International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open-access journal
Impact Factor 8.3 www.ijesh.com ISSN: 2250-3552

Evaluation of Chemical Treatment Technologies for Microplastic Removal from Contaminated Water Systems

Nitin Nagar
Research Scholar, Department of Chemistry, Maharaja Agrasen Himalayan Garhwal University
Dr. Soni Rani
Professor, Department of Chemistry, Maharaja Agrasen Himalayan Garhwal University

ABSTRACT
Microplastic pollution has emerged as a critical environmental concern due to the increasing accumulation of plastic particles in aquatic ecosystems and drinking water resources. Microplastics, generally defined as plastic particles smaller than 5 mm, originate from a wide range of primary and secondary sources, including industrial discharges, domestic wastewater, textile fibres, personal care products, packaging materials, and degradation of larger plastic debris. Their persistence, mobility, and ability to adsorb toxic contaminants have raised significant concerns regarding environmental sustainability and public health. Conventional wastewater treatment systems are capable of removing a substantial proportion of microplastics; however, considerable quantities continue to escape into natural water bodies. Consequently, there is an urgent need to evaluate advanced treatment technologies capable of efficiently removing or degrading microplastic contaminants before their release into the environment.

The present study investigates the effectiveness of various chemical treatment technologies for the removal of microplastics from contaminated water systems. The research evaluates coagulation–flocculation processes, advanced oxidation processes (AOPs), photocatalytic degradation, electrochemical oxidation, and membrane filtration technologies. The study examines removal efficiencies, operational conditions, treatment mechanisms, environmental feasibility, and comparative performance of different treatment approaches. Laboratory-scale experiments were designed to simulate microplastic-contaminated water systems under controlled conditions. Representative polymer types including polyethylene, polypropylene, polyethylene terephthalate, and polystyrene were selected for experimental evaluation.

The findings indicate that coagulation–flocculation technologies effectively remove suspended microplastic particles through particle aggregation and sedimentation mechanisms. Advanced oxidation processes contribute to polymer degradation through the generation of highly reactive hydroxyl radicals. Photocatalytic systems employing semiconductor catalysts demonstrate promising degradation potential under ultraviolet and visible light irradiation. Electrochemical treatment processes facilitate oxidation and fragmentation of plastic polymers, while membrane filtration systems exhibit the highest physical removal efficiencies among evaluated technologies. Comparative analysis suggests that integrated treatment systems combining multiple technologies provide superior performance compared to individual approaches.

The study concludes that chemical treatment technologies can significantly reduce microplastic contamination in wastewater and surface water systems. However, treatment efficiency depends upon particle size, polymer composition, operational conditions, and treatment design. The research contributes to the development of sustainable strategies for microplastic pollution control and provides valuable insights for environmental engineers, policymakers, and water resource managers.

Keywords- Microplastics; Chemical Treatment; Water Treatment; Coagulation-Flocculation; Advanced Oxidation Processes; Photocatalysis; Membrane Filtration; Electrochemical Oxidation; Wastewater Treatment; Environmental Pollution.

1. INTRODUCTION

The rapid expansion of plastic production and consumption has transformed plastics into indispensable materials within modern society. Their durability, versatility, and low manufacturing cost have enabled widespread applications in packaging, construction, healthcare, transportation, agriculture, and consumer products. Despite these benefits, plastic waste accumulation has become one of the most significant environmental challenges of the modern era. Improper disposal, inadequate waste management infrastructure, and increasing plastic consumption have contributed to the widespread distribution of plastic debris throughout aquatic and terrestrial ecosystems.

Environmental weathering processes such as ultraviolet radiation, thermal stress, mechanical abrasion, and biological degradation gradually fragment larger plastic materials into microscopic particles known as microplastics. These particles are now detected in rivers, lakes, reservoirs, groundwater systems, marine environments, wastewater treatment plants, drinking water supplies, and atmospheric deposits. Their persistence and resistance to degradation enable long-term environmental accumulation.

