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REVIEW ARTICLE

Research and Trends of Filtration for Removing Microplastics in Freshwater Environments

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ABSTRACT

Microplastics (MPs) are a pollutant that increasingly threatens freshwater ecosystems and requires effective solutions for their removal. The aim of this study is to review current filtration methods used to remove MPs from freshwater environments. This study uses a systematic review method of existing literature regarding filtration techniques for removing MPs. Data were collected from various scientific sources published between 2015 and 2023. The filtration techniques analyzed include traditional filtration and advanced filtration technology. The study results show that advanced filtration technologies such as nanofiltration and biofiltration have a high potential in removing MPs from freshwater. However, each technique has its own challenges, including removal efficiency and implementation cost. The conclusion is that filtration is an effective method for dealing with MP pollution in freshwater ecosystems; however, further study is needed to address the existing challenges. This study provides in-depth insights that can help develop more efficient policies and technologies for managing MP pollution in the future.

1 | Introduction

Microplastic (MP) pollution has emerged as a growing environmental concern globally (Ghosh et al. 2023; Lamichhane et al. 2023; Ziani et al. 2023). MPs, plastic particles less than 5 mm in size, come in a variety of shapes and materials, ranging from synthetic fibers to biodegradable plastic fragments (Park and Park 2021). Recent study has uncovered that MPs, commonly linked to oceanic environmental pollution issues (Alfaro-Núñez et al. 2021; Courtene-Jones et al. 2022; Nair and Gopinath 2023), also pose a significant problem to terrestrial freshwater environments (Baho, Bundschuh, and Futter 2021; Oveisy et al. 2022; Parker et al. 2021; Ullah et al. 2021). These problems include changes in behavior, biological reactions, how energy is used, and life traits. Sendra et al. (2022) found that MPs kill cells in the marine diatom *Phaeodactylum tricornutuma*. Moreover, *Apostichopus japonicas* plants exposed to oxidative stress and immune system responses were affected by MPs at concentrations that occur naturally in the environment (0.6 and 1.2 particles/g). Furthermore, Pittura et al. (2022) found that immunocytes of the *Mytilus galloprovincialis* fish were affected when they were exposed to microfibers (MFs) (50 particles/ml). *Hydroides elegans* eggs that were subjected to MPs (1–20 µM) from medical face masks had the lowest rate of hatching after 30 and 120 days of degradation compared to 24 h. Study on MPs' effects on cytotoxicity, oxidative stress, immune system reactions, and developmental toxins in different animals is limited. Meanwhile, MPs in plants suppressed germination, inhibited plant growth and production, and interfered with seedling physiology (Haider et al. 2021).

MPs are primarily introduced through agricultural activities, urban runoff, and atmospheric deposition (Garfansa et al. 2024a). Studies indicate that MPs in marine environments originate from the use of consumer products such as cosmetics and textiles, which are carried into the water from land. Harikrishnan et al. (2024) found that MPs released into seawater changed a lot as they broke down, with numbers ranging from 2300 to 22,500 particles. From days 1 to 120, the number of MPs released went up steadily, reaching 11,343 ± 1215 on day 30 and 21,495 ± 902 on day 120. Studies showed that MPs are found in high concentrations in urban and industrial areas, where plastic usage and waste disposal are more intensive (Chen et al. 2020; Nematollahi et al. 2022). One of the primary pathways for MP accumulation on land is through the application of sewage sludge as fertilizer in agricultural fields. This sludge often contains large amounts of MPs, which are then dispersed into the terrestrial environment. Additionally, MPs can be carried by wind and rain, spreading from their source to wider areas. MPs from land can be transported to the sea through river flows, eventually settling in marine sediments (Darabi et al. 2021). The distribution of MPs was significantly influenced by geographical factors and human activities (Avinash, Namasivayam, and Bharani 2023). For example, areas with intensive plastic industrial activities tend to have higher levels of MP contamination (Jaubet et al. 2021). Furthermore, weather patterns and climate play crucial roles in the spread of MPs, with storms and floods potentially accelerating the transportation of these particles into the surrounding environment. MPs can accumulate in the bodies of organisms. Zooplankton species, for example, *Centropages typicus*, make them lose their ability to feed due to MPs (Cole et al. 2013). Bivalves, for example, oysters and blue mussels, filter large amounts of seawater and store MFs. Mussels that are raised have higher MF levels because they are grown with plastic ropes. MFs are found in both cultured blue mussels from Germany's North Sea and oysters from France's North Atlantic Ocean. This can affect the safety of seafood and potentially enter the human food chain. Mitigation efforts include the development of effective water treatment technologies to remove MPs, which need to be further studied.

