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Microplastic Removal from Wastewater: A Review

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Abstract

Water, essential for all life forms, faces increasing contamination due to rising population and industrialization. Microplastics (MPs), defined as plastic particles smaller than 5 mm, contribute significantly to water pollution, entering ecosystems from various sources and subsequently affecting organisms. These microplastics exhibit diverse characteristics, including size, type, and color. Upon ingestion or absorption by organisms, they pose detrimental effects on animals, plants, and humans, leading to various diseases. In wastewater, microplastics interact with other pollutants, complicating removal processes. Factors such as particle size, weathering, and surface properties influence the behavior of microplastics in aquatic environments. Microplastics must be correctly identified before they can be removed. Scanning electron microscopy (SEM), SEM-energy-dispersive X-ray spectroscopy (SEM-EDS), and environmental SEM-EDS are some of the techniques that are commonly used for this. Traditional methods for microplastic removal have proven less effective over time, prompting the development of advanced techniques. Emerging approaches, including the use of micro-algae, magnetic extraction, and metal-organic frameworks, show promise in enhancing microplastic removal efficiency. However, it is imperative to prioritize strategies aimed at reducing plastic consumption and minimizing microplastic release into the environment. In conclusion, addressing microplastic pollution in water necessitates a multifaceted approach, combining awareness-raising efforts, improved detection methods, and innovative removal technologies. By implementing these strategies, we can mitigate the adverse effects of microplastics on aquatic ecosystems and human health.

Keywords: Microplastics (MPs), Industrialization, Micro-algae, Magnetic extraction, Metal-organic.

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1. Introduction

Plastics that are smaller than 5 mm in diameter are most defined as microplastics (MPs), which are everywhere in several terrestrial and aquatic environments. There are various types of microplastics, such as primary, secondary, biodegradable, and non-biodegradable microplastics. Primary microplastics originate from daily-use products (e.g., toothpaste, scrubbers, and facial cleansers), and secondary microplastics originate from the breaking up of large plastics into small waste particles through chemical, mechanical, photo-oxidation, or biological interactions [1]. Biodegradable microplastics (MPs) are completely degraded by microorganisms into carbon dioxide and water and are environment friendly. On the other hand, non-biodegradable microplastics are not degraded easily by microorganisms. From different sources, these microplastics discharged into aquatic environment and primarily originate from terrestrial environment: discarding plastic wastes, mismanaged landfills, and accidental loss or mishandling of plastics, i.e., the lack of a barrier surrounding the landfill with no suitable synthetic material to cover wastes. These microplastics cause pollution in aquatic environment [2]. Currently, microplastic pollution has attracted more focus from community and has become a worldwide environmental issue.

Evidence has revealed that in the aquatic environment, microplastics may be stable for thousands of years due to their chemical stability. Both food chain and human health could be affected by this microplastic pollution. The harmful chemicals attached to plastic particles also have various harms to marine organisms and pass to human beings through food chain [3]. Sewage sludge from around world has demonstrated to contain microplastics. In recent years, pollution through microplastics in both terrestrial and aqueous environments has of rising worldwide consideration, owing to (a) possibility to adsorb persistent organic pollutants because of their large specific surface areas; (b) poor degradation that thus results in accumulation; and (c) the possibility that they might be possibly ingested by fish and other living organisms. A variety of microplastics are also identified in samples collected from wastewater treatment plants [4]. Microplastics could be identified in all ecological systems and environments, like rivers, oceans, lakes, sediments, soils, and marine animals. For microplastic recovery, first sample collected and pretreated. Microplastics are recovered from wastewater to make water usable.

Although most of the MPs in the wastewater can be recovered by passing over wastewater treatment methods, significant amounts of microplastics remain in the wastewater and discharged to the surrounding receiving waters, such as ocean, river, and lake systems [5]. There are different methods of microplastic recovery, such as biological, physical, and chemical methods. Even if maximum amount of microplastics (greater than 90%) can be removed from wastewater treatment plant according to current treatment methods, several microplastics can even pass wastewater treatment plant and enter aquatic environment through wastewater. Conventional separation methods sedimentation, clarification, filtration, floatation, sieving, density separation, and activated sludge have many demerits [6]. To separate small microplastic particles, advanced separation techniques can be unified with conventional techniques or employed as separate steps. Micromachines, magnetic separation, membrane bioreactors, and degradation-based methods such as biodegradation, photocatalysis, thermal degradation, and electrocatalysis are advanced microplastic separation methods. However, all these techniques are expensive. So, there is a need for an energy-saving, cheap, and innovative technique can be a substitute for existing techniques to recover microplastics from wastewater [7].

2. Types of microplastics

Microplastics can be divided into three main types according to their source, shape, and degradation.

2.1. Types of microplastics based on source

Microplastics are categorized into primary and secondary microplastics based on their source. Primary microplastics are created from toothpaste, clothing fibers, medical products, and cosmetics. Some examples of primary MPs are plastic fibers utilized in synthetic textiles (e.g., nylon), microbeads present in personal care products, and plastic pellets used in industrial manufacturing [8]. Through any of several channels, primary microplastics come into the environment directly: for example, accidental loss from leaks during production or transportation, scraping during washing (e.g., laundering of clothing formed with synthetic textiles), and product usage (e.g., personal care products being washed into wastewater systems from households). Secondary MPs are formed from the breakdown of larger plastic products. Examples of secondary MPs include fibers from synthetic clothing and fragments of items such as plastic bags and bottles. Different types of microplastics are also represented in Figure 1 [9].

2.2. Types of microplastics based on degradation

Based on degradation, MPs are also classified into two types: biodegradable and non-biodegradable microplastics. Biodegradable microplastics are environmentally friendly and entirely degraded by microorganisms (e.g., fungi, algae, and bacteria) into carbon dioxide (CO_2) and water (H_2O). Examples of biodegradable MPs are polylactic acid, polyhydroxyalkanoates, and polycaprolactone. Microplastics that cannot be degraded readily by microorganisms are known as non-biodegradable. Polystyrene, polyethylene terephthalate, polyethylene, polypropylene, and polyurethane are some examples of non-biodegradable MPs [10].

2.3. Types of microplastics based on shape

Microplastics are categorized into four types based on their shapes observed under the optical microscope. These microplastics are fibers, fragments, granules, and film. Such types of microplastics have different sources based on their shape. The possible sources of fibrous microplastics include two major types, such as industrial products and synthetic clothing. Industrial products, for example, plastic films and coil frameworks, will produce fibrous microplastics, and the main constituents of synthetic clothing are polyester and nylon fiber. The fragmentary microplastics may originate from the plastic goods used in humans' daily lives (like packaging bags) or from resin-like plastics that are used in industrial manufacturing activities, containing adhesion agents, insulation boards, and foam boards [11]. These plastics will be progressively divided into fragmentary shapes using chemical, biological, and physical methods. The possible sources of granular MPs are commonly correlated to microspheres in personal care products, such as toothpaste, shower gel, and facial cleansers. Moreover, granular microplastics may also be present in some parts and components of some industries, such as electronics and automobile manufacture. The film-like microplastics are usually derived from packaging products like preservative films, bottles for drinking water, and fast-food boxes, or from commercial-grade plastic films, for example, X-ray plates, magnetic tapes, and photographic films [12].

3. Colors of microplastics

Dyes and pigments are employed in the manufacture of plastic goods to increase their attractiveness for usage and their performance. The microplastics of different colors in the water are a sign that microplastics are mixed within aqueous environment from various sources. The presence of colored (white, black, blue, green, red, yellow, and other colors) or transparent microplastics in wastewater treatment plants and aqueous environments has described by various researchers. Even though it is thought to be unimportant because impact of color feature on microplastic removal effectiveness cannot be determined, dyes within microplastics have a poisonous effect on marine organisms. There is also research demonstrating surfaces of colored microplastics can contain toxic substances, for example, heavy metals and persistent organic contaminants [13]. Because colored or transparent microplastics discharged from sewage and wastewater are like food, intake by organisms in marine environment gathers in their bodies and reaches human beings through food chain.

