Martin C, Eizhvertina O (2014) Quantitative analysis of microplastics in WWTP Effluent in the Niagara region. Niagara Coll Canada, Niagara-on-the-Lake, Canada
38. Sutton R, Mason SA, Stanek SK et al (2016) Microplastic contamination in the San Francisco Bay, California, USA. Mar Pollut Bull 109:230–235
39. Gallagher A, Rees A, Rowe R et al (2016) Microplastics in the Solent estuarine complex, UK: an initial assessment. Mar Pollut Bull 102:243–249
40. Koelmans AA, Bakir A, Burton GA, Janssen CA (2016) Microplastic as a vector for chemicals in the aquatic environment: critical review and model-supported reinterpretation of empirical studies. Environ Sci Technol 50:3315–3326
41. Shim WJ, Hong SH, Eo SE (2017) Identification methods in microplastic analysis: a review. Anal Methods 9:1384–1391
42. Lenz R, Enders K, Stedmon CA et al (2015) A critical assessment of visual identification of marine microplastic using Raman spectroscopy for analysis improvement. Mar Pollut Bull 100:82–91
43. Zhang K, Xiong X, Hu H et al (2017) Occurrence and characteristics of microplastic pollution in Xiangxi Bay of Three Gorges Reservoir, China. Environ Sci Technol 51:3794–3801
44. Scherer C, Weber A, Lambert S, Wagner M (2018) Interactions of microplastics with freshwater biota. Freshwater microplastics. Springer, Cham, pp 153–180
45. Komyakova V, Vince J, Haward M (2020) Primary microplastics in the marine environment: scale of the issue, sources, pathways and current policy
46. Li L, Xu G, Yu H, Xing J (2018) Dynamic membrane for microparticle removal in wastewater treatment: performance and influencing factors. Sci Total Environ 627:332–340
47. Juliastuti SR, Hisbullah MI, Abdillah M (2018) High density Polyethylene plastic waste treatment with microwave heating pyrolysis method using coconut-shell activated carbon to produce alternative fuels In: IOP conference series: materials science and engineering. IOP Publ 334:12015
48. Kasavan S, Yusoff S, Fakri MFR, Siron R (2021) Plastic pollution in water ecosystems: a bibliometric analysis from 2000 to 2020. J Clean Prod 313:127946
49. Qin M, Chen C, Song B, Shen M, Cao W, Yang H, Zeng G, Gong J (2021) A review of biodegradable plastics to biodegradable microplastics: another ecological threat to soil environments? J. Clean Prod 312:127816
50. Hamidian AH, Ozumchelouei EJ, Feizi F, Wu C, Zhang Y, Yang M (2021) A review on the characteristics of microplastics in wastewater treatment plants: a source for toxic chemicals. J Clean Prod 295:126480
51. Zhang L, Liu J, Xie Y, Zhong S, Gao P (2021) Occurrence and removal of microplastics from wastewater treatment plants in a typical tourist city in China. J Clean Prod 291:125968
52. Lv X, Dong Q, Zuo Z, Liu Y, Huang X, Wu W-M (2019) Microplastics in a municipal wastewater treatment plant: Fate, dynamic distribution, removal efficiencies, and control strategies. J Clean Prod 225:579–586
53. Shen M, Huang W, Chen M, Song B, Zeng G, Zhang Y (2020) (Micro) plastic crisis: un-ignorable contribution to global greenhouse gas emissions and climate change. J Clean Prod 254:120138

54. Cai Y, Mitrano DM, Heuberger M, Hufenus R, Nowack B (2020) The origin of microplastic fiber in polyester textiles: The textile production process matters. J Clean Prod 267:121970
55. Koongolla JB, Lin L, Pan YF, Yang CP, Sun DR, Liu S, Li HX (2020) Occurrence of microplastics in gastrointestinal tracts and gills of fish from Beibu Gulf South China Sea. Environ Pollut 258:113734
56. Hidayaturrahman H, Lee TG (2019) A study on characteristics of microplastic in wastewater of South Korea: Identification, quantification, and fate of microplastics during treatment process. Mar Pollut Bull 146:696–702
