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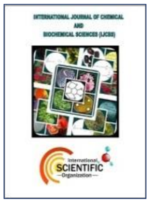

# Removal of microplastics and nanoplastics from water: A review

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## Abstract

Plastics are a necessary part of people's lives in today's society. However, these plastic products will continue to wear down, become damaged, and degrade into micro- and nano-scale plastics, or microplastics and nanoplastics (M/NPs), when they are thrown away after being used and exposed to outside influences. Even though M/NPs are receiving more attention, the main focus is still on their detection and hazards; the removal of M/NPs is a topic that is less frequently discussed. The purpose of this review is to encourage additional researchers to eliminate M/NPs. Water is becoming scarce, so it's imperative to raise the standard of wastewater released into the environment. This review first provides a brief overview of the history of M/NPs research and lists the primary analytical techniques currently employed for both qualitative and quantitative M/NPs. The current methods for treating these pollutants from water are discussed. The benefits and drawbacks of various approaches are enumerated and contrasted to assist more researchers in selecting the best research method. Lastly, several recommendations for future research are made regarding the state of the M/NPs removal field. This review discusses the benefits and field-scale applications of recent research developments in wastewater treatment. In the end, the difficulties in enhancing treatment methods for realistic commercial applications are recognized, and future paths are suggested. This is intended to further advance the development of a method for removing M/NPs.

**Keywords:** Microplastics, nanoplastics, wastewater treatment, WWTPs, AOPs

**Full length review article**

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## 1. Introduction

Human activity has contaminated most water sources and natural ecosystems are harmed. It occurs by the release of organic contaminants, pesticides, colors, medicinal sewage, polymers, and other inorganic pollutants like heavy metals into aquatic ecosystems over their volume to be absorbed. 71% of the Earth's surface is covered in water, even though some freshwater is accessible [1-2]. Plastic is one of the greatest innovations of the 20th century. This is due to its long resilience, superb mechanical properties, and economical availability. However, the careless usage of plastic products has left a terrible mess that puts biological life and the ecosystem in danger. Hazardous materials are now able to enter the environment due to the use of plastics. It is also the cause of water pollution which have adverse effects. It is necessary to know the main causes of water pollution. Some sources are shown in Fig.1 [3]. Every year, around 300 million tons of plastic are manufactured worldwide. By 2025, it's expected that 13 million tons instead of 250 million tons of plastic will wind up in rivers and the ocean. Plastic is used in a growing range of industries, such as toys, packaging, apparel, personal hygiene products, and automobiles. Regretfully, a substantial quantity of waste included plastic that spilled out onto the surroundings. These polymers are referred to as primary plastics because they release MPs and NPs into the environment by several mechanisms, including hydrolysis, mechanical abrasion, photo-oxidative breakdown, and bio-degradation. In environmental Nano-science research, plastic particles larger than 5 mm are referred to as Microplastics (MPs), and those smaller than 100 nm are referred to as Nano-plastics (NPs) [4]. Many NP categories are reported since the classification is not publicly accessible. A study found that whether or not NPs have a diameter of one millimeter or more determines whether they are categorized as microscopic or large. Because of its complex surface properties and greater surface area, NP is more prone than MPs to absorb hazardous chemicals and change into a more toxic compound. Furthermore, it's been proposed that certain NPs intensify toxicity upon interaction with organic matter, perhaps leading to endocrine abnormalities in humans. Personal hygiene products have the potential to let NP into the skin and lead to serious health problems. The blood-brain barrier is essential for preventing potentially hazardous neurotoxins from entering the brain, stable nanoparticles (NPs) in aquatic environments have the potential to cause greater harm to living organisms. Water contamination in NP has become a major concern due to its negative effects on the environment [5-8]. A relatively new form of pollution that has a big impact on both organism growth and aquatic quality is microplastics. Approximately 80–90% of the microplastics found in aquatic environments originated on land [9]. Microbeads cause the microplastics found in soil and water. Most microplastics found in soil and water have frequently been shown to have their origins in textiles, detergents, cosmetics as well as plastic bottles, building supplies, bags, and clothing [10]. Some other sources of microplastics include farm irrigation water, municipal sludge, surface runoff from farms, and deliberate releases of microplastics into the environment [11]. These actions also increase soil porosity, change the enzyme activity of soil organisms, and increase the variety and number of soil microbes [12-13]. MPs and NPs have negative effects on the gastrointestinal tract in addition to being dangerous to the developing embryo, gametes, progeny, and liver. Water-producing alternatives, such as treating wastewater, are becoming more common as a result of worldwide water scarcity [14]. Substances that change the chemical and physical properties of water can be considered pollutants because they lower the water's quality [15]. Clean water availability is reduced when industrial effluents are released into freshwater systems [16]. Table 1. Lists the main environmental pollutants along with their harmful effects. Pathogens, organic and inorganic chemicals, such as heavy metals, dyes, volatile organic compounds (VOC), oil, plastics, insecticides, pesticides, and herbicides, are the main categories of water pollutants [17]. Among the things is toxicology to the digestive system itself. They could choke or starve marine life when consumed. Furthermore, the aquatic biota may be harmed by consuming various contaminants, such as polybrominated diphenyl ethers (PBDEs), heavy metals, and polycyclic aromatic hydrocarbons (PAHs). Moreover, eating some aquatic animals that include this detritus may be harmful to one's health. They were discovered to be a constant source of operational interruption in facilities that handle drinking water, wastewater, and aquatic environments. Their high stability makes it difficult to remove them from water using traditional water treatment methods, even if it is possible to concentrate them in the sludge phase. However, it should be highlighted that conventional treatment techniques, which frequently result in a sizable number of M/NPs, are frequently the reason why mud M/NPs are released into aquatic and terrestrial environments. Therefore, creating efficient removal techniques becomes essential. Therefore, when the European Union (EU) evaluated the Urban Waste Water Treatment Directive (UWWTD), MNPs were deemed pollutants of major concern [18].