Furthermore, microplastics of various colors are discharged into marine environment and affect anatomy of algae by varying light absorption into marine environment and producing a shading effect. In current research investigating effect of black, white, and green polyethylene terephthalate microplastics on *Microcystis aeruginosa*, it observed that particularly green microplastics enhanced growth and photosynthesis of *M. aeruginosa* because of their color near cyanobacteria, and black and white microplastics were determined to prevent photosynthesis because of their greater shading effect. Additionally, in research, it observed that microplastics of green color restrained microcystin manufacture; on other hand, white and particularly black microplastics caused a considerable rise in microcystin manufacture [14].

4. Sources of MPs

The MPs originate from different sources, and the quantity of MPs entering the wastewater can be impacted by human activities, resulting in daily, monthly, and seasonal differences. The primary source of plastic pollution is produced in the city and sub-city areas, followed progressively by the overflow of plastic pollution that ends in rivers, seas, and oceans. A few of the other sources of microplastics are plastic waste, such as washing synthetic clothes, cosmetics, toothpaste and rubber, derelict vessels and car tires, and cleansing agents in personal care products [15]. Terrestrial-based sources contribute eighty to ninety percent of microplastics to aquatic environments, which comprise plastic bags, plastic bottles, personal care products, plastic incinerators, construction materials, and textiles. Marine-based sources impart ten to twenty percent of microplastic release into aquatic environments, mostly marine vessels, plastic waste on coasts, and fishing tackle. In Table 1. Different sources of microplastics are represented. In Figure 2: from different activities, the percentage release of microplastics is also described [16].

5. Transfer of Microplastics in Organisms

There is firm support for transport of MP particles to human beings. Ingestion of plastic particles by humans can happen through consumption of terrestrial and aquatic food items, drinking water, and inhalation. Even though seafood is a recognized source of pollutants in human food, presence of MPs in seafood is neither measured nor regulated. Seafood might be polluted with MPs through intake of natural prey, attachment to organism's surface, or during manufacturing and packaging stage [17]. Medical studies on both animals and humans have revealed transfer of MPs from gut cavity to lymphatic and circulatory systems. Very thin particles can cross cell membranes, blood-brain barrier, and the placenta, with recognized effects comprising cell damage, redness, oxidative stress, and impairment of energy distribution identical to that described for aquatic organisms. Figure 3 represents way microplastics transfer to human beings [18].

6. Microplastics demerits

Microplastics' effects on surroundings can be due to direct contact with microplastics themselves or because of discharge of pollutants that related to microplastics. There is a considerable requirement to eliminate microplastics from wastewater before release, as they pose a risk to marine animals' health. Marine organisms consume microplastics, unclearing them as food, which can then go into their main organs and circulatory system, resulting in various abnormalities such as genotoxicity and stunted growth [19]. Microplastics can also cause physical harm to an organism because of their aggregation in the digestive tract. The hazards of harm caused by direct exposure to microplastics vary according to type of organism, microplastic polymer type, and period of exposure, concentration of exposure, and size and shape of microplastic. One more hazard for marine organisms because of microplastic exposure can be due to the existence of microbes like viruses, bacteria, and other microorganisms on the surface of microplastics, which can lead to health problems in marine organisms [20].

Fish are frequently chief or intermediary predators and thus ingest microplastics directly or indirectly. Decreases in predatory performance and efficiency, genotoxicity, and neurotoxicity are some of the major effects of microplastics on fish. The consequences of microplastics observed in crustaceans and mollusks include slow growth and birthrate, enhanced energy usage, neurotoxicity, genotoxicity, and finally death. Besides the effects of direct microplastic intake, various studies have also recognized the combined effects of microplastics with other different environmental contaminants, for example, pharmaceutical contaminants, metal ions, heavy metals, etc. Microplastics have a higher adsorption ability for several contaminants [21]. Formation of biofilm on its surface furthermore raises capability of microplastics to adsorb heavy metals, persistent organic pollutants, and pharmaceutical and antibiotic pollutants. Accumulation of microplastics and their related pollutants in wastewater treatment plant effluents can give rise to a risk of pollutant accumulation for higher-level organisms and pollutants transfer over food chain that can eventually cause health effects in terrestrial organisms, including humans [22].

Fish is believed to be a promising source of protein for human beings. Therefore, at the end of the food chain, humans consumed a vast range of fish and crustaceans and, at the same time, consumed MPs through this class. Thus, this kind of consumption shows a potential risk to human health and has become an emerging concern in recent decades. Microplastics are accessible in the organs (tissue, intestine) of many marine animals, for example, crustaceans, bivalves, and fish. Several factors, for example, size, density, shape, and color, are responsible for bioavailability of microplastics to marine species. A few plastics are responsible for releasing harmful components that can cause tumors in humans. Due to microplastic contamination, a range of disorders, such as obesity, lung cancer, respiratory issues, birth defects, asthma, cardiovascular diseases, and viral diseases, also observed. In Figure 4 some demerits of microplastics described [23].

7. Microplastic interactions with pollutants in wastewater

Microplastics coexist with contaminants, for instance, pesticides, heavy metals, bisphenols, antibiotics, polychlorinated biphenyls (PCBs), and polyaromatic hydrocarbons (PAHs) in wastewater. Microplastics adsorb contaminants from wastewater, and MP-pollutants in marine environments have a synergetic poisonous effect on organisms because of their large surface area. Studies show that different factors, such as the type of pollutant, its concentration, the type of microplastic, its concentration, its properties, pH, ionic strength, and the amount of organic matter present, can help different contaminants stick to microplastics in water [24]. Furthermore, studies have indicated that several different mechanisms, like electrostatic interaction, hydrogen bonds, hydrophobic interactions, and $\pi - \pi$ interactions, are efficient in the adsorption of contaminants to microplastics, which depends on microplastic and contaminant properties. Most of the current studies about microplastic adsorption and contaminants have been conducted in distilled water and surface waters [25].

8. Factors affecting the interaction mechanism of microplastics

The mechanism of interaction must be examined more to obtain a further understanding of the fate of microplastics in the water environment. Microplastics are found because of the breakdown of larger plastic particles (secondary microplastics) through mechanical abrasion methods during conversion. Because of turbulence in the water stream and the activities of the mechanical devices in the wastewater treatment plants, microplastics are formed by the breaking up of solid plastic waste and microplastics [26]. Microplastic modification occurs in the form of enlarged surface oxidation and micro-cracking in old plastic, which is commonly produced through the natural effects of exposure to the marine environment. Their physical interactions play a vital role in procedures because of intermolecular hydrogen bonding, electrostatic interactions, and partition coefficient. From the study of microplastic modification, it was found that a few basic characteristics, for instance, chemical nature of plastic, environmental circumstances, loads, and hydrophilicity, controlled rate of modification [27] and [28].

a. Particle size

The environmental fate of microplastics is determined by size of a particle in the plastic. The adsorption capacity of microplastics also depends on particle size of the microplastic. The studies also revealed that the particle size can affect the adsorption mechanism of organic chemicals in addition to equilibration times. The adsorption properties of plastic particles differ with size; smaller particle sizes have higher adsorption capabilities than larger plastic particles. In Table 2. The percentage of different sizes of microplastics, according to width, in toothpaste is described [29].

b. Weathering process

The physical changes of the plastic particles are caused by their breakdown into small fragments, and the chemical changes are because of photo-oxidation, which alters the functional groups of the plastic particles and is included in weathering processes. Plastic becomes more proficient at absorbing chemicals through the weathering processes. Extended friction, saltwater corrosion, photo-oxidation, and some other factors affect the breakdown of the old plastic in the surroundings. The specific surface area and surface irregularity of microplastics are enhanced due to the larger particles' decay by photo-oxidation and friction, which also raise the capacity of adsorption [30].

c. Surface functional groups

Various characteristics, for example, movement, accumulation, pollutant adsorption, biological availability, and toxicity of microplastics might be affected by the variations in surface functional groups that change the hydrophobicity and the surface charges of microplastics. The functional group that contains oxygen can be created on the surface of the weathered microplastics. This might decrease the hydrophobicity and, therefore, the capacity of adsorption. The process of weathering and environmental circumstances describes the types and production directions of functional groups containing oxygen [31]. The existence of excessive hydrogen atoms in a marine environment increases the creation of the phenolic hydroxyl group on the surface of microplastics, whereas UV radiation is responsible for the development of the C-O group, more probably in a dry environment. The more reactive and heterogeneous surfaces of microplastics formed because of the aging treatment. This mechanism promotes good adsorption by enhancing the negative charges on the surface of microplastic, which increases the electrostatic interactions [32, 33].