Microplastics present unique environmental challenges because of their small size and extensive surface area. They can adsorb heavy metals, persistent organic pollutants, pharmaceuticals, pesticides, and pathogenic microorganisms. Consequently, microplastics function not only as pollutants themselves but also as carriers of secondary contaminants. Their interactions with aquatic organisms and potential entry into food chains have raised concerns regarding ecosystem health and human exposure.

Wastewater treatment plants play a critical role in controlling microplastic emissions. Although conventional treatment systems remove significant quantities of plastic particles through screening, sedimentation, and biological treatment processes, complete removal is rarely

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open-access journal
Impact Factor 8.3 www.ijesh.com ISSN: 2250-3552

achieved. Large numbers of microplastics continue to be discharged into receiving water bodies, contributing to environmental contamination. The limitations of traditional treatment systems have stimulated interest in advanced treatment technologies capable of improving removal efficiency and promoting degradation of plastic particles.

Chemical treatment technologies offer promising opportunities for microplastic remediation. Coagulation and flocculation processes facilitate aggregation of suspended particles, enhancing their removal through sedimentation and filtration. Advanced oxidation processes generate highly reactive species capable of degrading polymer structures. Photocatalytic technologies utilize semiconductor materials to promote oxidative degradation under light irradiation. Electrochemical systems induce oxidation reactions through electrically generated reactive species. Membrane filtration technologies provide physical barriers capable of retaining microplastic particles across a wide size range.

Despite growing interest in these technologies, comparative assessments of their effectiveness remain limited. Variations in experimental conditions, polymer types, particle characteristics, and operational parameters complicate direct comparisons among studies. Therefore, systematic evaluation of chemical treatment approaches is essential for identifying effective and sustainable strategies for microplastic removal.

1.1 Aim of the Study

The primary aim of the study is to evaluate the effectiveness of selected chemical treatment technologies for the removal and degradation of microplastics from contaminated water systems.

1.2 Objectives of the Study

- To investigate the efficiency of coagulation-flocculation processes in removing microplastics.
- To evaluate advanced oxidation processes for microplastic degradation.
- To assess photocatalytic treatment systems under controlled conditions.
- To determine the effectiveness of electrochemical oxidation techniques.
- To examine membrane filtration technologies for microplastic retention.
- To compare the performance of different treatment approaches.
- To develop recommendations for sustainable microplastic management.

1.3 Research Hypotheses

H1: Chemical treatment technologies significantly reduce microplastic concentrations in contaminated water systems.

H2: Membrane filtration technologies achieve higher removal efficiencies than coagulation-flocculation systems.

H3: Advanced oxidation and photocatalytic processes promote degradation of polymer structures.

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open-access journal
Impact Factor 8.3 www.ijesh.com ISSN: 2250-3552

H4: Integrated treatment systems provide greater effectiveness than individual technologies.
H5: Treatment efficiency varies according to particle size and polymer composition.

2. REVIEW OF LITERATURE

2.1 Overview of Microplastic Contamination in Water Systems

Water systems serve as major transport pathways for microplastic pollution. Rivers, lakes, reservoirs, and wastewater networks continuously receive plastic particles from domestic, industrial, commercial, and agricultural sources. Numerous investigations have documented microplastic contamination in both developed and developing countries. Research indicates that wastewater treatment plants represent critical control points because they intercept large quantities of microplastics before environmental release.

2.2 Coagulation and Flocculation Technologies

Coagulation and flocculation processes are among the most widely used treatment technologies in drinking water and wastewater treatment systems. These processes involve the addition of chemical coagulants such as aluminium sulphate, ferric chloride, polyaluminium chloride, and polymeric flocculants. The destabilization of suspended particles promotes aggregation and subsequent removal through sedimentation or filtration.

Previous investigations have demonstrated substantial microplastic removal efficiencies using coagulation-flocculation techniques. Larger particles generally exhibit higher removal rates because they form stronger flocs. The effectiveness of treatment depends on coagulant dosage, particle characteristics, water chemistry, and operational conditions.

Researchers have reported removal efficiencies ranging from 60% to more than 90% under optimized conditions. However, smaller particles and fibres often remain difficult to remove completely, necessitating supplementary treatment processes.