> "*Presently, numerous studies have been conducted on approaches to remove MPs in water.*"

Presently, numerous studies have been conducted on approaches to remove MPs in water. Various methods, including photocatalysis (Mayorga-Burrezo, Mayorga-Martinez, and Pumera 2023), adsorption (Ramirez Arenas et al. 2021), coagulation (Gao et al. 2023b), bioremediation (Gao, Ning, and Deng 2023a), air flotation (Wang et al. 2021), and filtration (Amirah Mohd Napi et al. 2023), have been used to reduce the number of MPs found in water. Filtration stands out as the most cost-effective and user-friendly method among these options. In contrast, other techniques such as coagulation or advanced oxidation may demand specialized equipment or costly chemical additives (Gao et al. 2022). Filtration emerges as a practical and cost-effective approach to mitigate MP contamination in freshwater environments. This technique employs membranes or filters to trap and remove MP particles from water (Pizzichetti et al. 2021). Combining microfiltration and ultrafiltration within membrane bioreactor technology achieves 99.4% efficiency in removing MPs, surpassing the 98.3% efficacy of traditional sludge-based methods. Techniques such as dissolved air flotation and rapid gravity sand filters are over 95% effective, while electrocoagulation shows over 90% efficiency, with the highest removal effectiveness being 99.24% through a two-stage process. Keerthana Devi et al. (2022) highlighted that various water-cleaning steps can enhance the breakdown and removal of nanoplastics. Dr. David Manz pioneered filtration technology in the 1990s with the development of the bio-sand filter (BSF) model (Freitas et al. 2022). The BSF model emphasizes specific construction guidelines, advocating for intermittent operation, also known as on-demand operation. The model's evolution is shaped by the synergistic interplay of physicochemical and biological processes occurring within the sand filter media (Joo et al. 2021). This combination facilitates the elimination of organic and inorganic chemicals, as well as many infections that cause diarrheal episodes, while also aiding in the retention of contaminants. Recently, different filtration systems include the use of coir and pith fibers (Ganesan and Nallathambi 2024), hydrophilic graphene oxide (GO) membrane (Sun et al. 2024), sand (Sembiring, Fajar, and Handajani 2021a), biochar (Hsieh et al. 2022), advanced technologies filtration (Vu and Wu 2022) have been crafted to remove MPs from various water-based environments. Li et al. (2018) found that membranes fabricated on a diatomite platform with a 90-µm-supporting mesh are influenced by variables such as particle concentration and influent flow rate. Moreover, the efficiency of sand filters depends on design factors including effective size (d10), homogeneity coefficient, proportion of small particles (those passing through a 150 sieve), density, and porosity of the filter media.

Studies on MP reduction through filtration methods have increased, while bibliometric studies remain limited. Currently, no studies have utilized the Scopus database for the bibliometric analysis of filtration methods aimed at reducing MPs. Various databases, including Scopus, Web of Science, and Google Scholar, contain conference proceedings, research papers, book chapters, and reviews on MP reduction. However, navigating the vast amount of information can be challenging, making it difficult to discern current study trends. Therefore, employing bibliometric analysis to statistically analyze available database sources can help identify future research directions (Pozzo et al. 2022; Velez-Estevez et al. 2023). Gusenbauer (2022) suggested that while Scopus provides more consistent and accurate results compared to Google Scholar, it offers broader coverage. Meanwhile, Web of Science excels in citation analysis with its superior coverage (Martín-Martín et al. 2021; Moed et al. 2016). Furthermore, Scopus emerged as the most effective search engine for literature study when compared to Web of Science, which typically does not index most study papers in the field. This is especially true when seeking a broad comprehension of a subject or conducting thorough investigations in life sciences and related disciplines (Tober 2011). Utilizing Scopus as a data source to explore filtration methods for reducing MPs in water presents a significant opportunity to discern the worldwide study emphasis and forthcoming outlook in this specific domain.

This paper deliberated the global research focus and prospects related to filtration methods for diminishing MPs in freshwater environments, employing a bibliometric approach. It also intends to scrutinize the attributes of MPs that could be ensnared by filtration methods and pinpoint factors influencing the efficacy of such methods.

2 | Bibliometric Data Collection

The bibliometric data collection focusing on the filtration method for removing MPs from water was conducted between February

EXHIBIT 1 | Search queries used for each phase.