8.4. Composition of Plastics

The interactive mechanism of microplastic is affected by the composition of the plastic. The differences in their chemical composition and their structures might be the cause of the change in interactive mechanisms. This happens due to the sequence of the polymer chain and intermolecular attraction. It was shown that the polymers rich in rubber had greater interaction with respect to their empathy for organic contaminants (like pharmaceuticals) and mobility. In other words, the greater the rubber constituent, stronger capacity of adsorption. This is because of chemical characteristics of rubbery microplastic, which produce a lot of invalid or free space within chain, assisting adsorption [9-34-35]. According to the glass transition temperature (Tg), polyethylene (PE) is considered rubbery plastic, whereas polyvinyl chloride (PVC) and polystyrene (PS) both considered glassier plastic. Rubbery plastic has a low Tg (for example, polyethylene has a Tg − 20 ◦C), while glassier plastic has a higher Tg (for example, polyvinyl chloride has a Tg of 80–90 ◦C). This is due to rigid chains and greater intermolecular attraction, which results in more closely located chains and a smaller free volume among chains. Thus, glassier plastics such as polyvinyl chloride and polystyrene attain larger diffusivity than rubbery polymer polyethylene, which results in higher adsorption efficiency of rubbery plastics such as polyethylene in comparison to former plastics. On other hand, polystyrene polymers give a larger distance between neighboring polymeric chains in presence of benzene, which provides an easier approach to organics than polyethylene [36].

9. Identification of microplastics

The characteristics of microplastics, for example, shape, size, color, abundance, density, and chemical properties, affect their dispersion in environment. Currently, characterization of microplastics primarily emphasizes structural and physical characterization and identification of chemical properties of microplastics. Optical microscopy, particularly stereomicroscopy, has used for optical analysis and pre-classification of microplastics in several studies [37]. Scanning Electron Microscopy (SEM), Scanning Electron Microscopy and Energy Dispersive X-ray Spectroscopy (SEM-EDS), and Environmental Scanning Electron Microscope with an Attached X-ray Energy Dispersive System (ESEM-EDS) have also employed to describe surface morphology of fibers and microplastic particles. Optical observation has conducted to calculate and classify microplastics into several classes according to shapes, colors, and sizes of microplastics.

Whereas visual observation is an important phase for the identification of microplastics in sludge samples and wastewater, it is not enough to approve chemical characteristics of particles and fibers. As such, it won't be feasible to differentiate natural fibers from synthetic fibers [38]. In urban wastewater, cellulose usually arises from toilet tissue, which could account for about 71.99% of the total suspended solids (TSS); therefore, visual inspection could simply overestimate amount of microplastics because of misidentifying fibers and particles are not microplastics. To put it simply, if visual inspection cannot tell the chemical makeup of fibers apart from other particles in wastewater samples, then they need to be characterized in some other way. It is therefore necessary to use the Fourier transform infrared spectroscopy (FTIR), the Raman spectroscopy, or any other thermo-analytical methods for the precise characterization and quantification of the microplastics [39].

10. Challenges in microplastic removal

It is significant to know that the harmful effects of MPs are not merely caused by their innate nature but also because of several flavoring agents and plasticizers that are added during production. Additionally, when these MPs come into the environment, several chemicals adsorb contaminants and microorganisms attached to their surface. So, it is not only the MPs that are of interest; instead, but the attached pollutants also pose important health hazards [40]. The guideline for primary MPs, which is present in pharmaceuticals and cosmetic products, is rare, particularly in developing nations. Lack of appropriate plastic trash management methods additionally results in the discarding of plastics combined with other wastes at dumping sites, resulting in secondary MPs over a prolonged period. Elimination of MPs becomes difficult due to their vast existence and smaller size, which commonly permits them to run away through filtration processes [41].

Traditional WWTPs are not completely effective for their elimination, and therefore final sewage contains considerable amounts of MPs. Release of this sewage into the surface water bodies and surface overflow permits MPs to become combined with the drinking water supply chain. Additionally, the quantity of MPs that are captured in sludge frequently gets no more treatment and is discharged on the land. Due to this pollution of seawater as well as land, Furthermore, usually, it is considered that groundwater is safe for drinking and thus does not pass during any process of treatment, but MPs that are present in the groundwater do not even get any chance of elimination and hence make humans more susceptible to the intake of microplastics. Where developing countries are yet striving for complete solid waste and wastewater management, the development of new techniques for MP removal in the supply chain is an extra load. So, the advanced treatment options are required to be low-cost and easy to integrate. In Figure 5, various challenges in microplastic removal are represented [42].

11. Strategies to reduce microplastics in wastewater

Following are some strategies to reduce microplastics in wastewater.

a. Plastic and microplastic replacement

Microplastics (MPs) can be reduced by developing suitable waste management plans and recycling methods. Several other alternatives to plastics and microplastics can play a vital role in reducing microplastics in wastewater, for example: The new alternative materials may need new raw materials at various costs and sizes, and with the information available, it is not yet apparent whether the same amount of raw materials is required to form a similar quality and quantity of the product [43]. There might be a necessity for key modifications to the equipment or size of current manufacturing facilities. In research and development, significant investment should be made in initial testing and checking to define whether new alternatives fulfill customer demands. There is a considerable variance in the efficiency of those guidelines because of differences in the plastic's definition. For example, plastic is defined as a synthetic material whose shape maintained throughout its life cycle and after removal. Some kinds of the microbeads can decay slightly when they distributed within environment. According to this definition, use of such kinds of the microbeads is acceptable.

Another idea that can be precisely defined is decomposition. In other circumstances where there is no exact definition for this idea, the insignificantly decomposable types of microbeads can be permitted for use [44]. However, the MPs released from personal care products only account for a small proportion of the entire release of MPs into the environment. Consequently, while a lot of effort has been made to substitute MPs with biodegradable materials in personal care products, this measure has not effectively resolved the issues related to MP pollution problems. On the other hand, because of the direct contact of cosmetics with the human body, this source is of huge significance from a human health viewpoint. Care must be given to other sources of microplastic emissions as well. It requires much time and significant cost to discover suitable alternatives to MPs through research laboratory and bench-scale experiments and techno-economical valuations to ensure the applicability of such alternatives regarding product quality and customer satisfaction [45].

b. Reforming plastics for circularity

In recent years, a range of standards and various environmental labels have been published to cover the environmental aspects of products. Among the set of standards is ISO 14006, which gives instructions for the integration of eco-design. Eco-design describes activities taken at the development stage to minimize the environmental effect of the entire life cycle of the product. Regarding plastics, eco-designing projects should be implemented to modify the existing method. Plastics are manufactured with the purpose of recycling and reduction, and there needs to be a good balance between principles and motives. Other activities can be focused on the manufacture of plastics without poisonous additives, the use of alternate materials, or the formation of long-life plastics [46].

c. Microplastic removal

Different types of microplastics (MPs) are present in wastewater, which exhibit various characteristics. Due to these characteristics, removal of microplastics becomes extraordinarily complex. During microplastic removal approach, most traditional wastewater treatment plants are being employed to control microplastic pollution [47]. To improve efficiency, pre-treatment with photocatalytic and biological degradation would minimize release of MPs into the environment. Conventionally, activated sludge is used to remove microplastics; removal of sludge is an important sustainability issue. Membrane filtration has promising up to now, with maximum amount of disposal observed in recent work. However, it is also complex with membrane-polluting problems [48]. Work is in progress, including adsorption, magnetic extraction, and electrocoagulation in chronological order in elimination process.