## 2. Sources of microplastics and nanoplastics

The two sources of plastic particles that contribute to the presence of microplastics (MPs) in the environment are the primary source and the secondary source. But pinpointing the precise source of MPs found in the environment is difficult, if not impossible. Plastic pellets, paint, washing wastewater, sewage sludge, artificial turf, rubber roads in cities, plastic running tracks in schools, and tire wear on vehicles are the main sources of environmental microplastics (MPs). Secondary sources, on the other hand, include large-scale plastic wastes from farming, fishing, and other sources, as well as municipal wastes like plastic bottles and bags. Because of the quick rise in the number of cars on the planet, tire wear on vehicles is thought to be one of the most significant sources of environmental microplastics among these [19]. Studies on the existence of rubber particles in the environment are, however, extremely rare. Although large plastic wastes require hundreds of years to decompose into MPs in the natural environment, secondary sources of MPs are thought to currently account for the majority of MPs in the environment. The first step in preventing and controlling future environmental microplastics pollution is to manage wastewater and plastic wastes properly [20]. Primary sources of nanoplastics include nano-sized particles released into the environment by paints, cosmetics, medications, electronics, spills, and improper waste disposal [21]. Secondary sources are created when MPs break down and fragment naturally. In the environment, NPs can clump together and agglomerate [22]. Some sources of microplastics and nanoplastics are shown in Fig. 2. [23].

## 3. Environmental impacts

As they can gather and carry persistent organic pollutants, personal hygiene items, toxic metals and medications, microplastics and nanoplastics pose a threat to ecotoxicology [24]. Public health issues are also related to NP pollution. In actuality, the human beings are constantly exposed to NPs, for example, through the MPs and NPs present in food and drinking water [25]. Additionally, MP particles may play a role in immunological or neurological disorders [26]. What effects does this kind of pollution have on the environment, and on the health of people and animals? NPs are highly bioavailable and have the ability to cross physiological barriers due to their minor size, which is comparable to that of natural proteins and macromolecules. This can result in oxidative stress, cytotoxicity, and tissue translocation [27]. Additionally, because of their persistence, they can be concentrated in organisms, which raises the risk of cancer and causes severe inflammation [28]. Furthermore, NPs have the potential to release different heavy metals, environmental contaminants, and persistent organic pollutants (POPs), as well as chemicals found in their formulation, such as organic plastic additives (OPAs) [29]. Additionally, they may serve as a platform for pathogens and microbial biofilms [30]. MPs and NPs can enter the human body orally. Following oral ingestion, a series of processes occur that influence the particles and, consequently, their connections: interaction with intestinal cells, contact with digestive fluids, acceptance and transportation in the liver and intestine, and excretion [31].

## 4. Methods for Removing Microplastics and nanoplastics from Wastewater

### *4.1 Existing Quantitative and Qualitative Methods*

With the increasing urgency of detecting M/NPs, analytical techniques for both qualitative and quantitative micro and nanoplastics have been established. The primary techniques used today can be categorized as follows: spectroscopic, chromatographic, and visual observation methods [32]. The human eye is the primary tool used in visual observation to see and count M/NPs. However, in order to quantify M/NPs using the mass method, weighing must be done or assistance from a microscope must be obtained if the detected M/NPs are too small [33]. One benefit of this approach is its low cost. But there are drawbacks to this approach as well, like the possibility of human error and the need for additional steps in preprocessing and a combination of approaches [34]. These days, liquid chromatography (LC) and gas chromatography-mass spectrometry (GC-MS) are the most widely utilized chromatographic techniques for the detection of M/NPs. To determine the composition of MPs and NPs thermal analysis technology must typically be used in conjunction with GC-MS to investigate the mass spectra of the products of M/NPs' thermal degradation [35]. Additionally, pyrolysis-GC-MS and thermal extraction-desorption-GC-MS are two frequently used GC-MS methods in conjunction with thermal analysis techniques. Currently, size exclusion chromatography and other auxiliary coordination methods are required for the more popular LC [36]. Whichever chromatographic technique is currently in use, it can all examine the different kinds of MPs and NPs in the sample and has the benefit of being highly precise. However, chromatographic techniques also have some limitations. Specifically, it is stated that chromatographic techniques cannot directly provide information about size or quantity of M/NPs; they can only reveal information about the chemical composition of M/NPs. Therefore, it is not possible to correlate quantity and quality of M/NP. The spectroscopic method is more widely used than the chromatographic method. The most popular of these are Fourier transform infrared spectroscopy (FT-IR) and Raman, which work by analyzing M/NPs using the spectrum that is created when light and molecules interact. FT-IR and Raman are non-destructive techniques, in contrast to the previously discussed chromatographic methods. Raman spectroscopy gives the details of vibrational mode of molecules, whereas FT-IR shows specific infrared spectra of various polymers [37]. The procedure gives details nearly the system's vibrations of molecules. Even though these two chromatographic techniques are starting to become more widely used, there is still need for future improvements to address their shortcomings. Due to inadequate interpretable spectra, FT-IR can identify merely IR-active MNPs greater than 20 µm. Despite being able to identify M/NPs as small as 1 µm, Raman spectroscopy is sensitive for non-polar functional groups to greater extent and affected by pollutants or pigments. In terms of other techniques, they include dynamic light scattering (DLS), turbidity measurement, surface-enhanced Raman spectroscopy (SERS), and scanning electron microscopy (SEM) coupled with energy dispersive X-ray spectroscopy (EDX) The properties and comparisons of different methods are shown in Table 2 [38].

### *4.2 Current methods to remove M/NPs*

A quick review of the current status of microplastics and nanoplastics in food and the environment, along with an association and summary of the methods available for both qualitative and quantitative MNPs analysis, are given in the preceding section. Merely detecting MNPs is far from sufficient given their current state. Eliminating them is more crucial in order to lessen the likelihood of individuals being exposed to M/NPs and the harmful effects of M/NPs on human health. The comparison of different methods for the treatment of wastewater are given in Table 3. These techniques includes physiochemical, physical and biological methods [39].

