B. Samuel Jacob
K. Ramani
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Applied Biotechnology for Emerging Pollutants Remediation and Energy Conversion

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Preface

Emerging pollutants sourced from both industries and anthropogenic activity have created havoc in recent years for public health and destruction of biodiversity at multiple levels. The alarming increase in the global population and rapid industrialization might aggravate the problems associated with these hazardous pollutants in the near future. Effluent from different industries may contain high amount of xenobiotic hazardous contaminants such as dyes, hydrocarbons, synthetic surfactants, and microplastics. Industries and public sewers handling such waste streams are facing a plethora of challenges in the effluent treatment and solid waste disposal due to various factors that start from production to adoption of appropriate technologies. Therefore, there is an immediate circumvention of bottlenecks through sustainable mitigation strategies.

Recent boom in circular bioeconomy have created an opportunity to consider the wastes as a resource for value-added products and fuel-similar chemicals. As developing countries are strongly dependent on second- and third-generation biofuels for future energy security, trends in decrease of cultivable land area and water scarcity have forced to depend on waste streams for biofuels and other green alternatives. Waste to wealth could be a sustainable option for the circular economy.

This book entitled *Applied Biotechnology for Emerging Pollutants Remediation and Energy Conversion* encompasses the chapters that provide a deep insight into pollution abatements and energy production with biotechnological interventions that afford cost-effective technologies. To have a clear view from reader's perspective, the book chapters have been fragmented into two parts as follows:

Part I: Pragmatic treatment for hazardous pollutants

Chapter 1 focuses on principles and methods for the removal of microplastics in wastewater.

Chapter 2 elucidates the impacts of plastics on environmental sustainability and ways to degrade microplastics.

Chapter 3 provides an insight into the biosurfactants for plastic biodegradation.

Chapter 4 discusses the effluent xenobiotics and prospects of biogenic zinc oxide nanoparticles for the treatment of textile dye effluent.

Chapter 5 examines the significant advancements on biotechnological and microbial degradation of textile wastewater.

Chapter 6 emphasizes the emergence of antimicrobial resistance among microbiome in wastewater treatment plant and strategies to tackle their effects in environment.

Chapter 7 discusses the role of wastewater treatment technologies in municipal landfill leachate treatment.

Chapter 8 exemplifies the fungal bioremediation of soils contaminated by petroleum hydrocarbons.

Chapter 9 provides an overview on microbial biosurfactant in the removal of hydrophobic (oily) pollutants laden industrial wastes.

Chapter 10 examines hazardous organic pollutant contamination in Indian holistic rivers risk assessment and prevention strategies.

Chapter 11 details the marine wastes its source, production, disposal, and utilization.

Chapter 12 demonstrates a waste-to-wealth prospective through biotechnological advancements.

Part II: Waste to Energy—Bioconversion route

Chapter 13 explains the industrial perspectives of the three major generations of liquid and gaseous-based biofuel production.

Chapter 14 provides an insight into metabolic engineering approaches for bioenergy production.

Chapter 15 discusses exploitation of marine waste for value-added products synthesis.

This book will help to conceive and take up short term, small budget projects that instill confidence among the industry and academia personnel and promote the development of translational projects. More importantly, this would facilitate closer co-operation between industry and academia in the area of environmental cleanup and bioenergy.

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1 Principles and Methods for the Removal of Microplastics in Wastewater

Muneeswari Rajasekaran, Swathi Krishnan Venkatesan, Thanmaya Mohan, Maseed Uddin, Ramani Kandasamy, and Sekaran Ganesan

Abbreviations

ESEM-EDS	Environmental scanning electron microscopy-energy dispersive X-ray spectroscopy
FT-IR-ATR	Fourier transform-infrared spectroscopy-attenuated total reflectance
py-GC-MS	Pyrolysis-gas chromatography-mass spectrometry
SEM	Scanning electron microscopy
SEM-EDS	Scanning electron microscopy-energy dispersive X-ray spectroscopy
TDS-GC-MS	Thermal desorption coupled with gas chromatography-mass spectrometry

1.1 Introduction

Plastic has become a necessary commodity in modern-day life. The manufacturing of plastic has been increasing substantially since 1950, and global production has reached 348 million tons in the year 2017 (Qi et al. 2018; Oliveira et al. 2019) As it is a lightweight, versatile, resilient, and inexpensive material, plastic has been

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profoundly used as an essential constituent for a range of commercial and consumer products. Approximately 50% of plastics are used for single-use disposable products, and nearly 80% of the 8 billion metric tons of plastic produced to date are in landfills or accumulating in the environment (Wagner and Lambert 2018).