However, higher energy consumption, secondary microplastic contamination, and longer periods limit the commercial use of these technologies. MPs based on polystyrene (PE) and polyethylene (PE) are usually found in the environment, mostly in garments and household utensils, respectively. Source separation on sites and awareness-raising campaigns should be implemented through the resident authority to decrease microplastics in wastewater as well as in surface water. Attention should also be given to the improvement of membrane-based antifouling techniques as a further area of research that would permit the release of microplastic pollution from sewage [49].

12. Separation of microplastics from other organic components

Since most of the components of solids recovered from wastewater treatment plants are non-plastic (MP) organic materials, it is essential to eliminate non-microplastic organic components in the samples before microplastics are characterized using microscopy and some other techniques, for instance Raman spectrometry and FTIR. The purification of non-microplastic substances may comprise the physical and biological pre-treatment, chemical treatment, and microplastic isolation stages [50].

a. Pre-treatment

The solids recovered from sludge and wastewater include accumulated cell debris, bacterial cells, and microbial polymeric substances (EPS). The pre-treatment before the chemical treatment stage can disturb the accumulated and flocculated cell matrix and hydrolyze proteins, polysaccharides, and cellulose materials [51]. Pretreatment may give rise to dissolution of non-microplastic particulate organics, and the dissolved organics can then be separated by filtration using 19.9 μm strainers. Pre-treatment stage will minimize organic load for further chemical treatment, which will not only increase the chemical treatment effectiveness but will also decrease chemical consumption and prospective aggressive range of chemical reaction [52].

b. Chemical treatment

Acidic treatment, alkaline treatment, and oxidation using hydrogen peroxide (H_2O_2) or Fenton's reagent (30% H_2O_2 and 0.05 M iron (II) as the catalyst) are included in the chemical treatment. In various studies, the organic removal efficiency, and the effect of these procedures on microplastics have been examined [53]. The sole H_2O_2 treatment process for the removal of organic components in the sludge and wastewater usually needs more time for treatment, which can be from twelve hours for heated H_2O_2 treatment (59.9 °C) to many days with the treatment without heating. For wastewater sludge treatment, sole H_2O_2 treatment may require a high amount of H_2O_2 reagent and a long time for treatment, although the treated samples of sludge can still hold a large number of organic components. As compared to treatment of a sole H_2O_2 solution, treatment of Fenton's reagent is more efficient at eliminating organic matter [54].

The treatment using Fenton's reagent has been noted to lower the time of reaction from days to some minutes without damaging plastics, based on microscopic visible inspection and FTIR spectroscopic analysis. Fenton's reagent is said to be good at breaking down organic compounds from complicated environmental materials. It especially works well at breaking down highly chlorinated aromatic compounds and other organic compositions that H2O2 cannot manage. The ordinary reaction of Fenton's reagent for the treatment of wastewater and sludge samples can be completed within one hour. However, one of the difficulties in the treatment with Fenton's reagent is the foaming and overflow issues caused by the intense reactions when raising the temperature to above 64.8 °C [55].

c. Density separation and membrane filtration

To separate or remove microplastics from the samples after the elimination of non-microplastic organic materials by chemical oxidation, density separation methods are used. These separation methods are distinguished by different stages, comprising mixing extracted microplastics with saturated salt solutions with distinct densities by vigorous shaking and then settling the solution till the clear separation of the particles of lower and higher densities [56]. The low-density microplastic particles will float to upper suspension layer, whereas high-density particles remain at bottom layer, which permits the recovery of microplastics through filtration of collected upper microplastic-containing solution. According to some scholars, density separation of microplastics cannot be an efficient method to recover all kinds of polymers, and so would result in an underestimation of amount and kind of plastic polymers [57].

d. Separation of microplastic particles through adsorption

A syringe cascade comprising 3 syringes was prepared, for the microplastics adsorption separation. The syringes were coated with lubricating oil composed of propane (19–26%), isobutane (11.9–21.2%), butane (13.1–21.4%), and light naphtha (26–49%) and washed with purest water to eliminate extra oil residuals before the use, to gain uniform surface lipophilicity. For the recovery rates of the adsorption separation, the particles of microplastics were mixed with 19.5 mL of the purest water and poured into the cascade in 3 repetitions [58] . The use of 3 successive syringes and the three times repetition raises the interaction possibilities between the microplastic particles and the lipophilic syringe surface to confirm the maximum microplastic particle adsorption. The individual syringes from the cascade were washed with purest water to eliminate non-adsorbed particles of microplastic, after the adsorption. Each syringe was filled 3 times with a 49 °C detergent solution, for the recovery of the adsorbed particles of microplastic. The solutions that are obtained having the desorbed particles of microplastic filtered on a glass microfiber filter and at the end examined under microscope. In Figure 6: removal of different microplastic particles through adsorption in one day are described [59].

13. Removal of microplastics

Following are some methods for the removal of microplastics.

13.1. Microplastic removal through traditional methods

Microplastics are removed by using traditional wastewater treatment systems. Wastewater treatment methods include treatment in three phases: primary, secondary, and tertiary. In many cases, a preliminary phase is also applied to eliminate the grit and large floating substances. Primary treatment includes the physical settling of insoluble solids from the wastewater or sludge by using several mechanisms, for instance, screening, the removal of grit and oil, the removal of grease, and sedimentation (with coagulation). At this point, the pollutants that can easily float or settle due to the action of gravity are extracted [60]. The enclosed growth system or the suspended growth system are both used for secondary (or biological) treatment to break down the biological content of the wastewater. The last treatment step in which filtration (ultrafiltration, microfiltration, nanofiltration), reverse osmosis, chemical disinfection, ozonation, etc. are applied is known as a tertiary or advanced treatment. In WWTPs, the removal efficiency is measured according to the particle concentration of MPs (such as the number of microplastic particles per liter) in the wastewater. These techniques are less efficient for the removal of MPs so there is a need for more suitable techniques that can remove the MPs with the greater efficiency and consume less energy. In Figure 7, different phases for the removal of the microplastics from wastewater are described [61].

13.2. Modifications in the conventional method for the removal of microplastics

MPs removal through current water treatment methods is highly advisable as compared to any other new technique due to its feasibility for operation, understanding of the system, and the less expensive methods included. It is investigated that the Al (aluminum) and Fe (iron)-based salts ($AlCl_3 \cdot 6H2O$ and $FeCl_3 \cdot 6H_2O$, respectively) were used for coagulation throughout the wastewater treatment process and achieved microplastic removal up to 35.90% for particle sizes smaller than 0.49 mM using Al-based salts. A notable characteristic was that greater efficiency can be attained for smaller-sized particles, whereas it reduces slowly for larger-sized MPs (5% for sizes between 1.9 and 4.9 mm). Iron-based salts, though, were less efficient for the removal of microplastics. Charge neutralization and sweep flocculation were the key mechanisms included in the removal [62].

a. Electrocoagulation

Electrocoagulation is one more practicable solution for microplastic removal. It is a more efficient method as compared to conventional methods for the removal of MPs. Electrocoagulation does not need chemicals, therefore making it eco-friendly. Electrocoagulation includes the formation of coagulants electrically. Generally, Fe+2 and/or Al+3 ions of the metal electrodes react with the $O\bar{H}$ ions formed after the electrolysis and produce metal hydroxide coagulants. MPs, as solid particles, become destabilized in the presence of these coagulants and, afterward, are captured in the waste blanket formed by the coagulants. Flocs that contain MP particles can then be eliminated from the water. During the filtration step of the wastewater treatment, MPs can also be eliminated. Microfiltration (0.1–0.99 μm), ultrafiltration (2–100 μm), and nanofiltration (∼1.99 nm) have been employed for microplastic removal [63].

b. Pulse clarification

Another technique that is employed for MP removal from wastewater is known as pulse clarification. This is an advanced technique and has greater removal efficiency as compared to other removal techniques. Pulse clarification and filtration are collectively capable of eliminating up to 84.5% of MPs. The mechanism that is involved here is the entrapment of MP particles in the wastewater blanket made because of the coagulation. Pulsation assists in holding the wastewater blanket in expansion, which helps in the entrapment [64]. In the end, filtration helps in the elimination of MPs. Even though traditional wastewater treatment methods can assist in the removal of MPs a little, none of these methods are particularly aimed at removing or reducing MPs. Considerable amounts of the removed MPs remain in wastewater or sewage, which further pollutes the environment and then groundwater. Hence, alternative options that are aimed at the removal of microplastics need to be discovered [65].