Remarks	Search query
General search	TITLE-ABS (Microplastic AND removal AND Filtration OR Filtering OR Filter OR Separate)
Narrowing	TITLE-ABS (Microplastic AND removal AND Filtration OR Filtering OR Filter OR Separate) AND (EXCLUDE (PUBYEAR, 2024)) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (DOCTYPE, "ar")
Potential review article	TITLE-ABS (microplastic AND removal AND filtration OR filtering OR filter) AND (TITLE ("recent" OR progress OR review OR critical OR revisit OR advance* OR highlight OR perspective OR prospect OR trends OR bibliometric OR scientometric OR insights OR overview OR "state of the art" OR challenges OR updates) OR ABS (progress OR review OR bibliometric OR scientometric)) AND (EXCLUDE (PUBYEAR, 2024)) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (DOCTYPE, "ar")
EID review articles	(2-s2.0-85166082565) OR (2-s2.0-85161269225) OR (2-s2.0-85175974020) OR (2-s2.0-85164754112) OR (2-s2.0-85146129329) OR (2-s2.0-85145952112) OR (2-s2.0-85145359709) OR (2-s2.0-85131927550) OR (2-s2.0-85125012958) OR (2-s2.0-85073815542)
Final	TITLE-ABS (Microplastic AND removal AND Filtration OR Filtering OR Filter OR Separate) AND NOT EID ((2-s2.0-85166082565) OR (2-s2.0-85161269225) OR (2-s2.0-85175974020) OR (2-s2.0-85164754112) OR (2-s2.0-85146129329) OR (2-s2.0-85145952112) OR (2-s2.0-85145359709) OR (2-s2.0-85131927550) OR (2-s2.0-85125012958) OR (2-s2.0-85073815542)) AND (EXCLUDE (PUBYEAR, 2024)) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (DOCTYPE, "ar")

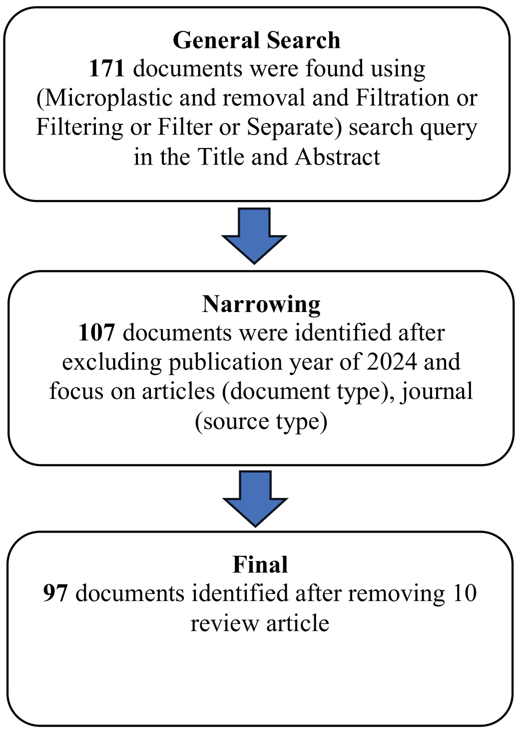

EXHIBIT 2 | Flow chart of bibliometric data mining for research articles on removing MPs in water. [Color figures can be viewed at wileyonlinelibrary.com.]

16, 2024, and February 26, 2024, using the search queries outlined in **Exhibit 1**. Terms such as "Microplastic AND removal AND Filtration OR Filtering OR Filter OR Separate" were employed to gather data from the SCOPUS database spanning the period from 2015 to 2023. The initial search query utilized in this study was TITLE-ABS (Microplastic AND removal AND Filtration OR Filtering OR Filter) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (EXCLUDE (PUBYEAR, 2024)), resulting in 107 documents.

The exploration was carried out utilizing the "Title and Abstract" feature accessible on the advanced search form within the database. Initially, the search query targeted journal articles while excluding those published in 2024. To identify any remaining review articles and exclude them from the search results, additional phrases and terms (such as review, progress, recent, critical, revisit, advance, and highlight) were incorporated into the initial search query (Garfansa et al. 2024b; Iswahyudi et al. 2023; Loh et al. 2023). Subsequently, 10 potential review articles were identified and assessed. Following the elimination of the 10 review papers, the final search query generated 97 documents. The procedure for identifying suitable search queries is summarized in **Exhibit 2**. Google My Maps was utilized to illustrate the countries and organizations leading the study on filtration methods for MP removal. Moreover, data on total publications by country (TPC) and total publications by institution (TPI) were collected and ranked based on their publication count. Furthermore, single-country publications (SPCs) were considered by filtering out papers with affiliations to other countries and focusing solely on those affiliated with the selected countries.