### *4.3 Wastewater treatment plants (WWTPs)*

The scientific community became interested in MPs and NP-related environmental pollution at the start of the twenty-first century. The identification and study of MPs in aquatic environments, including seas, rivers and lakes, is well-established. Globally, freshwaters have been found to contain MPs and NPs, even in polar regions [40]. But only recently has the scientific community become concerned about technologies for decreasing and/or eliminating MPs and NPs from water. Eliminating every MP and NP found in oceans seems unfeasible and unachievable. It is feasible to reduce their environmental discharges, though, for example, by taking action upstream on municipal WWTPs [41]. The smallest plastic debris, known as NPs, which range in size from 20 to 100 nm, have the potential to elude all stages of treatment and end up back in the environment. Because NPs are challenging to identify and measure, no extensive research on their release in surface water has been done to date. According to numerous studies, WWTPs continue to be a potential source of regular MP and NP releases into the environment even after they were upgraded [42]. The two types of WWTP processes are degradation processes (photo-oxidation, biological treatment, etc.) and separation processes (membrane separation, flocculation, coagulation, etc.). They are regarded as primary, secondary, tertiary, and preliminary treatment steps as well [43]. Before their release into freshwater reserves, it would be ideal to create some environmentally friendly and effective techniques to protect water resources from microplastics. Wastewater and natural water bodies have traditionally been treated for hazardous contaminants using a variety of techniques. Depending on the kind of contaminants present, several treatment methods are chosen for contaminated water [44].

### *4.3.1 Preliminary and primary treatment steps*

Initially, the WWTP proceeds through preliminary and primary treatments. They permit the removal of items like wood fragments, grit, bottles, and grease that could hinder or interfere with downstream processes. They include grit and grease removal, skimming, primary settlement, coarse and fine screening, and permit for the removal of 50% to 98% of MPs and Particles of plastic greater than 5 mm. These performances are contingent on a number of variables, including the concentrations of MPs and NPs, the shapes (spheres, fibers, etc.), and the formulation (type of polymer or copolymer, additives, toxicity, etc. [45]. The drinking water and wastewater treatment processes require the usage of inexpensive aluminum or iron-based coagulants for flocculation and coagulation (primary treatment). Depending on the pH of the water, concentration of pollutants, and surface charge, flocks instantly form and sink to the bottom of the sedimentation tank. However, higher coagulant concentrations are required as negatively charged microplastics and nanoplastics relate with few aluminum or iron salts, and process efficiency decreases with high concentrations of MPs or NPs in the effluent. As it is difficult to evaluate the concentrations of MPs and NPs in water, they are a limiting factor for coagulation processes [46]. MP surfaces are either negatively or neutrally charged because of surface weathering and oxidation. However, during coagulation these particles can act as ligands or adsorb on (Al $(OH)_3$ or metal hydroxides ($Fe(OH)_3$ , forming larger, more stable accumulations that can precipitate. Additionally, the coagulation efficiency is controlled by MP size. As a result, MPs between 30 and 100 nm were nearly eliminated, whereas particles between 10 and 30 nm were only partially removed. Additionally, it seems that the coagulation process improved by 60% when an anionic surfactant was added, and it was 25% more effective when $Al^{3+}$ was used rather than $Fe_2$+ to remove 0.1–5 mm microplastics [47]. After coagulation, which allows the charge neutralization, flocculants are added to promote particle aggregation through various mechanisms that depend on the kind of flocculant, the properties of the material to be aggregated, and the flocculation medium set-up. For flocculants, polyacrylamides and their derivatives are the most frequently employed. After coagulation/flocculation step earlier moving on to the next stage, the secondary treatment step, solid-liquid separation occurs. The majority of the MPs in the sludge are present at this level [48].

#### *4.3.2 Secondary treatment steps*

Biological treatment is the traditional method for the secondary treatment steps. This treatment eliminates some of the MPs that were not eliminated in the first treatment step. MP may become entrapped in solid flocs, sediment in secondary clarifiers, or even be consumed by microorganisms such as protozoa or metazoans. Up to 36% of MPs can be eliminated from the primary treatment effluent using this method. MPs' contact time is essential to their elimination. In actuality, the biofilm will grow on the MPs' surface over longer contact times, changing their surface characteristics and improving the treatment. More fragment particles than fibers were eliminated by this secondary treatment [49].

#### *4.3.3 Tertiary treatment steps*

The elimination of MPs and NPs from water through primary and secondary treatment processes is insufficient. Micro-particles from the primary effluent are yet present, but latest, considerably smaller plastic processing results in the formation of particles (NPs). NPs and MPs experience various shear forces as they move through a WWTP's processes due to associating or pumping. This may lead to the NPs and MPs disintegrating into smaller pieces, which would increase the quantity of harmful NPs discharged into the water. The relationship between NPs/MPs and WWTP processes is poorly understood, particularly regarding NP generation via MP fragmentation. The following procedures are included in the tertiary treatment steps: membrane filtration techniques, including disc filtration, dissolved air flotation, reverse osmosis, and rapid granular filtration [50].

##### *4.3.3.1 Rapid Sand filtration*

Via three layers made up of anthracite grains, silica sand, and gravel, rapid sand filtration, also known as rapid granular filtration, or RGF, allows for the mechanical straining or physical adsorption of suspended solids from wastewater. The primary drawback of RSF is that it requires frequent backwashing because the uppermost layers clog easily. However, once MPs get to the silica bed, weathering-induced surface hydroxyl sites allow them to associate with $SiO_2$, which can be advantageous since RSF retains a significant portion of MPs/NPs. It is also a disadvantage because, following NPs/MPs adsorption, filter regeneration becomes more challenging. MPs can be stopped by this process, but how well they are removed depends a lot on both the type of polymer and the size of the particles. As compared to microplastics having size range from 10 to 20 µm , the M/NPs particles having size less than 1 µm were easier to sustain on the filter [51].