13.3. Emerging Techniques for Microplastic Removal

There is a need for more advanced techniques that are more feasible, cheaper, save energy, and have higher removal efficiency. So, the following are some emerging techniques for microplastic removal.

a. Micro-algae

Micro-algae may provide a probability for microplastics removal, as it has been looked at that micro-algae colonize particles of microplastics, therefore changing the resilience of the aggregates. This leads to differential sedimentation rates in comparison to the non-aggregated particles. Because of narrow channels in the cells of algae, the microplastic movement was limited, and consequently, the plastic particles were trapped. Efficiency as high as 95% was noted, particularly in the dissected parts of the algae. Bioinspired molecules have been developed by some scientists to remove particles of microplastic [66]. These bioinspired molecules contain an inclusion unit (IU) and a capture unit (CU), which are joined together to make an inclusion compound (IC). In this, IU is the alkoxy silyl functionalized bioinspired constituent of the molecule, and the CU constituent can connect with several materials using functional groups. Upon trapping the guest molecules (MPs) in the inclusion cavity, the embedded molecules of water are shifted. These released molecules of water furthermore combine with other surrounding water molecules through van der Waals forces. Therefore, cavity formed by the release of water molecules is filled up by guest molecules, hence allowing IC to support elimination of guest molecules [67].

b. Magnetic extraction

According to recent studies, magnetic extraction is more likely to isolate microplastics from wastewater. This technique comprised magnetic seeds (iron nanoparticles), oxalic acid (as an iron di-sorbent), and external magnetic attraction to isolate microplastics from seeds. Iron-based nanoparticles have been used because of their ferromagnetic characteristics, inexpensive accessibility, and more available definite surface area [68]. The hydrophobicity of nanoparticles was assured by the deposition of hexadecyltrimethoxysilane on the nanoparticle's surface, and this alteration permitted the bonding of plastic particles. 91.9% of polystyrene (PS) and polyethylene (PE) beads with a range of 9 to 21 μm can be separated [69].

c. Metal-organic frameworks (MOFs)

Metal-organic frameworks (MOFs) are another strategy, which are porous structures made of a mixture of metals and organic ligands. These chemical moieties have a high surface area, porosity, and varied functionality that aid in the trapping of many types of contaminants. The material needs to be exceptionally durable, have an appropriate framework to catch the pollutant, and have enough porosity to trap the microplastics [70]. Because MOFs have these qualities, they may therefore function well.