2.1 | Analysis of Bibliometric Mapping Based on Countries' Co-Authorship and Keyword Co-Occurrence

The bibliographic details of the 97 documents retrieved from the final Scopus search were utilized to construct a bibliometric map using VOSviewer (version 1.6.16, Centre for Science and Technology Studies, Leiden University, The Netherlands). This involved extracting citation and bibliographic data, abstracts, and author-provided keywords. To analyze co-authorship among countries, a thesaurus file was imported into VOSviewer along with the csv file for renaming (e.g., changing "université de

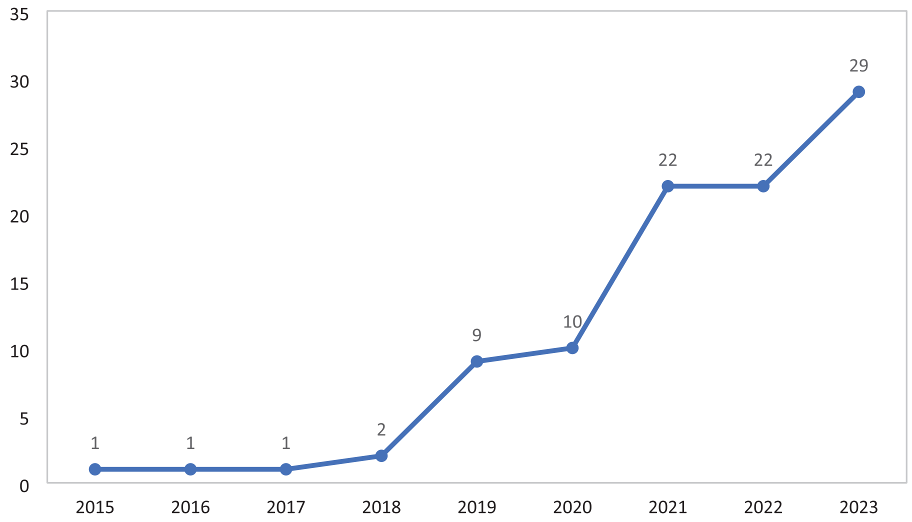

EXHIBIT 3 | Publications trends on filtration removal in wastewater treatment from 2015 to 2023. [Color figures can be viewed at wileyonlinelibrary.com.]

toulouse" to "France," "Harvard University" to "United States") and excluding any irrelevant countries or affiliations, such as "coordinación industrial," "wastewater treatment laboratory," and "West Germany," from the bibliometric map. Moreover, affiliated countries or institutions were categorized into different continents such as Asia, Europe, America, Africa, and Oceania. A total of 44 keywords were identified by setting the minimum threshold number of keyword occurrences to three. Additionally, based on the keyword analysis, an exhaustive literature review covering the filtration process method, factors impacting filtering efficacy (such as pore size, material type, and operational conditions), the application of filtration in treating various wastewater types, and future research prospects were incorporated.

3 | Bibliometric Analysis

3.1 | Research Trends Based on Publications per Year

A total of 97 documents were chosen, focusing on MP filtration in water from 2015 to 2023. **Exhibit 3** illustrates the yearly publications on MP filtration using filtration methods during this period. The findings indicate a steady rise in publications on filtration methods for MP removal over the 9-year period. This consistent increase suggests a continuing upward trend in annual publications in the years to come. Notably, the utilization of filtration methods received minimal attention in 2015, 2016, and 2017, with only one publication during each of these years, but began to gain traction in 2018.

The surge in interest regarding filtration methods for MPs commenced in 2019, witnessing a notable uptick in publications that year. Remarkably, the number of publications exhibited a steep rise since 2021, totaling 22 publications, and maintained the same count in 2022. The pinnacle of this surge occurred in 2023, with a total of 29 articles published, signifying the increasing attention researchers worldwide are giving to the process of reducing MPs using filtration methods. The growing focus on the filtration method in recent years primarily stems from its efficacy, cost-effectiveness, and adaptability in capturing MPs of varying sizes. Filters can be tailored to specific sizes, and the materials used are adjustable, contributing to its environmentally friendly nature.