The injudicious plastic consumption and the poor management of plastic waste disposal around the world have led to high levels of pollution. Currently, small size plastic particles known as microplastics are widely studied as an emerging anthropogenic contaminant due to their detrimental biological effects on biotic life. The most critical concerns of microplastics are their harmful effects, which are often overlooked due to their microscopic size (Andrady 2017; He et al. 2019) The ubiquitous presence and persistence of these smaller sized microplastics in the environment pose a significant threat to all life on earth. They could physically and chemically harm a variety of exposed aquatic organisms ranging from zooplankton to mammals by blocking their digestive tract as well as providing a feasible pathway to transfer via the food chain and ultimately pose a hazard to human health (Alimi et al. 2018). Another issue concerning these particles is that they act as a vector for the transportation of toxic substances such as persistent organic pollutants, pharmaceuticals, or even heavy metals such as nickel or copper present in wastewater (Li et al. 2019; Naqash et al. 2020). Over the last 10 years, many studies have investigated the distribution and effects of microplastics within the aquatic environment, including ocean, a range of freshwater ecosystems worldwide, and even in Polar regions (Herbort and Schuhen 2017). Despite the contribution of several terrestrial sources of microplastics, wastewater treatment plants are suspected to be a primary point source for microplastics to enter the aquatic environment (Talvitie et al. 2017; Tofa et al. 2019). The origins of microplastics can be of both land and aquatic-based in which urban run-off and wastewater treatment plant effluent fall under land-based sources, while fragmented products of weathering, photolysis, and biodegraded products of macroplastics in the aquatic environment come under marine sources (Sun et al. 2019; Padervand et al. 2020). In several studies, smaller fragments of some conventional plastics including polyethylene and polypropylene beads and polyester, acrylic, polyamide, and nylon fibers were identified in the marine environment, and the researchers suggested that wastewater treatment plant effluent could be a leading source of these contaminants (Li et al. 2018a). This was confirmed by many researchers who have also witnessed a significant presence of microplastics in wastewater treatment plant effluent. For example, in a study conducted by Talvitie et al. (2017), microplastics extracted from the tertiary treated effluent of wastewater treatment plant in Finland and seawater from the Gulf of Finland were found to be similar (Ziajahromi et al. 2017). The extracted microplastics from the marine sediment and the wastewater treatment plant effluent were identical, which signifies that wastewater treatment plant effluent could be the main route for the entry of harmful microplastics into the environment. The sampling and the detection of microplastics in the aquatic environment is a significant challenge in the identification of point source for the release of microplastics into the environment (Song et al. 2015; Padervand et al. 2020). Apart from being microscopic, the analysis of the complex mixture of different plastics is even more tedious. Due to the lack of standard methods for the investigation of microplastics, the development of reliable protocols for the sampling, identification, and characterization of microplastics present in the environmental samples has become the recent research focus among researchers (Godoy et al. 2019). Moreover, studies on the eco toxicological effects of microplastics on living organisms and the pervasive nature of microplastics in the environment emphasize the necessity of more research in this field (Cloutier et al. 2012).

This chapter discusses the environmental interactions of microplastics, different methodologies for the extraction of microplastics, analytical techniques for the characterization of microplastics, and also discusses the challenges and the possible mitigation strategies for the complete elimination of microplastics present in the environment.

1.2 Fate and Occurrence of Microplastics

1.2.1 Occurrence of Microplastics

Wastewater treatment plants can efficiently remove the microplastics in the wastewater but also may act as an entry point for microplastics to migrate into the aquatic environment (Prata 2018). The primary and secondary treatment processes of conventional wastewater treatment can eliminate microplastics from the wastewater by up to 99%. Despite the high removal efficiency, conventional wastewater treatment plants become the most crucial source of microplastics due to the discharge of huge volumes of effluent. Even though 95–99% of solid plastic particles settled with the biosolids, a tenfold increase in the microplastic concentration was observed in downstream of a wastewater treatment plant in the Chicago river (Mintenig et al. 2017). In Europe, it has been estimated that 520,000 tons/year of plastic waste is released in wastewater treatment plant effluent, despite that a substantial proportion of microplastics are suspected to be stuck in biosolids. Also, it is necessary to mention that the usage of wastewater treatment plant biosolids on cultivation lands also could be the potential source of microplastic contamination (Eerkes-Medrano et al. 2015). The schematic representation showing how the treatment plants become the major reservoir of microplastics and entry point for environmental contamination is given in Fig. 1.1.