##### *4.3.3.2 Disc and membrane filtrations*

Disc filtration functions by physically holding the material in the filters, forming a mud cake. It was evaluated how well disc filters removed microplastics (MPs) from treated wastewater. They demonstrated that 89.7% of the particles and the disc filter retained 75.6% of their mass. The unexpectedly high number of MPs in the filtrate, whose sizes significantly exceeded the disc filter's pore size, however, indicated that Particles could go through or not the filter mesh, lowering the filter's efficiency to some extent [52].

##### *4.3.3.3Membrane separation*

One of the most popular methods for treating wastewater and drinking water is membrane separation. The advantages of this process are its straightforward operation and consistent effluent quality. Depending on the type of membrane, it can reduce the resistance of the water and efficiently eradicate or isolate organic pollutants, suspended solids, bacteria, multivalent ions, and byproducts. Membranes can act as tangible barriers for MPs. Due to their size resembling that of membrane pores, a considerable fraction of MPs ought to be removed through membrane separation [53]. For instance, looked into what happened to MPs in Sydney's WWTPs [54]. Their findings demonstrated that only 1.515% of MPs particles/L were present in the primary treated effluents following ultrafiltration and reverse osmosis [53] (Figure 3). Membrane fouling is a problem with membrane filtration because it lowers throughput. Smaller MPs and NPs may have a more severe fouling effect than longer ones because they cause thorough to intermediate pore blocking. Dynamic membrane filtration and sequential membrane filtration are potentially novel ways to reduce membrane fouling and the associated energy and maintenance costs [53].

**Table.1** Major harmful pollutants and their impact on the environment

| **Major Pollutants** | Sources | Toxic effects | |
|---|---|---|---|
| | | Human beings | Environment |
| Plastics | Transfer of industrial wastes and packaging material into the ocean | Liver disorder, hearing impairment, Lung issues, weakened immune system | For aquatic organisms the blockage of the respiratory system |
| Heavy metals | Mining, industrial effluents, sewage sludge, pesticides | Damage of organs, diseases like cancer | Bioaccumulation, plants oxidative stress |
| Oil | Industrial wastes, oil spills during transportation | Neurological issues, breathing problems, cancer, nose and eye irritation | Decreases dissolved oxygen (DO) in water, aquatic habitat destruction |
| Dyes | Discharge of wastes from paper, printing, tanning, and textile industries | Mutagenicity, organ disorder, carcinogenic | Overall decreased growth of the plant, photosynthesis reduced activity, increases COD and BOD |
| Pathogenic microorganisms | Sewage, household waste, biohazard waste | Serious impact on human metabolic process | Decrease in the DO content |
| Pesticides and Herbicides | Farming practices | Organ damage, Endocrine system problem | Reduces the diversity of species |