3.2 | Country and Institution Analysis

Exhibit 4 illustrates the countries and institutions with the highest publication counts, while **Exhibit 5** depicts the distribution of publications based on TPC, SPCs, and TPI. Data analysis indicates that among the top 10 countries contributing to MP reduction through filtration treatment, four are Asian, six are European, and one is American. China leads with 13 publications, followed by South Korea (10) and Spain (9). Notably, Aalborg University tops the list of institutions with six publications, while Stanford University and Iskenderun Technical University have the lowest count with one publication each compared to the other top eight institutions. Regarding SPCs, China records the highest percentage (100%), followed by Canada and Germany at 75%, with the United States at 71%. These countries predominantly focus their research on membrane-based filters. Conversely, Denmark has the lowest SPC percentage (33%), indicating collaboration with international researchers, including those from China, Germany, the United Kingdom, and Spain.

The single-country publication (SPC) percentage quantifies the level of collaboration for each country. A high SPC value indicates robust collaboration among researchers within countries, whereas a low SPC value suggests stronger collaboration between countries. **Exhibit 6** illustrates the bibliometric mapping of co-authorship by country in network visualization mode, generated by VOSviewer software. This visualization underscores the significance of research collaboration between countries. Lines connecting country nodes on the bibliometric map represent co-authorship between countries, with the distance between clusters indicating the strength of this collaboration (Wang et al. 2024). Moreover, the thickness of these lines reflects the intensity of the relationship, influenced by the frequency of collaborations, while

EXHIBIT 4 | Top 10 leading countries and institutions for research on filtration removal in water treatment.

Rank	Country	TPC	SPC (%)	Institutions	TPI
1	China	13	13 (100%)	Zhejiang University	2
2	South Korea	10	7 (70%)	University of Science and Technology (UST)	2
3	Spain	9	5 (55%)	Universidad Politecnica de Cartagena	3
4	Germany	8	6 (75%)	Institute of Energy and Environmental Technology	2
5	United States	7	5 (71%)	Stanford University	1
6	Denmark	6	2 (33%)	Aalborg University	6
7	Indonesia	6	3 (50%)	Institut Teknologi Sepuluh Nopember	2
8	United Kingdom	6	4 (66%)	UK Centre for Ecology & Hydrology	2
9	Turkey	5	3 (60%)	Iskenderun Technical University	1
10	Canada	4	3 (75%)	University of Toronto	2

Abbreviations: SPC, single-country publications; TPC, total publications by the countries; TPI, total publications by institutions.

EXHIBIT 5 | Geographical mapping of leading countries and institutions. [Color figures can be viewed at wileyonlinelibrary.com.]

the size of each node corresponds to the number of publications from the respective country (Dagli, Haque, and Kumar 2024).

China, South Korea, and Spain emerged as the primary contributors to study findings, evident from the prominence of these countries as the three largest network nodes. Notably, China demonstrates robust collaboration with South Korea and Spain, boasting the highest link strength of 425 toward these nations. Furthermore, Chinese researchers engage in fruitful partnerships with counterparts from countries such as Indonesia, Japan, India, and Finland. This extensive collaboration and heightened productivity in China may be attributed to substantial government support, particularly in research funding dedicated to advancing wastewater treatment technology. Moreover, spurred by rapid urbanization, growing environmental consciousness, and stringent regulatory frameworks, numerous industries and researchers in China are actively exploring innovative and efficient wastewater treatment solutions (Xu et al. 2020; Zhang et al. 2024).

3.3 | Keyword Analysis

Including relevant keywords in their keyword lists can help authors attract researchers interested in a specific research area and boost citation scores, as author keywords encapsulate the field of publication or research topic (Corrin et al. 2022). This study identified the research focus on utilizing filters to capture airborne MPs through co-occurrence keyword analysis conducted using Vosviewer. A total of 392 keywords were identified, with