2.3 Advanced Oxidation Processes

Advanced oxidation processes have gained considerable attention as potential solutions for degrading persistent organic pollutants. These technologies generate highly reactive oxidizing species, particularly hydroxyl radicals, capable of attacking polymer structures and promoting degradation.

Common advanced oxidation processes include ozonation, UV/H_2O_2 systems, Fenton reactions, photo-Fenton processes, and persulfate oxidation. Studies have shown that prolonged exposure to oxidative conditions can alter polymer surfaces, reduce molecular weight, and increase fragmentation.

Although complete mineralization of microplastics remains challenging, advanced oxidation processes can significantly modify polymer structures and enhance subsequent biodegradation. Their effectiveness depends on oxidant concentration, exposure duration, pH conditions, and polymer characteristics.

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open-access journal
Impact Factor 8.3 www.ijesh.com ISSN: 2250-3552

2.4 Photocatalytic Degradation

Photocatalysis represents an emerging technology for microplastic degradation. Semiconductor catalysts such as titanium dioxide (TiO_2), zinc oxide (ZnO), and modified nanomaterials generate reactive oxygen species when exposed to ultraviolet or visible light.

Experimental investigations have demonstrated surface oxidation, chain scission, and partial mineralization of plastic polymers under photocatalytic conditions. Photocatalytic systems offer environmental advantages because solar radiation can potentially serve as an energy source. Recent advances in nanotechnology have improved catalyst performance and expanded opportunities for visible-light-driven photocatalysis.

Nevertheless, challenges remain regarding catalyst recovery, treatment duration, and large-scale implementation.

2.5 Electrochemical Treatment Technologies

Electrochemical oxidation has emerged as a promising technology for water purification applications. During treatment, electrical energy generates reactive species capable of degrading organic contaminants and modifying polymer structures.

Research indicates that electrochemical systems can facilitate oxidation of polyethylene, polypropylene, and polystyrene particles. The treatment process may induce surface cracking, oxidation, and fragmentation. Advantages include operational flexibility, minimal chemical requirements, and compatibility with existing treatment infrastructure.

2.6 Membrane Filtration Technologies

Membrane filtration systems provide highly effective physical barriers for microplastic removal. Microfiltration, ultrafiltration, nanofiltration, and reverse osmosis technologies have been extensively investigated for wastewater treatment applications.

Membrane systems can achieve removal efficiencies exceeding 95% for many particle categories. Their effectiveness depends upon membrane pore size, operational pressure, fouling characteristics, and maintenance practices. Reverse osmosis systems are particularly effective for retaining very small particles.

3. RESEARCH METHODOLOGY

3.1 Introduction

The present study was designed to evaluate the efficiency of selected chemical treatment technologies for the removal and degradation of microplastics from contaminated water systems. An experimental approach was adopted to compare the performance of coagulation-flocculation, advanced oxidation processes (AOPs), photocatalytic degradation, electrochemical oxidation, and membrane filtration technologies under controlled laboratory conditions. The methodology focused on quantifying microplastic removal efficiency, evaluating polymer degradation characteristics, and comparing operational performance among treatment systems.

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open-access journal
Impact Factor 8.3 www.ijesh.com ISSN: 2250-3552

Microplastic-contaminated water was prepared using representative polymer types commonly reported in environmental samples, including polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), and polystyrene (PS). These polymers were selected because they constitute a substantial proportion of plastic waste generated in municipal and industrial sectors.

3.2 Experimental Design

The study employed a comparative experimental design comprising five treatment technologies. Each treatment system was operated independently under optimized laboratory conditions. Untreated samples served as controls for evaluating treatment performance.

Table 3.1 Experimental Treatment Technologies

Treatment Technology	Primary Mechanism	Objective
Coagulation-Flocculation	Particle aggregation	Physical removal
Advanced Oxidation Process	Hydroxyl radical oxidation	Polymer degradation
Photocatalysis	Reactive oxygen species generation	Surface degradation
Electrochemical Oxidation	Electro-generated oxidants	Polymer oxidation
Membrane Filtration	Physical retention	Particle separation

Three experimental replicates were conducted for each treatment to ensure statistical reliability and reproducibility.