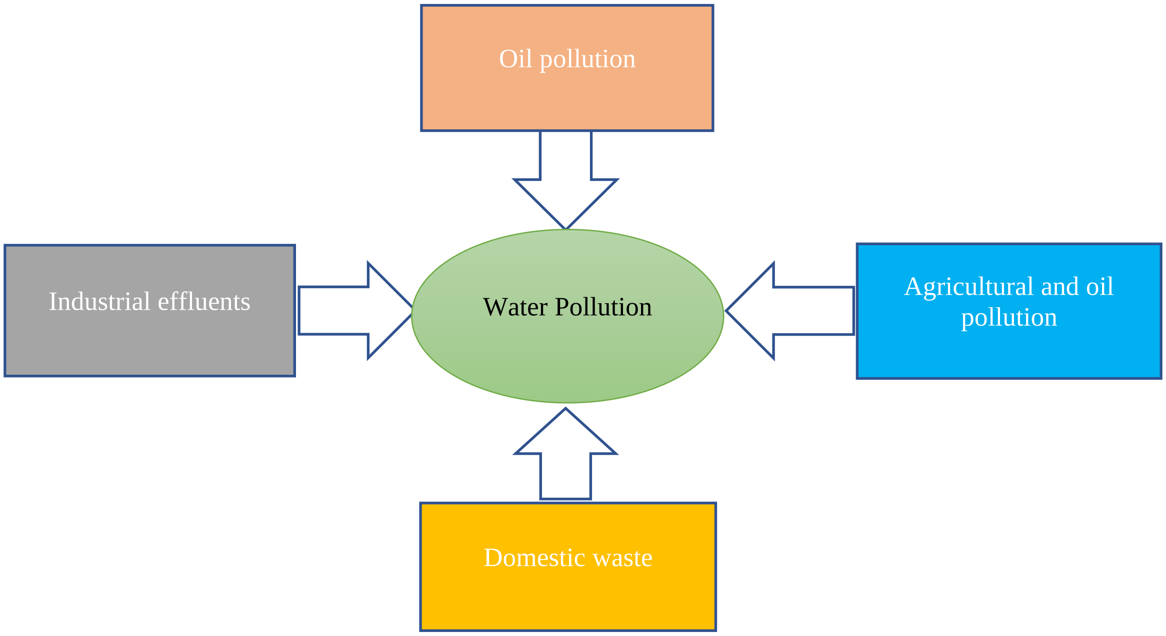

**Figure 1.** Main sources of water pollution

**Table 2.** Comparing qualitative and quantitative methods for analyzing nanoplastics and microplastics

| Techniques | Quantitative / qualitative | Detection range of MNPs | Properties |
|---|---|---|---|
| Fourier transform infrared (FTIR) | Qualitative nature | 20 µm or more | Quick and non-destructive process; able to obtain specific MP spectra; not appropriate for NPs; costly equipment; requires specialized personnel. |
| Gas chromatography-Mass spectrometry | Qualitative category | No size restriction | Greater accuracy, skilled labor, a variety of M/NP types that can be obtained, and the use of thermal analysis techniques in combination The size and quantity of M/NPs cannot be obtained by destructive methods. |
| Scanning electron microscopy-Energy dispersive X-ray analysis (SEM-EDX) | Quantitative (number, proportions) | No size boundary | Can produce high-resolution pictures of M/NPs; can obtain details regarding M/NPs' morphology and surface element composition;<br>expensive; requires a laborious preliminary stage |
| Raman | Qualitative (form) | Less than 1 µm | Fast and non-destructive method, precision, sensitive to non-polar functional groups, susceptible to contaminants (microorganisms and organic or inorganic substances), not suitable for NPs, need qualified personnel. |
| Visual observation | Quantitative (numeral, extent) | No size boundary | Low cost, sample cannot be qualified, requires cooperation with a microscope or staining, is particular and disposed to human error. |
| Turbidity | Numerical (in terms of concentration) | Unfit for M/NPs with low densities | Simple to use, quick, accurate, wide measurement range; however, it is not appropriate for M/NPs having lower density due to particle interference. |
| Liquid chromatography | Qualitative (nature) | No size margins | High accuracy, different types of M/NPs that can be attained, must be paired with other methods, are unable to provide M/NP size and quantity, and require skilled workers. |
| Weighing | Quantitative | (no limitations on size) | Low cost, subject to outside interference, requiring cooperation with microbalance and extra numerous steps (such as filtering and drying). |
| Dynamic light scattering (DLS) | Qualitative (extent) | 1 nm-10 µm | A quick, accurate, non-intrusive technique that works well for determining the size and weight of molecules. It works best with spherical particles and is delicate to changes in the viscosity and temperature of the solution. |
| Surface enhanced Raman Spectroscopy (SERS) | Qualitative (type) | 50 nm or more | Poor reproducibility, low lateral resolution, distinct molecular specificity, insensitivity to complex components, and high sensitivity. |

**Table 3.** Comparison of removal methods for microplastics and nanoplastics

| **Category** | Removal method | Advantage | Disadvantage | Application |
|---|---|---|---|---|
| Biological | Microbial degradation | Easy to use, inexpensive, broadly applicable, safe byproduct | The process is extremely slow, requires appropriate microbial communities, is difficult to control, and has low removal efficiency after many days of degradation. | Soil environment and liquid environment |
| | Membrane bioreactor | high efficacy of removal | fouling of membranes | environments with lots of liquid, like sewage treatment plants |
| | Microorganism aggregation | M/NPs can be released during recovery and are simple to remove. | Low effectiveness and a strong reliance on the microbes employed | fluid surroundings |
| Physiochemical | Coagulation, flocculation and sedimentation | Quick procedure, adjustable operating parameters, basic mechanical apparatus, appropriate for removing small-sized M/NPs, and simple removal of precipitated flocs | Different removal efficacy is, have limitation for massive size M/NPs, environmental matrix is disrupted by the higher application of coagulant | Fluid surroundings |
| | Electrocoagulation | Low conductivity requirements, no risk of secondary pollution, ease of removal of precipitated flocs, energy efficiency, affordability, and automation flexibility make them ideal aimed at the elimination of minuscule M/NPs. | In order to prevent excessive energy consumption, cathode passivation and the frequent replacement of sacrificial anodes require the right current density, which is unavailable in non-electric areas. | conductive liquid surroundings |
| | Adsorption and magnetization | Adsorbents can be recycled and modified, and the process is quick and easy. | The type of materials used, potential desorption, the need for adsorbent synthesis, the possibility of iron leaching, and the requirement that the magnetized material be super-paramagnetic all affect the outcome. | Fluid environment |
| | Thermal degradation | Eliminate entirely | High expense, high energy use, and matrix destruction | Preparation of M/NPs for qualitative and quantitative analysis |
| | Micromachine | Rapid transfer of M/NPs | continuous outside force or substances Essential, symmetrical form necessary to lessen drag and erratic motion, intricate synthesis | Liquid environment, not yet commonly employed in real-world situations |
| Physical | Density separation | Easy to use, requires no chemical processing | Salt types that required modification, were susceptible to M/NP interference and were applicable to real-world situations | Pretreatment M/NPs Static Liquid Environment Operation |
| | Constructed wetland | Natural-based remediation, habitat maintenance, encouraging the water cycle, and recycling nutrients | M/NPs are only appropriate for areas with minimal daily water intake because animals can spread them in wetlands. | Soil environment and liquid environment |
| | Filtration | Numerous filtration tools and apparatus, easy to use, no need for chemical treatment, and excellent removal effectiveness | Only useful for MP >20 μm, regular maintenance and cleaning | environments with lots of liquid, like sewage treatment plants |
| | Superhyrophobic materials | High removal efficiency and simultaneous removal of organic solvents | To attain superhydrophobicity, separate and transfer of these pollutants to the organic phase, or to superficial functionalize M/NPs, more chemicals are needed. | Liquid environment, not yet commonly employed in real-world situations |
| | | High selectivity, low energy consumption, mechanical strength, hydrophilicity, and high removal efficiency | Filter cake formation, pore blockage, potential membrane fouling, and a complex synthesis process | Liquid environment, not yet commonly employed in real-world situations |