Generally, microplastics are defined as human-made polymers of size less than 5 mm in diameter, and they are derived from a wide range of sources including textile fibers, pellets from plastic manufacturing and processing industries, and cosmetic industries and the breakdown of larger plastics due to mechanical abrasion and photochemical oxidation in the environment (Dris et al. 2015). Microplastics are found in different shapes such as fragments, foams, granules, and fibers. They are classified into primary microplastics and secondary microplastics (Meng et al. 2019).

1.2.1.1 Primary Microplastics

The primary microplastics are destined to be manufactured in a size >5 mm and are mostly found in clothing, pharmaceuticals, cosmetics like facial and body scrubs,

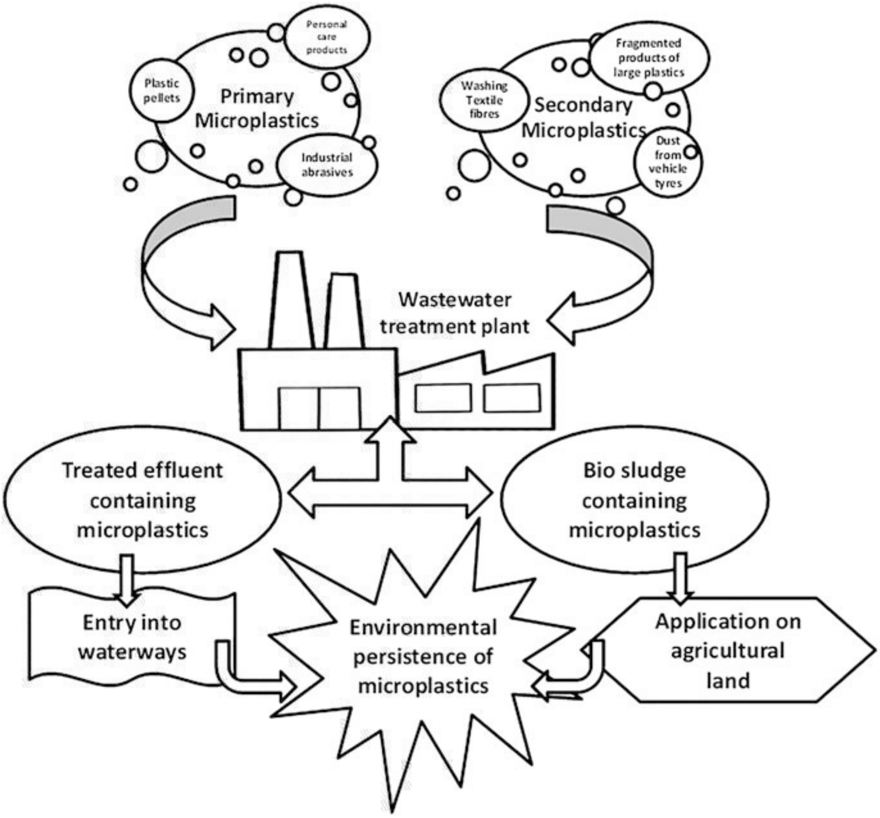

Fig. 1.1 Wastewater treatment plants—A major reservoir of microplastics. Microplastics of different origins discharged into wastewater treatment plants. While at treatment plants, these microplastics are removed via sequential treatment systems with varying efficiency and still large quantities of microplastics are yet again released into the environment through the discharge of treated effluent and biosludge

additives used to increase friction in consumer products, such as cosmetic and facial care products or hand-cleansers and toothpaste, medical supplies, such as grinding polishing agents used in dental teeth and capsules as vectors for inclusion of drugs, overflowing drilling fluid in oil exploration, industrial abrasives and air-blast cleaning media (Van Cauwenberghe et al. 2015). These primary microplastics can be transported by rivers, discharge from water treatment plants, and wind and surface run-off into either freshwater or seawater (Barboza and Gimenez 2015).