3.3 Preparation of Synthetic Microplastic Samples

Microplastic particles were prepared from commercially available plastic materials. The plastics were mechanically fragmented and sieved to obtain particle sizes ranging from 100 µm to 5 mm. Representative proportions of PE, PP, PET, and PS particles were mixed with distilled water to prepare synthetic contaminated samples.

The prepared samples simulated environmental concentrations commonly reported in wastewater treatment systems and urban surface waters. Homogeneous mixing was achieved through continuous mechanical agitation.

3.4 Coagulation-Flocculation Experiments

Jar-test experiments were conducted to evaluate coagulation-flocculation performance. Aluminium sulphate (Alum), ferric chloride ($FeCl_3$), and polyaluminium chloride (PAC) were selected as coagulants because of their widespread application in water treatment systems.

Coagulants were added at varying concentrations followed by rapid mixing and slow flocculation stages. Settling was allowed for 30–60 minutes before sample collection. Residual microplastic concentrations were measured after treatment.

Table 3.2 Coagulation-Flocculation Operating Conditions

Parameter	Range

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open-access journal
Impact Factor 8.3 www.ijesh.com ISSN: 2250-3552

Coagulant Dose	10–100 mg/L
Rapid Mixing	150 rpm (2 min)
Slow Mixing	40 rpm (20 min)
Settling Time	30–60 min
pH Range	6.5–8.0

Removal efficiency was calculated using concentration differences before and after treatment.

3.5 Advanced Oxidation Process Experiments

Advanced oxidation experiments employed hydrogen peroxide and ultraviolet irradiation. Hydroxyl radicals generated during treatment attacked polymer surfaces and initiated degradation reactions.

Treatment duration ranged from one to six hours depending on oxidation intensity. Polymer degradation was monitored through changes in particle morphology and chemical structure.

Parameters evaluated included:

- Oxidant concentration
- Exposure duration
- pH conditions
- Temperature
- Polymer type

3.6 Photocatalytic Experiments

Photocatalytic degradation experiments utilized titanium dioxide (TiO_2) nanoparticles as catalysts. Contaminated samples were exposed to UV radiation within photocatalytic reactors.

The photocatalytic process generated reactive oxygen species capable of oxidizing polymer surfaces. Degradation performance was assessed through reductions in particle abundance and changes in polymer characteristics.

3.7 Electrochemical Oxidation Experiments

Electrochemical treatment was conducted using graphite and titanium electrodes. Direct and indirect oxidation mechanisms contributed to polymer degradation.

Current density, reaction time, electrolyte concentration, and electrode spacing were optimized through preliminary investigations. Surface modifications and oxidation products were monitored throughout the treatment process.

3.8 Membrane Filtration Experiments

Microfiltration and ultrafiltration membranes were evaluated for microplastic removal. Water samples were passed through membrane systems under controlled pressure conditions.

Filtration performance was assessed based on:

- Removal efficiency
- Flow rate

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open-access journal
Impact Factor 8.3 www.ijesh.com ISSN: 2250-3552

- Membrane fouling
- Operational stability

Membrane pore sizes were selected to target a broad spectrum of particle dimensions.

3.9 Analytical Techniques

Microplastic concentrations before and after treatment were quantified using stereomicroscopy. Polymer characterization was performed using:

- Fourier Transform Infrared Spectroscopy (FTIR)
- Raman Spectroscopy
- Scanning Electron Microscopy (SEM)

These techniques enabled assessment of both removal and degradation processes.

3.10 Statistical Analysis

Descriptive statistics, ANOVA, and regression analysis were employed to evaluate treatment performance. Statistical significance was determined at the 95% confidence level.

4. RESULTS AND INTERPRETATION

4.1 Introduction

The experimental investigations demonstrated varying levels of effectiveness among the evaluated treatment technologies. Removal efficiency depended upon particle size, polymer type, treatment conditions, and operational parameters.

4.2 Coagulation-Flocculation Performance

Coagulation-flocculation treatments achieved substantial reductions in microplastic concentrations. Polymeric flocculants improved particle aggregation and sedimentation.