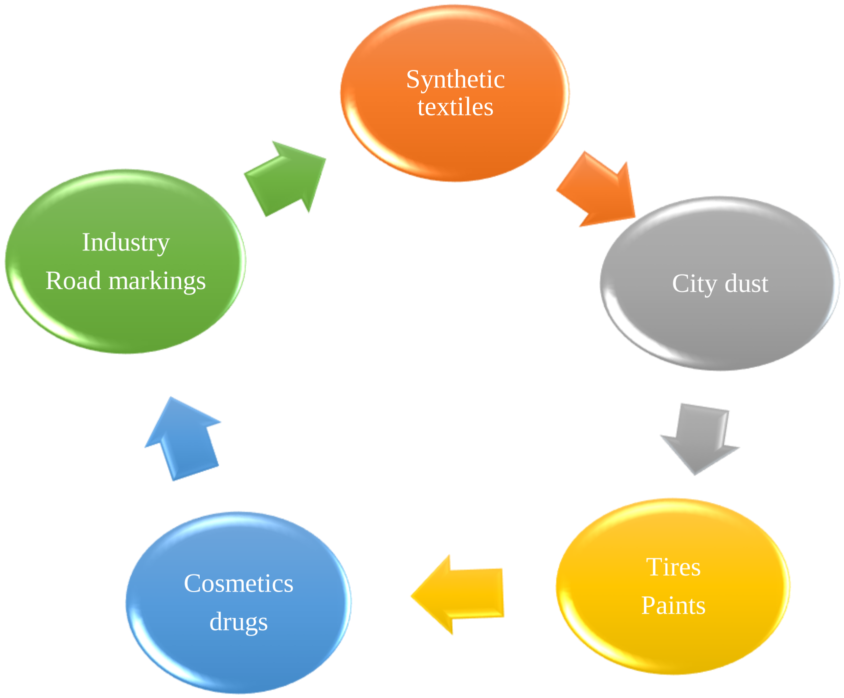

**Figure 2.** Sources of microplastics and nanoplastics

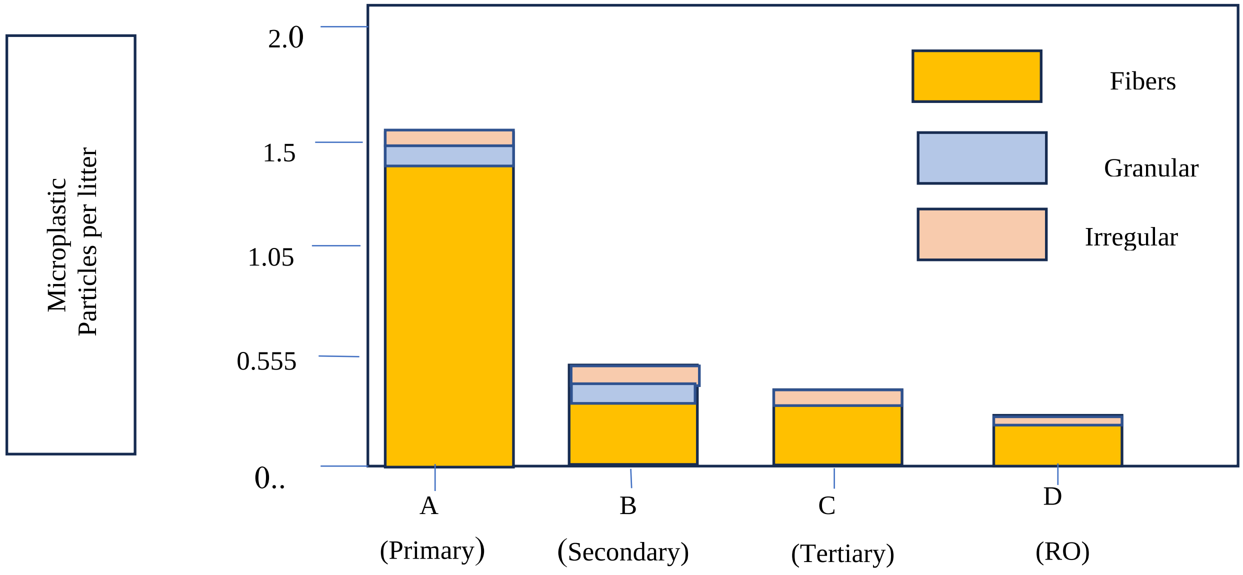

**Figure 3.** Based on their shape, and the numeral of microplastic particles per liter in each wastewater treatment plant's final effluent.