57. Ziajahromi S, Kumar A, Neale PA, Leusch FD (2018) Environmentally relevant concentrations of polyethylene microplastics negatively impact the survival, growth and emergence of sediment-dwelling invertebrates. Environ Pollut 236:425–431
58. Wang S, Lydon KA, White EM, Grubbs JB III, Lipp EK, Locklin J, Jambeck JR (2018) Biodegradation of poly (3-hydroxybutyrate-co-3-hydroxyhexanoate) plastic under anaerobic sludge and aerobic seawater conditions: gas evolution and microbial diversity. Environ Sci Technol 52(10):5700–5709
59. Oberbeckmann S, Kreikemeyer B, Labrenz M (2018) Environmental factors support the formation of specific bacterial assemblages on microplastics. Front Microbiol 8:2709
60. Ng EL, Lwanga EH, Eldridge SM, Johnston P, Hu HW, Geissen V, Chen D (2018) An overview of microplastic and nanoplastic pollution in agroecosystems. Sci Total Environ 627:1377–1388
61. Rillig MC, Ziersch L, Hempel S (2017) Microplastic transport in soil by earthworms. Sci Rep 7(1):1–6
62. Kershaw, P. J., & Rochman, C. M. (2015). Sources, fate and effects of microplastics in the marine environment: part 2 of a global assessment. reports and studies-IMO/FAO/Unesco-IOC/WMO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Mar Environ Prot (GESAMP) Eng No 93
63. Jiang JQ (2018) Occurrence of microplastics and its pollution in the environment: a review. Sustain Prod Consum 13:16–23
64. Rai PK, Lee J, Brown RJ, Kim KH (2020) Micro-and nanoplastic pollution: behavior, microbial ecology, and remediation technologies. J Clean Prod 291:125240
65. Gazal AA, Gheewala SH (2020) Plastics, microplastics and other polymer materials–a threat to the environment. J Susta Energy Environ 11:113–122
66. Anik AH, Hossain S, Alam M, Sultan MB, Hasnine MT, Rahman MM (2021) Microplastics pollution: a comprehensive review on the sources, fates, effects, and potential remediation. Environ Nanotechnol, Monit Manag 16:100530
67. Browne MA (2015) Sources and pathways of microplastics to habitats. Mar Anthropog Litter. https://doi.org/10.1007/978-3-319-16510-3_9
68. Wu M, Tang W, Wu S, Liu H, Yang C (2020) Fate and effects of microplastics in wastewater treatment processes. Sci Total Environ 757:143902
69. Chen G, Feng Q, Wang J (2020) Mini-review of microplastics in the atmosphere and their risks to humans. Sci Total Environ 703:135504
70. Tadsuwan K, Babel S (2021) Microplastic contamination in a conventional wastewater treatment plant in Thailand. Waste Manag Res 39:754–761
71. O'Donnell B (2020) Understanding the nature of microplastic pollution and identifying environmental impacts. To Protect Water Qual Around World 54:37
72. Zhang Q, Fan D, Pang X, Zhu W, Zhao J, Xu J (2021) Effects of polyethylene microplastics on the fate of antibiotic resistance genes and microbial communities in anaerobic digestion of dairy wastes. J Clean Prod 292:125909
73. Ding N, An D, Yin X, Sun Y (2020) Detection and evaluation of microbeads and other microplastics in wastewater treatment plant samples. Environ Sci Pollut Res 27(13):15878–15887
74. Zhou J, Gui H, Banfield CC, Wen Y, Zang H, Dippold MA, Jones DL (2021) The microplastisphere: Biodegradable microplastics addition alters soil microbial community structure and function. Soil Biol Biochem 156:108211
75. Calero M, Godoy V, Quesada L, Martín-Lara MÁ (2021) Green strategies for microplastics reduction. Curr Opin Green Sustain Chem 28:100442
76. Arpia AA, Chen WH, Ubando AT, Naqvi SR, Culaba AB (2021) Microplastic degradation as a sustainable concurrent approach for producing biofuel and obliterating hazardous environmental effects: a state-of-the-art review. J Hazardous Mater 418:126381
77. Anbumani S, Kakkar P (2018) Ecotoxicological effects of microplastics on biota: a review. Environ Sci Pollut Res 25(15):14373–14396