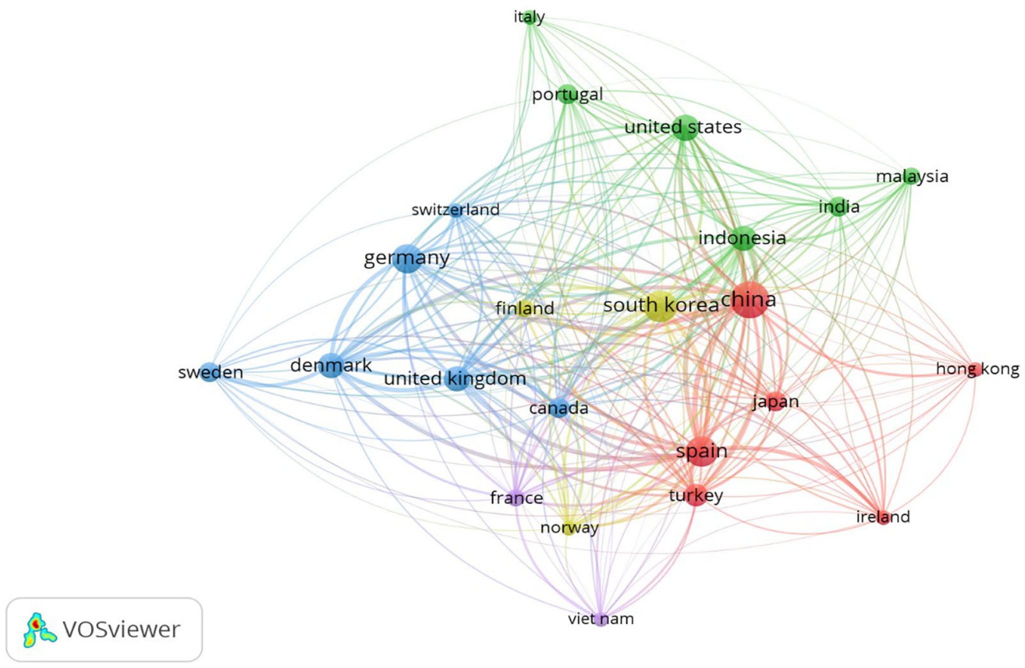

EXHIBIT 6 | Bibliometric mapping of co-authorship by countries. [Color figures can be viewed at wileyonlinelibrary.com.]

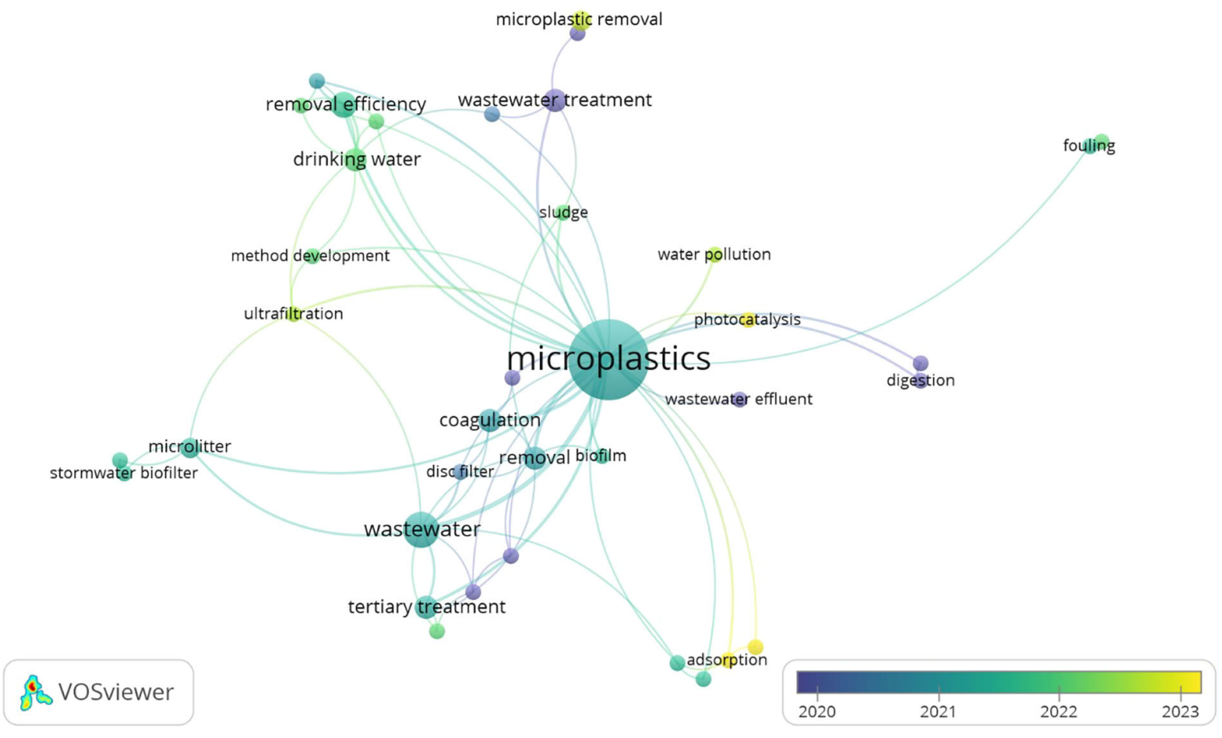

EXHIBIT 7 | Bibliometric mapping of co-occurrence by authors' keywords. [Color figures can be viewed at wileyonlinelibrary.com.]