1.2.1.2 Secondary Microplastics

Secondary microplastics are the products formed by the fragmentation of large plastic particles due to photo-degradation, physical, chemical, and biodegradation during its stay in the environment (Yu et al. 2018). Fragmentation can occur during the use of materials like textiles, paint, and tires, or once the plastics have been released into the environment. Most of the microplastics present in the environment are secondary plastics, and there would be an increase in the accumulation of secondary microplastics due to the unceasing disposal of plastics following the continuous transformation of secondary microplastics. Another concern arises since there is a higher probability of further breakdown of microplastics into nano plastics, which possesses environmental risks due to the nature of nano-sizes (Chen 2015).

1.2.2 Environmental Behavior of Microplastics

The increasing contamination of MP and its massive distribution in the environment becomes a potential threat to the lives of both terrestrial and aquatic systems. Microplastics are carcinogenic, genotoxic, teratogenic, and able to cause impaired reproductive activity, decreased immune response, and malformation in animals and humans (Ruimin et al. 2019). The number of research on the distribution and environmental effects of microplastics has been increasing recently. Microplastics are more readily consumed by organisms thus giving more chances for further exposure and subsequent effects compared to the larger plastic pieces (Toussaint et al. 2019). A diversity of organisms, including birds, fish, mammals, and aquatic invertebrates, has been shown to ingest microplastics, which has been related to many adverse effects. Furthermore, microplastics have been exposed as a vector for hydrophobic organic pollutants in the aquatic environment, increasing the accumulation of pollutants by marine organisms (Wang et al. 2019a).

1.2.2.1 Ecological Impacts: Interactions with Biotic Life

The migration of microplastics has been seen across all ecosystems in different trophic levels of both terrestrial and marine environments. Microplastics have entered the food chain: (1) animals including mammals, birds, amphibians, reptiles, and fish; (2) plants including algae of spore-producing plants and gymnosperms and angiosperms of spermatophytes; and (3) microorganisms including bacteria and fungi and ciliophoran, protozoa, and phylum. It has been found that three main factors, such as size, color and shape, and concentration, influence the consumption of microplastics by the organisms (Zhang et al. 2019). Mainly, upon contact with microplastics, either entanglement or ingestion by living bodies will occur, and it has been reported that over 200 marine species suffered from the entanglement and ingestion of plastic debris. However, the degree of the physical impact of microplastics on organisms remains unclear, and entanglement is frequently allied with relatively large animals and is observable when we compare it with consumption. Entanglement could cause severe impacts on aquatic species; they can even be lethal by means of drowning, suffocating, asphyxiating, or starving. The vulnerable species include sea turtles, mammals, seabirds, and crustaceans (Li et al. 2018a). Also, many studies evidenced that organisms at the bottom level of the marine food web ingest microplastic particles, which could lead to unintentional or deliberate consumption of these micro particles by the organisms as microplastics can be flawed for food. Also, there arises a concern about potential dangers to organisms at the upper trophic level as microplastics ingested by zooplankton can be biomagnified to organisms at higher trophic levels including humans (Auta et al. 2017).

1.2.2.2 Microplastics as a Chemical Threat: Interactions with Organic Contaminants

In recent times, studies on the toxicity of microplastics towards the aquatic ecosystem have also become the research focus. It has been found that microplastics could be a potential carrier for most of the environmental pollutants present in water systems (Li et al. 2019). Compared to freshwater environments, severe mechanical abrasion, and microbial function during the treatment processes in wastewater treatment plants might cause an improved effect on the physicochemical properties of the microplastics. Also, the physicochemical properties of microplastics present in biosolids were found to be influenced by the treatment. For instance, the microplastics are broken down into reduced sizes in lime stabilization, surface melting, and blistering were seen in thermal drying, and the microplastic concentration declined in anaerobic digestion. However, it is imprecise whether these surface alterations influence their adsorbing capacity (Auta et al. 2017). The adsorption and accumulation of several pollutants onto microplastics were widely studied, such as polychlorinated biphenyls, polycyclic aromatic hydrocarbons, antibiotics, and heavy metals. The larger surface area and the hydrophobic nature of the microplastics play a significant role in attracting hydrophobic organic pollutants (Guo et al. 2019). Many researchers also evidenced the presence of organic chemicals in a variety of microplastics. Yu et al. (2018) reviewed the behavior of adsorbed organic compounds on the microplastics in the aqueous environment. Previous studies reported that the size and hydrophobicity of Microplastics were the primary influence factors for plastic adsorption. In contrast, hydrogen bonding, hydrophilicity, and increasing specific surface ratio influenced the adsorption potential of aged microplastics. Besides, salinity and the pH of the water system also affect the sorption capacity of microplastics by altering the ionic nature of both microplastics and pollutants and lead to competing for adsorption (Chen 2015).