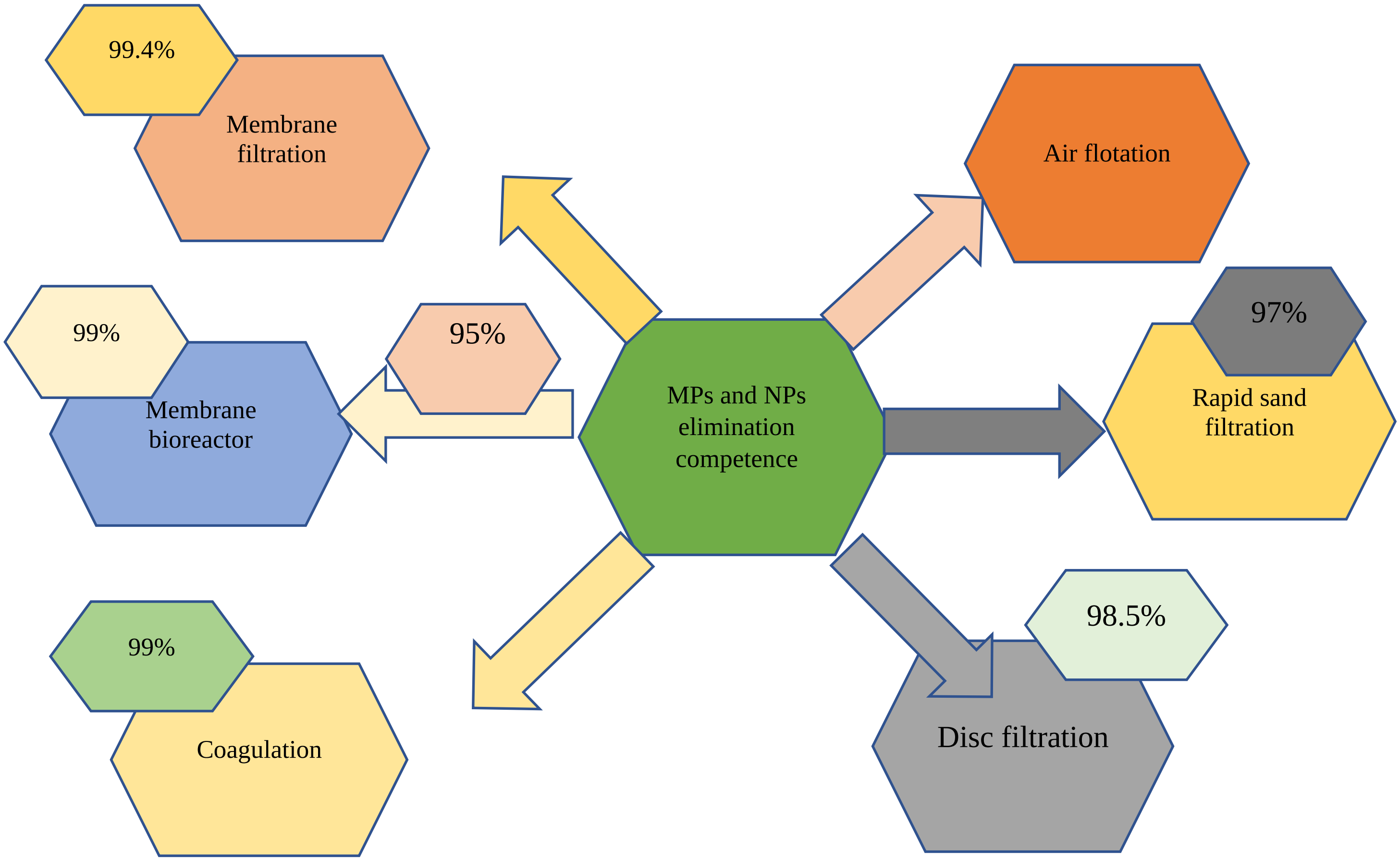

**Fig.4** Comparison of removal efficiency of different techniques for M/NPs

#### *4.3.3.4 Membrane bioreactor (MBR)*

Different techniques have different removal efficacy. Comparison of different techniques is shown in Fig.4.The membrane bioreactor (MBR) is a wastewater treatment technology that combines the traditional activated sludge (CAS) treatment process with a membrane separation process. MBR can efficiently generate a high-quality clarified effluent as the membrane hole proportions should be less than 0.1µm. Due to its benefits, which include reduced sludge production, space savings, and high removal efficiency for pollutants, the MBR process is achieving more and more focus. Nearly all MPs could be removed from surface waters contaminated by MPs using the MBR system [55]. Nevertheless, even at low concentrations (10 particles/L), MPs resulted in membrane fouling, which reduced the membrane's service life and required routine physical cleaning. According to this study, the majority of MPs resulted in irreversible membrane fouling [56]. Nevertheless, WWTPs are still a possible source of MP releases in the massive amounts of wastewater that are regularly released into the environment, even with the use of modern technologies. Therefore, creating new, effective technologies to eradicate MPs and NPs from water is crucial. To prevent the pollutants from being transferred to another form of final treatment, these processes need to be destructive rather than extractive [57].

## 5. Advanced remediation technologies

### *5.1 Dissolved air flotation*

The position of dissolved air flotation in WWTPs can be altered by making an effort to eliminate the presence of lightweight particles, oils, and greases (before or after primary, secondary, or final stages). As a result, particles with lower specific weight float to the top and are skimmed off. Due to low-density MPs, dissolved air flotation has shown a 95% removal efficiency of MPs; however, its true goal is not to remove NPs or MPs. The degree to which these plastic particles were removed from the air flotation solution depended on the size, pH, and types of NPs and MPs. An air flotation procedure is effective in removing 69%–85% of PES, PVC, and PE NPs [58].

### *5.2 Membrane technology*

One of the most effective methods for treating wastewater to get rid of MPs and NPs is membrane technology [59]. Membrane technology offers several advantages in terms of removing various pollutants from wastewater. Reverse osmosis (RO), ultrafiltration (UF), nanofiltration (NF), and microfiltration (MF) are the four primary techniques for separating membranes. At the secondary or tertiary stage, these membrane processes are employed to treat the primary effluent, either independently or in combination with biological processes. Numerous pollutants and particulates can be eliminated from wastewater using membrane technology, according to prior research [60].

More than 90% of the MP/NP fragments can be removed by MF and UF. The MP concentration decreased from 0.28 to 0.21 MPs/liter after RO. Because of flaws in the membrane or pipe fittings, MPs may show up even after they have passed through the RO filters. Using a gravity-driven filtration mode, the removal of PS NPs with a size range of 79 to 1091 nm greater than 92%. These nanofiber membranes were created for this reason. However, surfactants and acidic environments might make removal more difficult [61].

### *5.3 Membrane bioreactor*

Membrane bioreactors (MBRs) are devices that extract suspended or dissolved inorganic and organic matter as nutrients from primary effluent by combining membrane filtration technology with bioreactors that operate in anoxic, anaerobic, and aerobic conditions. Additionally, MPs and NPs can be extracted from wastewater using MBR [62]. There are essentially two methods for removing MPs from wastewater using MBR. Entangling MPs in sludge is one way to stop them from passing through micro-filters and into the effluent. Sedimentation from elevated HRT is the main mechanism for removing larger particles (0.1–5 mm) in anaerobic conditions; sludge adsorption interception is the mechanism for removing smaller particles (0.0308–0.1 mm) in aerobic processes [63]. Furthermore, despite having incredibly small pore sizes, the membranes have shown remarkably low MP concentrations in the MBR effluent. Treated wastewater can get contaminated with microplastics (MPs) in several ways. These pathways include leaks from other units, MPs with filters smaller than 0.25 mm, anomalies or unusual filter breaking, and MPs entering open tanks through the atmosphere [49]. Using a combination of MBR and RO systems, the authors' study of an integrated membrane system for the removal of MPs demonstrated a 98% removal efficiency [64].