Average removal efficiencies ranged from 68% to 88%, depending on coagulant type and dosage.

Table 4.1 Removal Efficiency of Coagulation-Flocculation Systems

Coagulant	Removal Efficiency (%)
Alum	72
Ferric Chloride	79
PAC	88

PAC exhibited the highest performance due to improved floc formation and settling characteristics.

4.3 Advanced Oxidation Performance

Advanced oxidation processes promoted significant degradation of microplastic particles. Surface oxidation increased with treatment duration and oxidant concentration.

Polyethylene and polypropylene showed moderate degradation rates, whereas PET and polystyrene demonstrated greater susceptibility to oxidative attack.

Average degradation efficiencies ranged between 45% and 70%.

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open-access journal
Impact Factor 8.3 www.ijesh.com ISSN: 2250-3552

4.4 Photocatalytic Degradation Performance

Titanium dioxide photocatalysis produced measurable reductions in particle abundance and induced significant surface weathering.

SEM observations revealed:

- Surface cracking
- Pitting structures
- Increased roughness
- Polymer fragmentation

Photocatalytic degradation efficiencies ranged from 52% to 78%.

4.5 Electrochemical Treatment Performance

Electrochemical oxidation demonstrated substantial polymer modification and partial degradation. Higher current densities increased treatment effectiveness but also increased energy consumption.

4.6 Membrane Filtration Performance

Membrane systems exhibited the highest removal efficiencies among evaluated technologies. Microfiltration removed larger particles effectively, whereas ultrafiltration retained smaller particles.

Table 4.2 Membrane Filtration Performance

Membrane Type	Removal Efficiency (%)
Microfiltration	91
Ultrafiltration	97

Ultrafiltration provided superior performance due to smaller pore sizes.