1.3 Sampling, Detection, and Extraction of Microplastics

1.3.1 Environmental Sampling of Microplastics

Though their search on microplastics has been increasing for years, no standard protocols for sampling, pretreatment, quantification, and identification are available. Also, a significant difference has been observed in previous research, which causes difficulty in developing solutions (Ziajahromi et al. 2017). For the sampling of microplastics from wastewater, two approaches are being followed: volume-reduced sampling and bulk sampling. Simple types of equipment like net-based devices (neuston or plankton nets) or a sieve are used for sampling and required no technical assistance. The sieve mesh size of 300 μm is used worldwide. The neuston nets are highly recommended for bulk sampling in large rivers and lakes since the microplastics of all size ranges can be retained (Li et al. 2018b).

1.3.2 Extraction of Microplastics

Several separation techniques are being applied for the extraction of microplastics from the aqueous samples. Some studies included a single step, whereas some used a series of separation steps. Sieving, homogenization, concentration, digestion, and density separation are the commonly used extraction techniques (Ou and Zeng 2018). Still, no standardized protocol has been established for the extraction of microplastics from wastewater. More methodological research has to be performed on the extraction of microplastics and their fate during those procedures. Furthermore, the effects of operational parameters such as pH, presence or absence of Fenton's reagent, and temperature remain unknown. The physical characteristics of the microplastics such as size, shape, and density and the chemical attributes like the composition of wastewater (inorganic and organic matters) are the most critical factors to be considered during the separation process (Quinn et al. 2017).

Sieving is the widely used technique applied for the separation of microplastics from the wastewater samples. Density-based separation is another method used for the extraction of microplastics. Typically, salt mixtures are used in density-based separations to provide the buoyancy capacity to plastic particles. The selection of salt mixtures for the separation is made based on the recovery, operation cost, and environmental effect. Some of the generally used salt solutions are NaCl, $CaCl_2$, NaI, $ZnCl_2$, and Sodium polytungstate. However, this method is time-consuming and cannot distinguish the type of plastic. Additional measures like staining and alcohol burning could be used to achieve accuracy in the microplastic's characterization (Ou and Zeng 2018).

1.3.3 Detection of Microplastics

The identification of microplastics from various environmental samples can be performed by using different advanced instrumental analyses. The techniques applied for the detection of microplastics are categorized into physical and chemical characterization methods (Fig. 1.2).

1.3.3.1 Scanning Electron Microscopy

Scanning electron microscopy (SEM) is broadly used for the physical characterization of microplastics. During analysis, the focused beam of electrons will be allowed to pass on the surface of microplastics which provides the morphological images of microplastics. SEM-energy dispersive X-ray spectroscopy (SEM-EDS), and environmental scanning electron microscopy-EDS (ESEM-EDS) could be additionally employed for the determination of elemental composition along with the surface

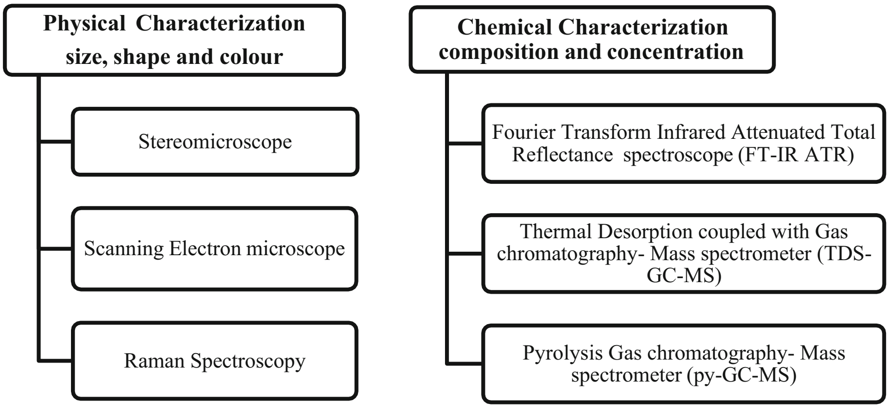

Fig. 1.2 Methods of characterization of microplastics. Analytical techniques available for the identification of microplastics are categorized accordingly

morphology of microplastics based on diffraction and reflection of emitted radiation from microplastics surface (Rocha-Santos and Duarte 2015; Talvitie et al. 2017).