43 keywords meeting the threshold of at least 2 occurrences (**Exhibit 7**). **Exhibit 8** presents a compilation of author keywords with the highest occurrence rate. The term "Microplastics," which is located at the center of the bibliometric map, outshined other authors' keywords with 48 occurrences (68 total link strengths), followed by the terms "wastewater" (10 occurrences), "removal efficiency" (4 occurrences), and "coagulation" (4 occurrences). The authors' keyword "Microplastic-Removal-Filter" had a strong link strength with these keywords, as these keywords represent the most extensively researched or utilized method, that is, coagulation. Additionally, the author's keyword "coagulation," averaging four publications. This popularity can be attributed to coagulation technology's potential in adsorbing MPs in water. Coagulation, a traditional, popular, and cost-effective technique, effectively removes inorganic and organic colloidal particles from water (Badawi, Salama, and Mostafa

EXHIBIT 8 | Most frequently occurring keywords of authors.

No	Keywords	Occurrences	Total link strengths	Links
1	Microplastics	48	68	33
2	Wastewater	10	25	13
3	Removal efficiency	5	11	6
4	Coagulation	4	9	6
5	Drinking water	4	12	9

2023; Koul et al. 2022). However, this method can only focus on removing large MPs (>10 μm) compared to relatively small ones (<10 μm) (Bayarkhuu and Byun 2022; Tang et al. 2022). A study has indicated that the removal efficiency of 10-μm polystyrene MPs using $AlCl_3$ and $FeCl_3$ as coagulants was less than 40% (Zhou et al. 2021). Furthermore, small MPs are known to be problematic (Carbery et al. 2022; Ziani et al. 2023), and their efficient removal through traditional coagulation methods is challenging (Girish, Parashar, and Hait 2023). Ongoing coagulation advancements aim to address this issue by reducing MPs at smaller sizes, employing techniques such as optimized coagulant aids addition, peroxidation, and pH adjustment (Sun et al. 2019; Tang et al. 2020). The inclusion of optimized coagulant adjuvants, such as anionic polyacrylamide (APAM), polycyclic acid (PSA), sodium alginate, and chitosan, represents a straightforward and effective approach (Huang et al. 2016). This method relies on efficient adsorption bridging flocculation (Li et al. 2022; Tang et al. 2022), demonstrating the superiority of the author's keyword "coagulation" over others.

The correlation between MP removal in water and the authors' keywords aids researchers in identifying global research focus and future trends. Besides the mentioned keywords, Drinking water was among the top 5 terms drawing significant attention, with 12 total link strengths from its association with 9 other keywords. A study on reducing waterborne MPs holds substantial implications for ensuring the provision of safe, high-quality drinking water (Wu, Hou, and Wang 2023). In the realm of drinking water, MPs can infiltrate water systems from diverse origins, including polluted rivers, insufficient water treatment methods, and even packaging used for bottled water. Consequently, investigating methods to diminish MPs in water holds paramount importance in preserving the quality of drinking water to meet consumption standards (Muhib et al. 2023). An essential aspect of this study area involves advancing water treatment techniques effective in eliminating MPs, with key terms such as Coagulation, Biofilm, and Membrane Bioreactor for treatment, and Sand, Biochar, and Granular Activated Carbon for filtration. These keywords signify operational approaches that significantly impact MP removal and filtration efficiency in water. The average publication year for these keywords exceeds 2020, indicating their increasing prominence in recent decades. Researchers were increasingly exploring strategies to reduce MPs using more compact filtration technologies. Consequently, there's a growing emphasis on employing advanced filtration methods in this endeavor. Cutting-edge filtration technologies such as microfiltration and ultrafiltration membranes effectively remove minute MP particles from water with exceptional efficiency. Furthermore, ongoing innovation in filtration materials, including nanofiber and activated carbon, aims to enhance MP-capturing capabilities. Enhancing filtration efficiency with finer granularity significantly contributes to mitigating MP contamination in aquatic ecosystems.

4 | Factors Influencing Filtration and Removal of MPs

The authors' keyword co-occurrence analysis identifies key factors influencing MP filtration in water, including MP size and type, filtration media structure, and flow rate. Various experiments reveal that smaller MPs are harder to trap, while filtration media possess unique adsorption properties (Namasivayam et al. 2023). The sizes and types of MPs were critical factors in the filtration process. Smaller MPs, especially those less than 1 mm in size, tend to be more difficult to trap compared to larger particles. Smaller particles can easily pass through the small gaps in the filtration medium, particularly if the medium has a larger porosity (Cai et al. 2020). Additionally, smaller MPs have a larger surface area relative to their volume, allowing them to disperse more easily and persist in the water column. The type also significantly affects the filtration process. For instance, MPs made from polyethylene, polypropylene, or polystyrene (PS) have lower densities compared to water, causing them to float on the surface. Conversely, MPs made from polyester or polyvinyl chloride (PVC), which have higher densities, will sink, necessitating different filtration approaches (Issac and Kandasubramanian 2021; Jiang et al. 2021).