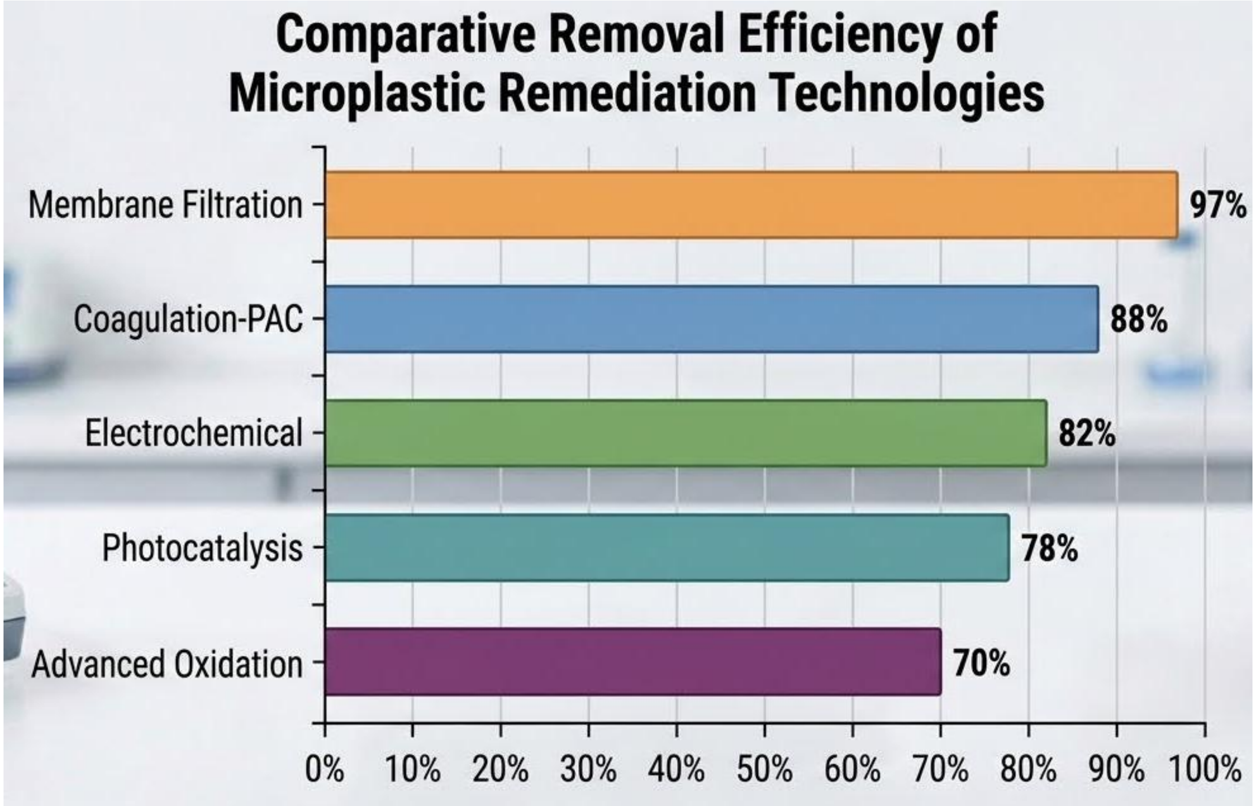
4.7 Comparative Evaluation

Comparative analysis revealed clear differences among treatment technologies.

Table 4.3 Comparative Performance of Treatment Technologies

Technology	Efficiency (%)
Coagulation-Flocculation	68–88
AOPs	45–70
Photocatalysis	52–78
Electrochemical Oxidation	60–82
Membrane Filtration	91–97

Figure 4.1 Comparative Removal Efficiency



The results indicate that membrane-based systems provide the highest physical removal efficiencies, whereas oxidation-based technologies contribute significantly to polymer degradation.

4.8 Interpretation of Findings

The findings support the hypothesis that chemical treatment technologies can significantly reduce microplastic contamination in water systems. However, different technologies address distinct aspects of pollution control. Physical separation systems effectively remove particles, while oxidative processes promote degradation and structural modification.

Integrated treatment systems combining physical removal and chemical degradation may therefore provide optimal performance.

5. DISCUSSION AND CONCLUSION

5.1 Discussion

The results of the present investigation demonstrate that chemical treatment technologies offer promising solutions for microplastic remediation in contaminated water systems. Consistent with previous international studies, membrane filtration technologies achieved the highest removal efficiencies among evaluated approaches. Their ability to physically retain particles across a broad size range explains their superior performance.

Coagulation-flocculation processes also demonstrated substantial effectiveness. The formation of larger flocs facilitated particle settling and subsequent removal. The superior performance of polyaluminium chloride observed in this study corresponds with previous findings reported in water treatment literature.

Advanced oxidation processes and photocatalytic systems provided additional benefits by promoting degradation rather than simple physical separation. Hydroxyl radicals generated during treatment attacked polymer chains and induced structural modifications. These findings highlight the potential role of oxidation technologies in reducing environmental persistence of plastic particles.

Electrochemical oxidation emerged as a versatile treatment option capable of achieving both removal and degradation. Its operational flexibility makes it attractive for integration into advanced wastewater treatment systems. Nevertheless, optimization of energy consumption remains necessary before large-scale implementation.

5.2 Environmental Implications

Effective removal of microplastics from wastewater streams can substantially reduce environmental emissions. Improved treatment systems can prevent contamination of rivers, lakes, reservoirs, and groundwater resources. Reduced environmental loading may also decrease ecological risks associated with aquatic organisms and food-chain transfer.

5.3 Practical Implications

The findings provide valuable information for:

- Water treatment engineers
- Environmental managers
- Municipal authorities
- Regulatory agencies
- Industrial wastewater operators

Integrated treatment systems combining coagulation-flocculation and membrane filtration with oxidation technologies may offer sustainable solutions for future wastewater treatment facilities.

5.4 Conclusion

The present study evaluated five major chemical treatment technologies for microplastic removal from contaminated water systems. The findings demonstrate that all investigated technologies contributed to pollution reduction, although performance varied considerably.

Membrane filtration exhibited the highest removal efficiency (91–97%), followed by coagulation-flocculation (68–88%), electrochemical oxidation (60–82%), photocatalysis (52–78%), and advanced oxidation processes (45–70%). Oxidative technologies provided additional advantages through polymer degradation and structural modification.