1.3.3.2 Fourier Transform-Infrared Spectroscopy-Attenuated Total Reflectance

Fourier transform-infrared spectroscopy-attenuated total reflectance (FTIR-ATR) is the most frequently preferred method employed for the characterization of microplastics extracted from the effluent of wastewater treatment plants. Here, the infrared spectrum of microplastics will be analyzed for the characteristic peaks corresponding to the test sample with reference to the spectral library (Wang et al. 2019b; Zarfl 2019). During analysis, microplastic samples are exposed to the definite interval of infrared radiation and based on the composition. The molecular structure of the microplastic, excitation vibration spectrum will be derived. In attenuated total reflectance mode, larger microplastics of size more than 500 μ can be analyzed whereas, sizes lesser than 20 μm can be examined under FT-IR coupled with microscopy. These techniques are simple, fast, specific, reliable, well-established, and non-destructive (Song et al. 2015). The newly developed focal array plane-based micro-FT-IR imaging technique is highly effective in the quick acquisition of a broad spectrum in a short duration. The limitations associated with this methodology are (1) sample should be active in the infrared region; (2) Not suitable for non-transparent materials; (3) exorbitant and requires experienced personnel for handling equipment; (4) the detection and interpretation of data could be intervened by environmental matrices such as biofilm (Rocha-Santos and Duarte 2015).

1.3.3.3 Raman Spectroscopy

Raman spectroscopy is another frequently used spectroscopic method for the characterization of microplastics. The functional characteristics of the microplastics can be identified in the form of a vibrational spectrum based on the molecular vibrations of the sample. This technique is highly sensitive towards nonpolar functional groups and is impervious to undesirable signals of water and atmospheric CO_2. Microplastics of particle size >1 μm can be analyzed using Raman spectroscopy coupled with microscopy, and it is the only technology existing for analyzing microplastics in the range of 1–20 μm.

However, this method is more susceptible to fluorescence intervention by biological, organic, or inorganic substances in samples. Hence, sample purification is necessary to avoid sample alteration before analysis. Some researchers used Nile red fluorescent dye for sample preparation for quick and precise analysis.

1.3.3.4 Thermal Desorption Coupled with Gas Chromatography-Mass Spectrometry

In Thermal desorption coupled with Gas chromatography-Mass spectrometry (TDS-GC-MS) analysis, the sample will be heated at high temperatures up to 1000 °C in a thermo-gravimetric balance; degraded products are allowed to adsorb onto the solid phase and then shifted to a thermal desorption unit. Then, the temperature will be raised to desorb the products, separated in the chromatography column, and finally analyzed by mass spectrometry. TDS-GC-MS is not suitable for qualitative analysis and is only preferred for samples of mass up to 100 mg (Ou and Zeng 2018; Nguyen et al. 2019).

1.3.3.5 Pyrolysis-Gas Chromatography-Mass Spectrometry

Pyrolysis-gas chromatography-mass spectrometry (py-GC-MS) is highly suitable for the characterization of microplastics of size >500 μm, which can be handpicked using tweezers. The analysis involves sample decomposition at elevated temperatures and separation of the gaseous products through the column of gas chromatography followed by mass spectrometric analysis. Reproducibility is challenging with py-GC-MS, as results are highly dependent on sample preparation, pyrolysis type, and pyrolysate transfer. Pyrolysis can be performed in three ways: (1) electrically heated filament pyrolysis, (2) furnace pyrolysis, and (3) curie point pyrolysis. Curie point pyrolysis is faster and more precise among the three methods, and quantification is possible since the temperature is high enough to avoid unpyrolyzed residue. When compared to TDS-GC-MS, py-GC-MS is highly specific and more suitable for the identification of small masses of particles (∼50 μg). The disadvantage of this technology is that the database is available only for selected polymers such as polyethylene and polypropylene (Ou and Zeng 2018; Toussaint et al. 2019; Zarfl 2019; Zhang et al. 2019).

1.4 The Fate of Microplastics during Wastewater Treatment

Understanding the transportation of plastic in wastewater treatment plants is challenging due to the complex nature of wastewater. The high concentration of microplastics is removed at the first screening operations, and microplastics removed during the secondary and tertiary treatment steps are stuck into biological sludge.