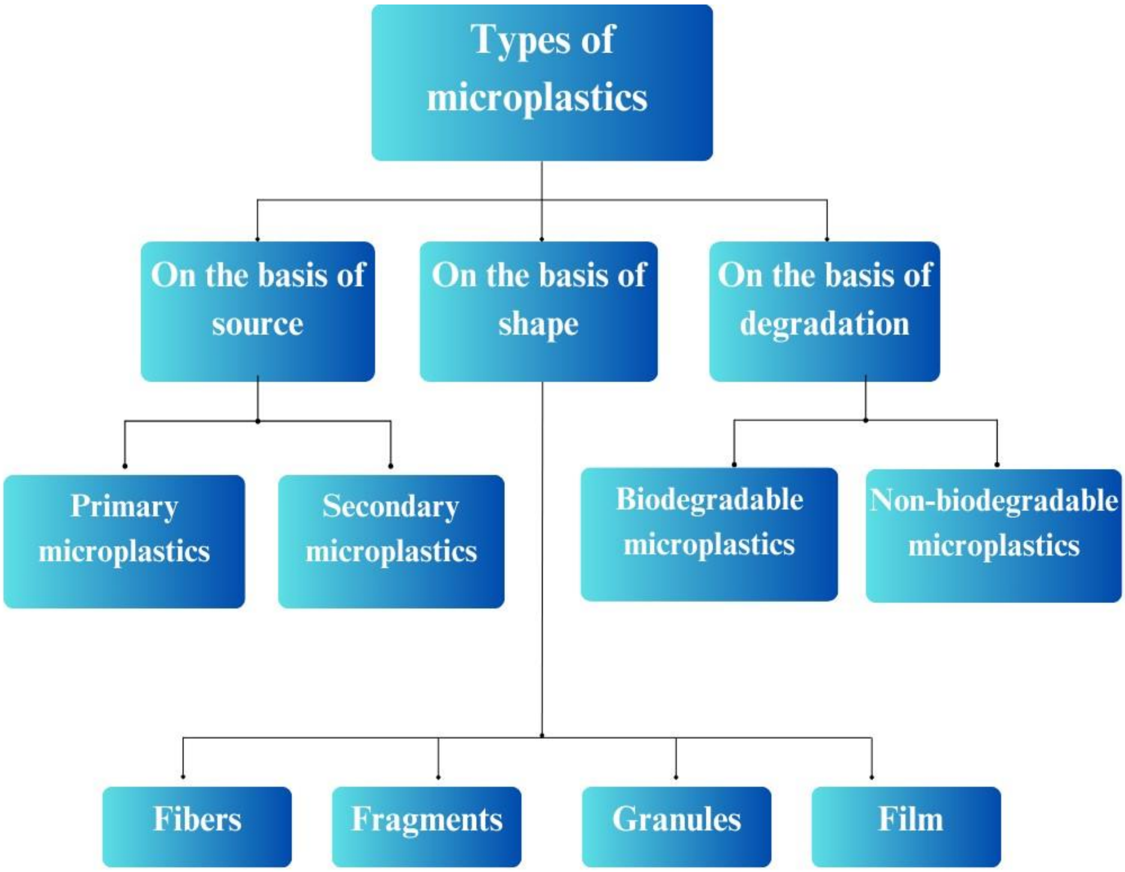

Figure 1: Different types of microplastics

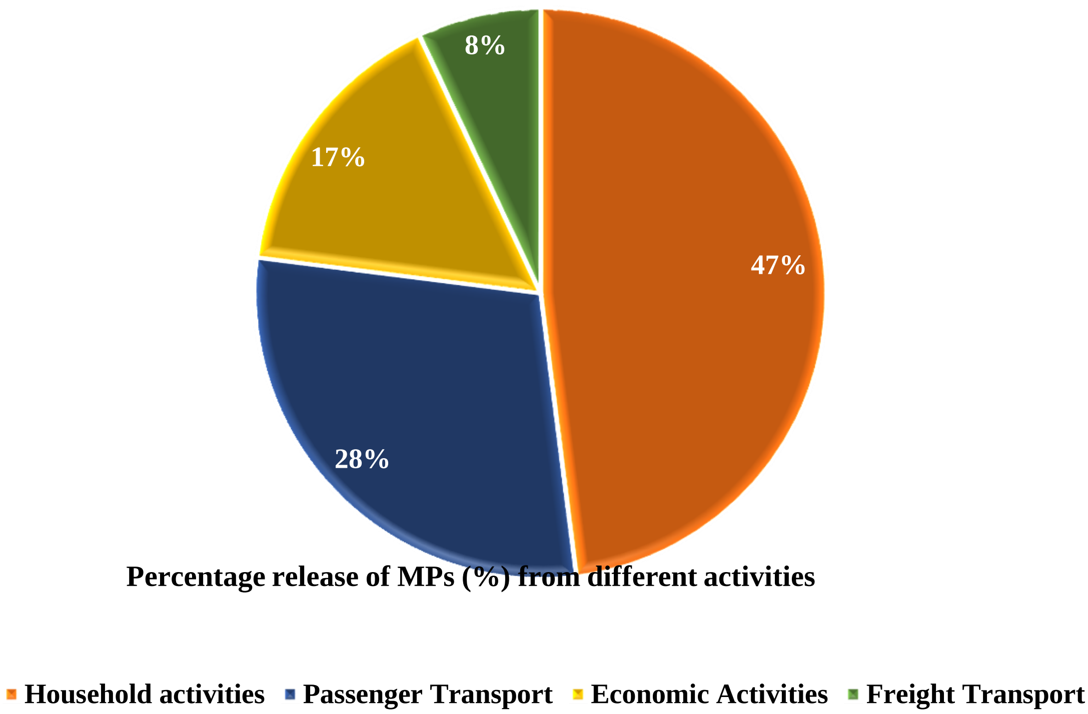

Figure 2: Percentage release of microplastics from different activities

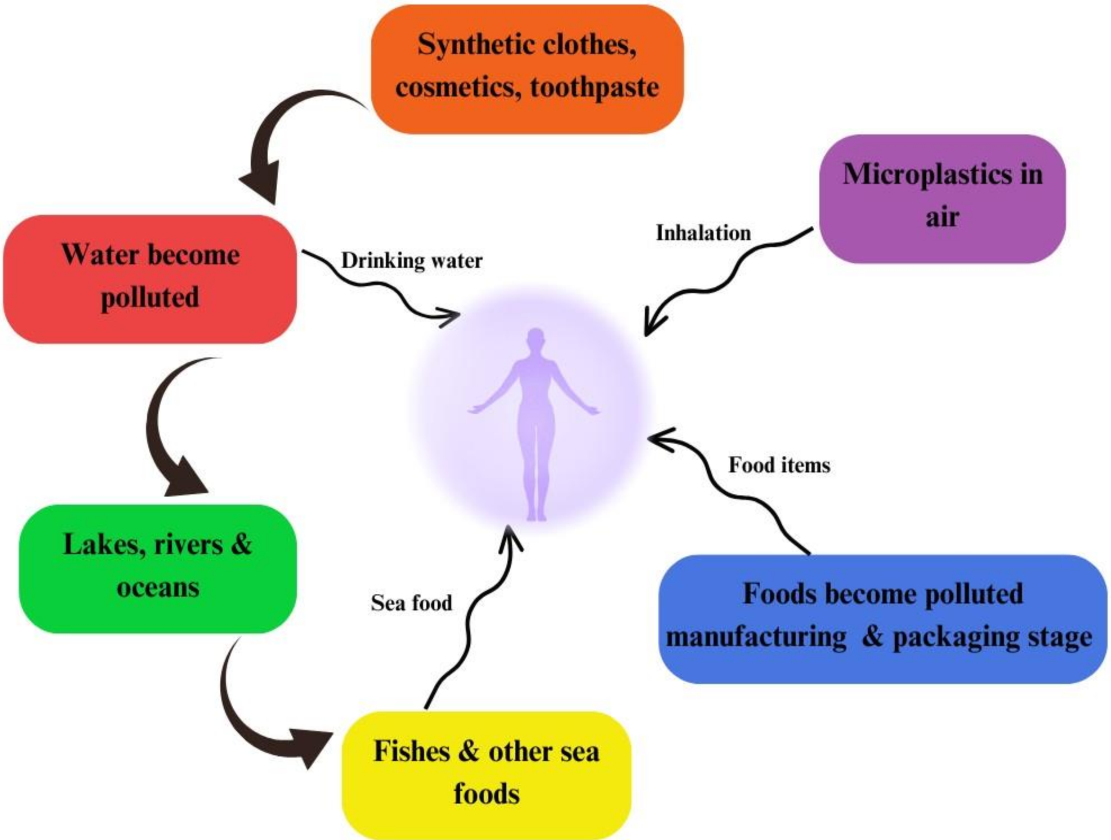

Figure 3: Transfer of microplastics from different ways to human beings

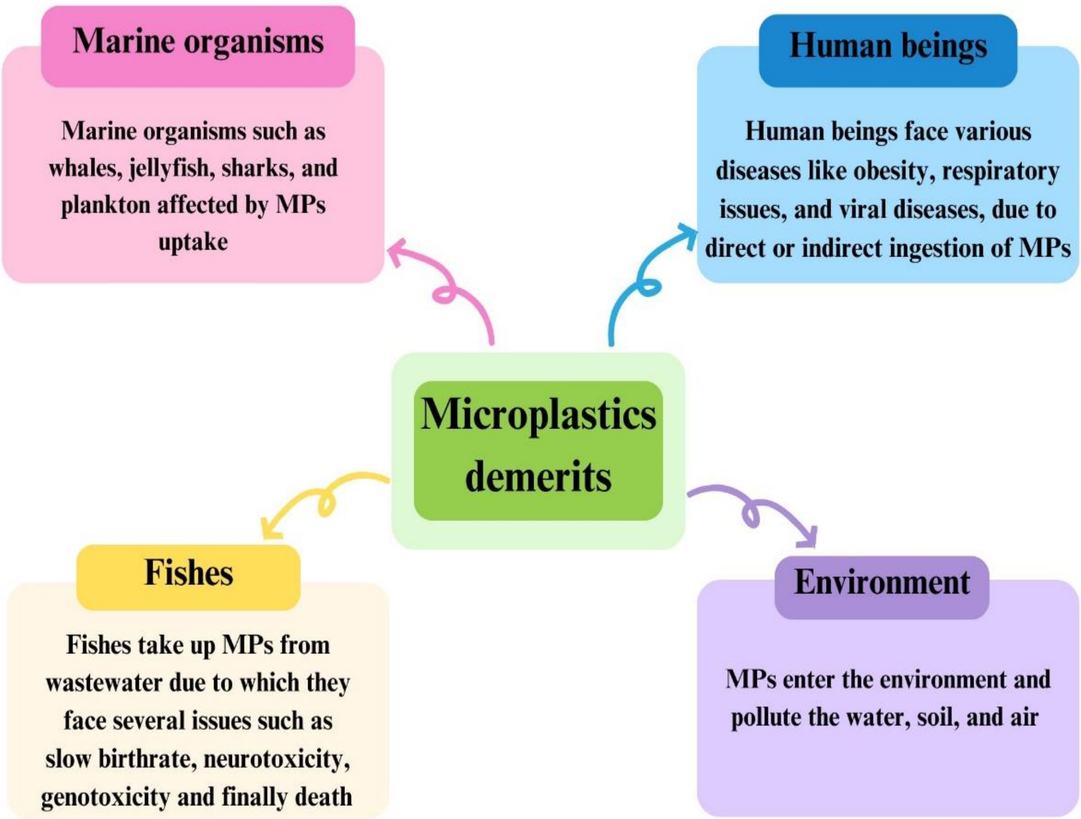

Figure 4: Microplastics Demerits

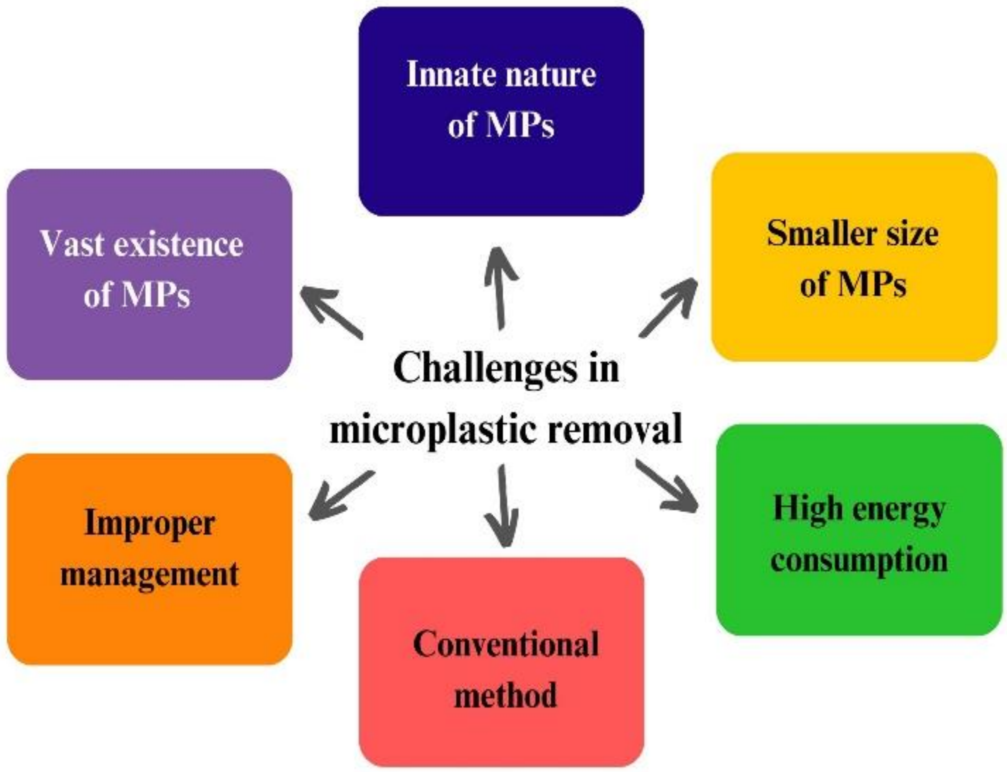

Figure 5: Challenges in Microplastic Removal

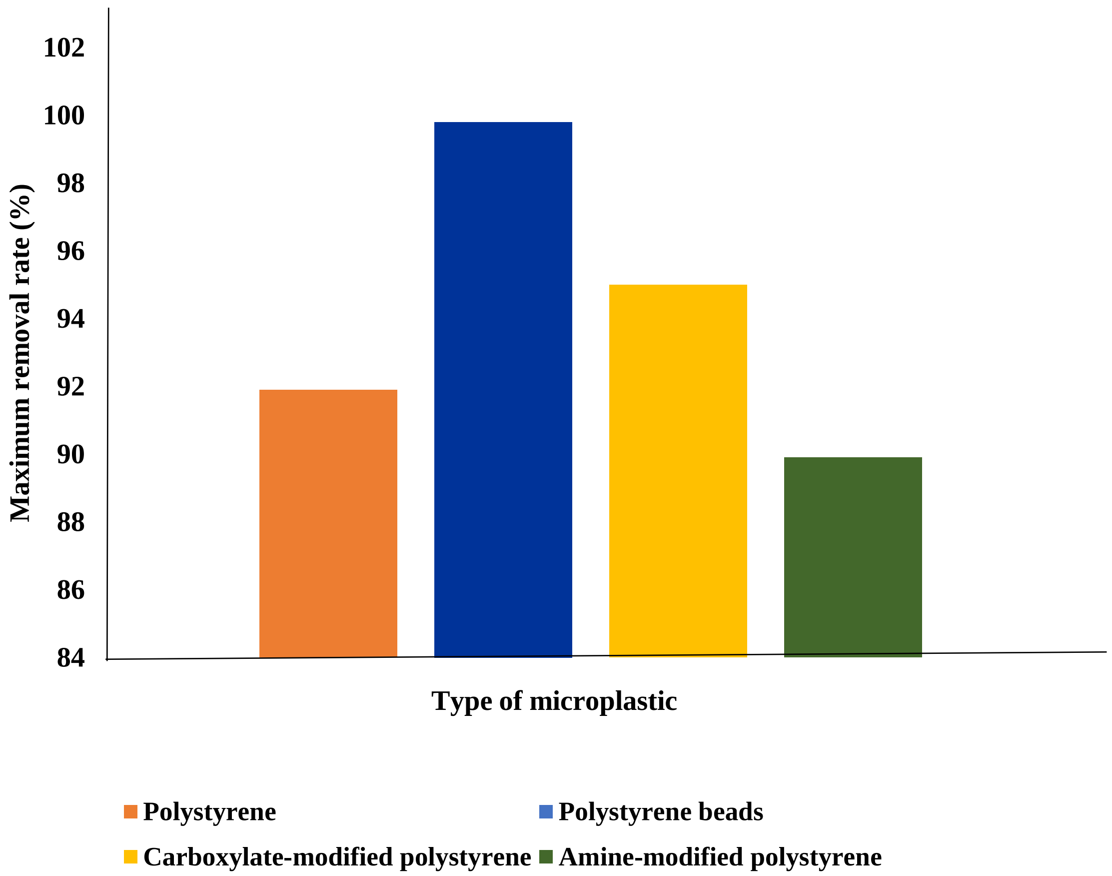

Figure 6: Removal of different microplastic particles through adsorption in one day

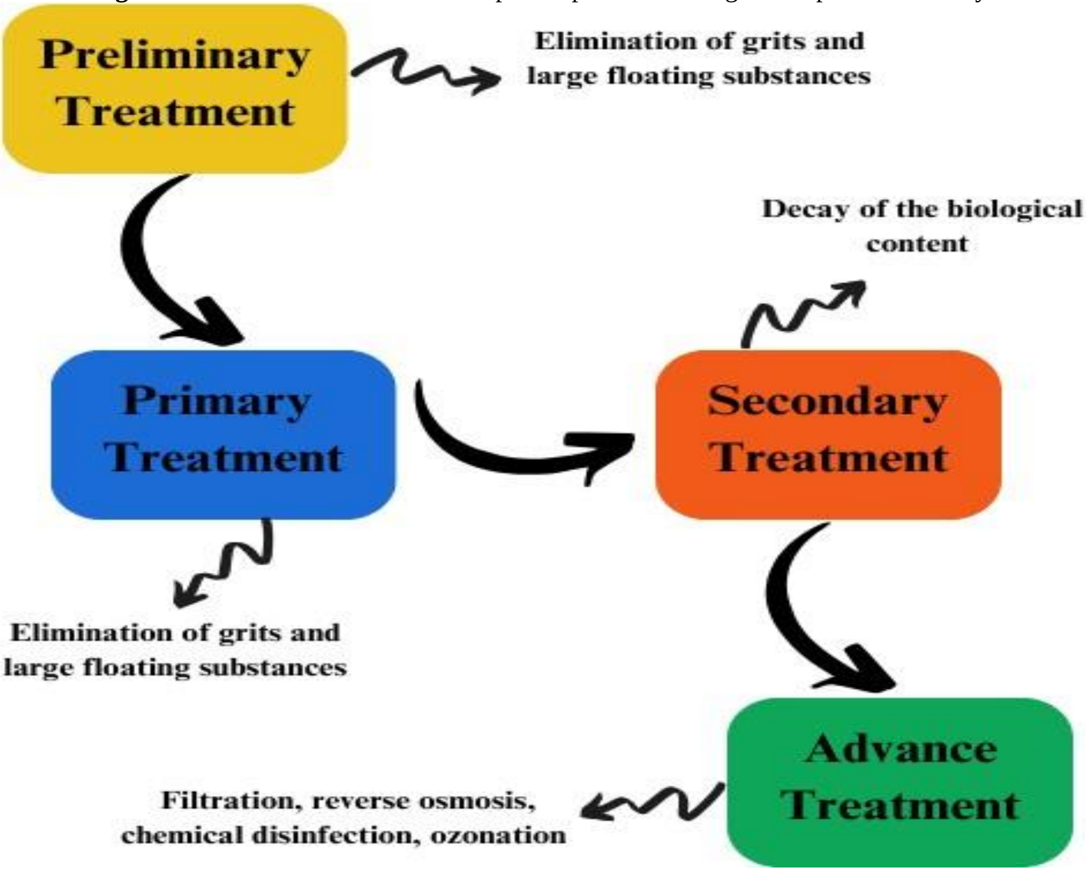

Figure 7: Different phases for the removal of microplastics from wastewater

Table 1. Different sources of microplastics

Primary Sources	Secondary Sources
Cosmetic industry	Fragmentation by sunlight and UV
Plastics production	Plastic fragmentation by mechanical Friction
Wastewater treatment plants	Degradation by microorganisms
Clothing industry	Plastic breakdown by wave

Table 2. Percentage of microplastics of different sizes

Width of microplastics in toothpaste (μm)	Percentage of microplastics of each size
90-100	12.5%
100-125	25%
150-200	32%
250-300	25%

Table 3. Comparison of different methods for removal of microplastics

Removal Method	Removal Efficiency (%)	Lowest MP particle eliminated (μm)	Main advantages
Electrocoagulation	89.9	15	Energy efficient, without microorganisms/chemicals
Micro-algae	95	19.5	Mechanical, & electrical process, without chemicals
Wastewater treatment plant (WWTP)	98.98	299	No additional cost, traditional method
Pulse clarification	84.88	102	Advanced method as compared to other removal methods
Filtration with activated carbon	58	3.5	Effective for removal of nano-sized particles range
Filtration with biochar	96.5	9	Efficient & cheap

For the mineralization of a variety of organic pollutants that are resistant to treatment, advanced oxidation techniques are among the best options. Reactive oxygen species, like sulfate and hydroxyl radicals, are commonly used to mineralize different kinds of organic materials. Therefore, this approach was also used to study the degradation of microplastics [71].