### *5.4 Advanced oxidation processes:*

In WWTPs, advanced oxidation methods are commonly employed as a tertiary treatment. These techniques are workable choices for MP and NP remediation as well as for reducing the effects of several recently discovered contaminants. When semiconductors are exposed to enough energy to force electrons to shift from the valance band to the conduction band, photo generated species are created during photocatalysis. After that, these species mix with oxygen and water to form radical species (superoxide and hydroxyl). Several recently identified pollutants, such as ZnO catalysts, or nano-rods, in conjunction with visible light, have been demonstrated to be a clean technology when applied to water. It has proven to be capable of breaking down LDPE MPs by chemically transforming the plastic into low molecular weight compounds and mechanizing viscoelastic properties [65]. Because longer ZnO rods have been demonstrated to be more effective in breaking down LDPE MPs due to their larger effective surface area, the catalyst is also necessary for the degradation process [65].

It has been observed that smaller MPs degraded more quickly than larger MPs when they used N-$TiO_2$ to study the photocatalytic degradation of LDPE/HDPE MPs. This suggests that there should be more opportunities for photocatalysis to break down the NPs [66]. Using immobilized copper oxide semiconductors being conducted photocatalytic degradation of PS NPs under visible light, reporting up to 23% degradation. According to their findings, PMMA nanobeads began to degrade by 50% at a pH of 6.3 and flowed at a rate of 10 ml/min after being exposed to 112 W/$m_2$ of radiation for 7 hours [67]. For the first time, scientists examined MP degradation under hydrothermal conditions using magnetic carbon nanotubes. MP degradation products may provide carbon to aquatic microorganisms. Among its many distinctive qualities, the technology was emphasized for its capacity to introduce microplastics (MPs) into the carbon cycle by offering an eco-friendly carbon source for the cultivation of algae [68]. The removal of 100% of the MPs (PE, PTE, and PA) was achieved through the adsorption of M-CNT onto the MPs and subsequent separation through magnetic action [69]. Using recycled M-CNTs in the same study, they were able to eliminate MPs by 80%. The degradation of NPs in water using electro-oxidation and electro-peroxidation, using boron-doped diamond as the anode, titanium as the cathode for electrooxidation, and carbon felt as the cathode for electrooxidation [70]. The in-situ generation of ROS, such as hydroxyl radicals, hydrogen peroxide, and persulfates, degrades the NPs. The maximum efficiency of NP degradation by electro-peroxidation under optimal conditions was 86.8%. Oxygen-containing groups can be formed when reactive oxygen species produced by AOP combine with NPs, altering the material's physicochemical characteristics such as hydrophilicity, surface charge, chemical composition, etc. For example, the hydrophilicity and negative charge of NPs treated with AOPs are enhanced, increasing their ability to absorb pollutants. Similarly, AOP-treated NPs experience physiochemical changes that affect how they are transported later on. Another thing to be concerned about is the possibility that the chemical conversion of NPs will produce a variety of hazardous byproducts. Examining the intermediate photoreactions and adjusting the parameters to gain additional insight into the NPs' degradation process is difficult [71].

## 6. Future research

Plastic pollution is getting worse as a result of their high level of stability and widespread use. It is difficult to decay and constantly compromises the health of the environment and living things. These observations are supported by past investigations, although much more has to be clarified and investigated in this area. They include, among other things:

- Potential method for locating, measuring, and evaluating the presence of nanoplastics in the environment.
- The process of degradation rates and mechanisms.
- Nanoplastic contamination and transmission in the environment.
- To use efficient technologies for eliminating microplastics and nanoplastics.

## 7. Conclusions

All surface waterways are impacted by plastic pollution, which is caused by non-biodegradable materials called micro- and nanoplastics. And as a result of this pollution getting worse, there is a global environmental problem. Wastewater treatment is arguably the most significant environmental protection measure that needs to be put into place globally. The first topic covered in this review is the potential of various qualitative and quantitative methods for MPs and NPs analysis that can be used to investigate water treatment processes. Given the narrow scope and application scenarios of these MNPs, we need to either improve upon the existing methods for eliminating MNPs or look into new approaches for a larger variety of scenarios. Second, it must be acknowledged that despite the fact that a number of current approaches have produced some fairly notable results, they also have some drawbacks. Some have high removal efficiency but are not environmentally friendly enough; some are very environmentally friendly but require a lot of time and money; and so on. Consequently, to address this issue, advanced removal techniques must be used when removing MNPs in real-world application scenarios. The removal efficacy of various sophisticated techniques is also contrasted. The majority of these technologies—disc filtration, rapid granular filtration, coagulation, etc. achieve performance levels above 90%. Specifically, removal efficiencies of MPs or NPs up to 97% were reported for rapid granular filtration, 98.5% for disc filtration, 99.4% for membrane filtration, 99% for MBR, 90% for dynamic membrane filtration, 99% for coagulation, 99% for electro coagulation, and 95% for air flotation. The wastewater treatment industry is seeing an increase in the use of advanced oxidation processes. However, there is still much to learn about the precise mechanisms underlying AOPs. AOPs should also be understood to be crucial technological tools for environmental management, and their development must start with a solid scientific and engineering foundation. Research on the removal of MPs and NPs from water is a new and rapidly developing field. The majority of earlier studies concentrated more on removing MPs from water than NPs. A few studies on the removal of nanoparticles (NPs) from water being conducted. Effectiveness to fully understand the potential of different processes in the removal of NPs from water, more research is therefore necessary. The main methods for removing or treating MNPs from wastewater are described in this article. It also covers how current treatment methods need to be enhanced to limit MNPs concentrations and there is necessity to ensure that therapy is effective everywhere. Monitoring and measuring the quantity of microplastics and nanoplastics generated at each stage of a WWTP treatment is especially important. The requirement for quick and easy methods to measure and characterize NPs in water presents another difficulty. Nanoplastics are gaining a lot of attention due to their propensity to spread throughout the ecosystem and damage all living creatures. In the end, thorough assessments of research using actual wastewater settings and solution compositions with different NPs and MPs matrices, forms, sizes, and compositions were required. Standardizing quantitative techniques for MNPs detection and management is also crucial. Nanoplastics have a far longer half-life in the environment than other contaminants. The rate of degradation and removal can be accelerated by a variety of water treatment techniques

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