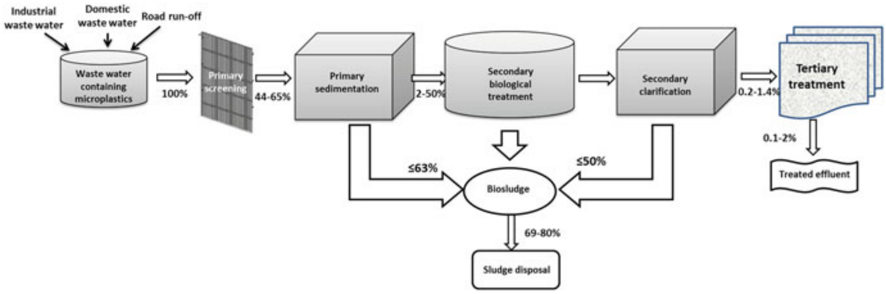

Fig. 1.3 Migration of microplastics during wastewater treatment—Microplastic removal efficiency is given for each stage in wastewater treatment plant

The treated wastewater of a single treatment plant releases around 105–10 numbers of microplastics per day into the environment since a massive quantity of treated effluent is being discharged from the wastewater treatment plants (Ou and Zeng 2018). The movement of microplastics through every treatment stage in a typical wastewater treatment plant was shown in Fig. 1.3.

The primary and secondary stages of the traditional wastewater treatment process can efficiently remove microplastics. However, many researchers suggested that wastewater treatment plants could be the potential sink for persistent microplastics due to the discharge of huge volumes of treated effluent and disposal of bio sludge bound with microplastics. Wastewater treatment plants have been incessantly operated to improve the quality of the effluent, but, there is no specific treatment technology available for the removal of microplastics from the wastewater. Conversely, some studies reported the improved removal efficiency of some unconventional final-stage wastewater treatment processes. Besides, more research have been performed to assess the stage-wise effectiveness of wastewater treatment plants in the removal of microplastics. It has been reported that most of the microplastics are removed during the primary stage itself and estimated that for every 1.14 thousand liters of discharge, an average of one microparticle was found.

Further, Talvitie et al. (2017) studied the efficiency of three different new tertiary treatment technologies: disc filter, rapid sand filtration, and dissolved air flotation in the removal of microplastics from the effluent of four wastewater treatment plants. Membrane bioreactor treating primary effluent and the tertiary treatment processes treating secondary effluent were included in the study. The membrane reactor removed 99.9%, rapid sand filter 97%, dissolved air flotation 95%, and disc filter 40–98.5% of the microplastics during the treatment. A recent study by Gies et al. (2018) conducted a study in secondary treatment plants in Vancouver, Canada. It estimated that 1.76 ± 0.31 trillion microplastics enter the wastewater treatment plant annually, with 1.28 ± 0.54 trillion microplastics settling into primary sludge, 0.36 ± 0.22 into secondary sludge, and 0.03 ± 0.01 trillion microplastics released into the receiving environment which corresponds to total retention of 99% microplastics in the wastewater treatment plant. Yang et al. (2019) evaluated the microplastic removal potential of China's largest water reclamation plant and detected 18 different types of micro polymers of average size 1111 μm with microfibers as the dominant type. The influent concentration of 12.03 microplastics/L was reduced to 0.59 microplastics/L in the effluent after treatment, i.e., more than 95% of microplastics present in the influent was removed by the treatment. The treatment characteristics of the three different biological processes, such as anaerobic-anoxic-aerobic, sequence batch reactor, and media processes of the sewage treatment facilities in Korea were studied by (Lee and Kim 2018). All three examined methods efficiently removed the microplastics up to 98%, and individual efficiencies were found as 49.3%, 44.7%, and 49% for the anaerobic-anoxic-aerobic process, sequence batch reactor process, and media process, respectively. Also, it has been reported that in spite of the greater removal efficiency of biological processes, still more than 4 billion microplastics were discharged every year due to the large volume of effluent. Although all the treatment stages are undoubtedly removing the large concentration of microplastics from the effluent, still it remains a concern towards the complete mitigation to avoid the escape of microplastics from wastewater treatment plants into the environment (Gies et al. 2018; Lee and Kim 2018).