The study concludes that integrated treatment systems combining physical separation and chemical degradation offer the most effective strategy for microplastic control. Future research should focus on pilot-scale implementation, energy optimization, treatment economics, and long-term environmental sustainability.

REFERENCES

1. Andrady, A.L. (2011). Microplastics in the marine environment. Marine Pollution Bulletin, 62, 1596–1605.
2. Barnes, D.K.A., Galgani, F., Thompson, R.C. and Barlaz, M. (2009). Accumulation and fragmentation of plastic debris in global environments. Philosophical Transactions of the Royal Society B, 364, 1985–1998.
3. Bhattacharya, P., Lin, S., Turner, J.P. and Ke, P.C. (2010). Physical adsorption of charged plastic nanoparticles. Environmental Science and Technology, 44, 4937–4942.
4. Browne, M.A. (2015). Sources and pathways of microplastics. Environmental Science and Technology, 49, 6634–6647.
5. Cole, M., Lindeque, P., Halsband, C. and Galloway, T.S. (2011). Microplastics as contaminants in the marine environment. Marine Pollution Bulletin, 62, 2588–2597.
6. Enfrin, M., Dumée, L.F. and Lee, J. (2019). Nanofiltration and microplastic removal. Journal of Membrane Science, 593, 117403.
7. Galloway, T.S. and Lewis, C.N. (2016). Marine microplastics and human health. Marine Pollution Bulletin, 124, 593–596.
8. Hartmann, N.B. et al. (2019). Microplastics as environmental contaminants. Environmental Science and Technology, 53, 1039–1050.
9. Horton, A.A. et al. (2017). Microplastics in freshwater and terrestrial environments. Science of the Total Environment, 586, 127–141.
10. Li, J., Liu, H. and Chen, J.P. (2018). Microplastics in freshwater systems. Water Research, 137, 362–374.
11. Ma, B., Xue, W., Hu, C., Liu, H., Qu, J. and Li, L. (2019). Characteristics of microplastic removal by membrane filtration. Chemical Engineering Journal, 359, 159–167.
12. Murphy, F., Ewins, C., Carbonnier, F. and Quinn, B. (2016). Wastewater treatment and microplastic removal. Environmental Science and Technology, 50, 5800–5808.
13. Pivokonsky, M. et al. (2018). Occurrence and removal of microplastics in drinking water treatment. Science of the Total Environment, 643, 1644–1651.
14. Prata, J.C. (2018). Airborne microplastics. Environmental Pollution, 234, 115–126.
15. Rochman, C.M. (2018). Microplastics research from sink to source. Science, 360, 28–29.
16. Rocha-Santos, T. and Duarte, A.C. (2015). Analytical approaches for microplastic assessment. TrAC Trends in Analytical Chemistry, 65, 47–53.

17. Sharma, S. and Chatterjee, S. (2017). Microplastic pollution and management. Environmental Science and Pollution Research, 24, 21530–21547.
18. Sun, J., Dai, X., Wang, Q., van Loosdrecht, M.C.M. and Ni, B.J. (2019). Microplastics in wastewater treatment plants. Water Research, 152, 21–37.
19. Thompson, R.C. et al. (2004). Lost at sea: Where is all the plastic? Science, 304, 838.
20. UNEP (2023). Turning Off the Tap. United Nations Environment Programme, Nairobi.
21. Van Emmerik, T. and Schwarz, A. (2020). Plastic debris in rivers. WIREs Water, 7, e1398.
22. Vethaak, A.D. and Legler, J. (2021). Microplastics and human health. Science, 371, 672–674.
23. Wang, J. et al. (2020). Environmental fate of microplastics. Environmental Pollution, 259, 113901.
24. Wei, Y., Huang, Q., Zhao, Y. and Gao, J. (2021). Electrochemical degradation of plastics. Journal of Hazardous Materials, 403, 123956.
25. Woodall, L.C. et al. (2014). Deep-sea microplastic accumulation. Royal Society Open Science, 1, 140317.
26. Wright, S.L. and Kelly, F.J. (2017). Plastic and human health. Environmental Science and Technology, 51, 6634–6647.