14. Microplastics removal by wastewater treatment plants

Sedimentation, flotation, coagulation-flocculation, activated sludge, aeration and clarifying, biofilm, chemical oxidation, membrane separation, chlorination, biological treatment, disinfection, and filtering are the processes used in wastewater treatment plants (WWTPs) to remove microplastics. According to some studies, the ultimate removal rate of microplastics by WWTPs ranges from 50% to 98.9%, and it differs amongst WWTPs that operate with different methods and serve different geographic areas. Diverse wastewater treatment phases remove microplastics to differing degrees [72]. The primary purpose of the pretreatment stage in WWTPs is to eliminate large-sized solid debris from the wastewater, along with any oil or gravel that can harm or impede the machinery's ability to function. The amount of microplastic in wastewater is decreased by the pretreatment procedure. It was discovered, meanwhile, that the pretreatment procedure only slightly decreased the amount of microplastics in wastewater by six percent. The significant disparity could be attributed to variations in wastewater characteristics and equipment [73].

Biological treatment technologies, including activated sludges, are typically used in WWTPs during the secondary treatment stage. Certain microplastics are captured in the sludges and consequently extracted from the wastewater during the process of separating wastewater from sludges containing microbial biomass. The activated sludge process removed 45 to 53% of the total microplastics from wastewater [74]. Wastewater containing microplastics can be further reduced to less than twenty percent by the secondary treatment step. Despite having excellent rates of microplastic removal, wastewater from WWTPs nevertheless releases a significant amount of microplastics into the environment. WWTPs are a significant source of microplastic discharge as well as a significant sink for microplastics. Microplastics released into surface water bodies when treated wastewater is discharged directly could present ecological risks (e.g., harmful effects on aquatic organisms consuming microplastics) as well as environmental risks (e.g., interactions between microplastics and other pollutants) [75]. Comparison of different methods for removal of microplastics are described in Table 3.

15. Factors affecting MP removal in WWTPs

In general, the effectiveness of microplastic removal differs depending on the degree of treatment. First, the total removal of microplastics is influenced by the operating circumstances of unit activities and processes. For instance, large quantities of microplastics cause membrane techniques to clog more quickly, necessitating frequent backflow and decreasing the effectiveness of the removal techniques. Microplastic removal can be varied using the same procedure under varying operating parameters (e.g., hydraulic retention time, flow rate, and treatment capacity). Second, the features of the influent influence the total removal efficiency of microplastics by dictating the microplastic concentrations and properties in the influent [76]. According to a study, sources, flow, population, and seasonal fluctuations all have a significant impact on influence (i.e., domestic wastewater or industrial wastewater).

Microplastics were twice as prevalent in industrial influence as they were in home influence. The makeup of the polymer type found in a WWTP typically represents the everyday lives of the people the plant serves. Urban WWTPs may contribute polyethylene (PE), polypropylene (PP), polyamide (PA), and polyether sulfone (PES) to the environment due to toothpaste and personal care items used, as well as synthetic clothing washing [77]. On the other hand, industrial effluent has elevated levels of PA, PE, and PP. Third, varying treatment levels' MP removal procedures are influenced by various unit operations and processes. The removal mechanism in preliminary treatment is unintentional removal by screening and grit/grease removal through entrapment between MPs and solids or adherence to surface of solids, whereas MP removal in primary treatment (i.e., sedimentation) is determined by polymer type and shape [78].

Using secondary sedimentation and interactions between microorganisms and MPs (such as biofilm formation), biological treatment, also known as secondary treatment, eliminates MPs from wastewater. Tertiary treatment is not a reliable means of significantly removing MP, and its efficacy varies according to the unit operations and procedures involved [79]. Specifically, the frequency of clogging and the pore diameters of the filter medium affect how efficient the filtration is. The effectiveness of microplastic removal is influenced by a variety of factors, such as site-specific WWTPs (design of treatment levels, treatment capacity, and flow rate), microplastic characteristics (size, shape, and polymer type), and the operating conditions of unit operations and processes. Further investigation is required into other factors influencing the removal of microplastics [80].

16. Conclusions

Wastewater is a major source of MPs released into the surrounding environment and receives significant concentrations of MPs from industrial and residential activities. Standard operating protocols, however, are currently lacking for the identification and elimination of MPs from wastewater. Microplastics vary in properties, and their complete elimination from the environment makes it difficult to establish standard procedures for their detection and removal. There are various methods for detecting and eliminating MP, both established and recently introduced. These approaches and procedures have proven to be successful in characterizing MPs in environmental samples; nevertheless, further research is required to develop dependable, easily available, and user-friendly procedures for identifying and eliminating microplastics from wastewater. Most traditional sewage treatment facilities are utilized to manage microplastic contamination as part of microplastic removal approach. Pretreatment with photocatalytic and biological degradation would decrease release of microplastics into environment, improving efficiency.

Historically, MPs have also been separated using activated sludge; however, sludge disposal poses a serious sustainability issue. Up until now, membrane filtration has shown great promise; current research has indicated the point at which removal can be maximized. However, there are complex problems with membrane fouling. The removal procedure is now being worked on to include electrocoagulation, magnetic extraction, and adsorption in chronological order. Nevertheless, the longer duration, increased energy consumption, and secondary microplastic contamination restrict the commercial application of these methods. Polystyrene (PE) and polyethylene (PE)-based microplastics are frequently detected in the environment, primarily from clothing and household utensils, respectively. The local authority should implement source isolation on sites and awareness-raising programs to lower MP levels in surface water and wastewater. To effectively remove MP from wastewater, further study should be done in advanced technology development.

17. Future Perspectives

It is obvious that to decrease pollution by microplastics from their source, a mutual effort is essential between national and international policies and a greater responsible awareness among the people to decrease plastic usage. It is crucial that society be educated to know and understand all the methods involved, for example, the reduction, recycling, and correct reuse of plastics, to avoid environmental hazards resulting from microplastics. According to a study, plastic manufacturing rises annually. It was considered that the world's production of plastics could rise by nineteen hundred million tons in the future, reaching a yearly rate of 4%. Internationally, the percentage of recycled plastics is only nine, and this percentage differs significantly by country. One of the best options for minimizing plastic pollution globally may be incineration, while at the same time gaining a source of energy. Microplastic waste comprises carbon, posing the issue of carbon dioxide (CO_2) emissions into the environment [81].

According to a report, it was proposed to prevent the addition of microspheres in personal care and cosmetic goods and to avoid production of four million tons of microplastics into atmosphere in next twenty years. A cheaper and more efficient method for removal of microplastics from wastewater is best way to decrease plastic contamination. It was noted that old and conventional methods for microplastic removal from wastewater are less effective [34]. So, there is a need for advanced and improved techniques to remove microplastics from wastewater effectively and at a lower cost. The replacement of traditional plastics with biodegradable plastics could be one more probable alternative. It is worth mentioning that cooperative measures should be employed, using at same time these proposed approaches to devise eco-design appropriate for decreasing plastic contamination, encouraging developments in plastic manufacture and management of plastic waste, replacing conventional methods with advanced methods for removal of microplastics from wastewater, & promoting environmental education [82].

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