1.5 Perspectives

Since research on wastewater microplastics is in its beginnings, many questions remain unsolved, and more research is required in specific fields. The following areas have to be explored widely for a more profound understanding of the providence of microplastics in wastewater treatment plants. (1) the standard protocol for the surveillance of the entry of microplastics into wastewater treatment plants, (2) a valid methodology for the detection and quantification of microplastics in water environment; (3) a complete study on the migration and ultimate fate during treatment (4) assessment on the potential of water reservoirs to be a source of microplastics to the oceans; (5) evaluation and understanding microplastics interactions with biotic life; (6) influential study on the ecosystem and evaluate the concerns of microplastics towards humans (Barboza and Gimenez 2015; Eerkes-Medrano et al. 2015).

Also, the current wastewater treatment focuses only on removing the microplastics and not aiming for its complete degradation, which makes microplastics global pollutants. Their persistence continues to upsurge as they appear to be very difficult to remove physically because of their small size and less visibility. Also, the rate of the entry of microplastics into the environment surpasses the speed of its removal. Hence, the need for viable technology with the potential of eliminating these persistent pollutants from wastewater becomes mandatory. Recently, complete mineralization of plastics by some particular microbial strains has been reported by many researchers, and they have also attained prospective results in the biodegradation of these dangerous polymer substances. Many bacterial species have been found to have the potential of degrading plastic compounds. Singh et al. (2016) studied the efficiency of soil bacterial isolates

Staphylococcus sp., *Pseudomonas* sp., *and Bacillus* sp., on the degradation of polyethylene.

In the same way, Asmita et al. (2015) evaluated polyethylene terephthalate and polystyrene degrading potential of soil microbes including species of *Aspergillus niger*, *Pseudomonas aeruginosa*, *Bacillus subtilis*, *Staphylococcus aureus*, and *Streptococcuspyogenes*. In addition, the biofilm-assisted polystyrene degradation was exhibited by abacterium *Rhodococcus ruber* in a study conducted by Mor and Sivan (2008). The use of plastic degrading microbes for the bioremediation of microplastics is considered an environmentally acceptable approach for the removal of microplastics during wastewater treatment (Deepika and Jaya Madhuri 2015). Also, *Pseudomonas putida*, *Brevibacillus borstelensis*, *Streptomyces* sp., *Pseudomonas stutzeri*, and *Alcaligenes faecal* were found as potential plastic degrader, and they produced enzymes for the breakdown of plastic polymers. Recently, a team of researchers identified the two enzyme systems PETase and MHETase, produced extracellularly by a bacterium *Ideonella sakiensis,* which degraded polyethylene terephthalate and terephthalic acid and ethylene glycol were released produced as the products (Yoshida et al. 2016). Hence, the application of these plastic assimilating organisms could be extended for the removal of microplastics from wastewater through biological interventions.

1.6 Conclusion

Being the major reservoir of microplastics, wastewater treatment plants become the essential point source of microplastic contamination in the environment. During treatment, microplastics are significantly removed stage-wise; still, an enormous amount of microplastics is being released into the environment via treated effluent and biosludge. Hence, more effort must be taken to mitigate the global rise of microplastic pollution. Although many policies are being proposed regarding the alleviation of microplastics, source elimination would be the best way to reduce microplastic pollution. In this way, the most efficient bioremediation approach could be employed to degrade the persistent microplastics, and further exploration in this field is compulsorily required.

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The Impacts of Plastics on Environmental Sustainability and Ways to Degrade Microplastics

2

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2.1 Introduction

Plastics are derivatives of petrochemicals and are usually synthesized of high molecular weight as a backbone and compensated with various complex chemical compounds. Plastics are derived from the polymerization of monomers, which are synthetic-based extracted from oil or gas. Due to various properties like easy manufacturing, flexibility, plasticity, toughness, durability, inert, corrosion-resistant, lightweight, sterile nature, comparative cost-effectiveness, and imperviousness to water**,** plastics have become one of the basic needs and most important requirement for everyone in daily life. But it triggers litter, harming nature, pollutes the environment, and reduction of valuable natural possessions on earth (Awasthi et al. 2017). Animals ingest plastic bags by thinking of their food, unfortunately, become sick and also cause death as it remains intact in their bodies and does not decompose even after their death (Puncochar et al. 2012). The polymer consists of non-renewable raw materials as well as renewable ones. These polymers are used in the industry, electrical appliances, transportation, construction, storing, and packaging purposes. (Eubeler et al. 2009). Polyvinyl chloride (PVC), Polystyrene (PS), Polypropylene (PP), and Polyethylene terephthalate (PET) are polymers that vary by their chemical structure, structural arrangement, physical properties, and their applications. When it gets discarded, it contaminates landfills, freshwater, damages ecological balance,

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