Larger MPs, such as plastic fragments or pellets, are easier to trap with filtration media because their larger size prevents them from passing through the media's gaps easily. However, smaller MPs, such as MFs or fragments, require filtration media with very small pores to be effectively trapped. Filtration media that combine layers with various pore sizes can enhance the efficiency of removing MPs of different sizes (Martín-García et al. 2022). Experiments show that smaller MPs, particularly those in the nano range, require specialized filtration techniques such as membrane filtration or carbon-based adsorption (Namasivayam and Avinash 2024). Membranes with nano-sized pores can effectively remove very small MPs; however, this method is usually more costly and requires intensive maintenance to prevent clogging (Dong et al. 2022; Xu et al. 2022).

Moreover, the types of polymers affect how they interact with filtration media. MPs made from more hydrophobic materials tend to adhere to hydrophobic filtration media, whereas hydrophilic MPs require media with similar properties for optimal efficiency.

The water flow rate also plays a crucial role in filtration efficiency. A fast flow rate can reduce the contact time between water and the filtration media, decreasing the effectiveness of MP removal. Conversely, a slow flow rate can cause clogging and reduce the overall system efficiency. Therefore, optimizing the flow rate is key in designing an effective filtration system (Cescon and Jiang 2020). Various studies have shown that combining physical and chemical filtration methods can yield better results. For example, using filters with adsorbent layers containing activated carbon can enhance the removal of MPs through adsorption mechanisms (Men et al. 2020).

4.1 | Sizes and Types of MPs

The sizes and types of MPs have a crucial role in influencing the performance and performance of the MP filtration process in water. The size of the MPs was a determining factor in filtration efficiency. Smaller MP particles tend to be difficult to filter using conventional methods because their size is close to the filtering pore size. For example, MPs with a size of <40 μm will be difficult to filter using conventional filtration and require more sophisticated filtration technology such as microfiltration or ultrafiltration membranes to be removed effectively (Gao et al. 2022). Umar, Singdahl-Larsen, and Ranneklev (2023) conducted a study and found that the sizes and types of MPs influence filtration performance using sand filtration. The study demonstrated that the sand filter was able to eliminate up to 100% of the MPs, with only a few instances where this was not the case. The treated sample (filtered onsite) exhibited a reduction of 86%–100% in all particle sizes, except for particles ranging from 125–250 μm, where the removal rate was only 49%. It is important to mention that the overall quantity of particles within this range was relatively small, averaging at 6 particles/L. Additionally, the wastewater samples used by Bayo, López-Castellanos, and Olmos (2020) were rich in fibers, which could be difficult to remove completely by sand filtration, as fibers can pass longitudinally through the sand filter. In fact, the authors reported a much lower reduction in fibers (53.83%) compared with other fractions such as MP particles (95.53%). When the particle size reached 10−20 μm, an increase in particle size corresponded to a higher fraction of particles being removed through filtration. Conversely, particles smaller than 10−20 μm exhibited a more pronounced removal effect compared to larger particles. The results indicate that filtration may be the optimal method for eliminating micro- and nanoplastics. This procedure can entirely eliminate MPs that are larger than 100 μm. This aligns with previous research that has shown a scarcity of MPs larger than 100 μm in treated drinking water (Koelmans et al. 2019; Wang, Lin, and Chen 2020a)

Moreover, the filtration performance was impacted by the types of MPs, which are determined by their physical and chemical attributes. For instance, MPs like PS, which share the density of water, present challenges in separation using gravity or sedimentation techniques. Employing coagulation technology in the filtration process can enhance effectiveness in eliminating such MPs, as it facilitates the formation of larger flocs, simplifying the filtration process. In another study by Zhang et al. (2020), particles ranging in size from 106 to 125 μm did not exhibit enhanced flocculation or sedimentation when PolyDADMAC was added. Curiously, the sedimentation efficiency of particles smaller than 45−53 μm did not show any improvement. Polymer-induced flocculation involves the formation of flocs through three primary mechanisms: charge neutralization, charge–patch interaction, and particle bridging (Khazaie et al. 2022). The formation of flocs can be influenced primarily by one mechanism or collectively by all mechanisms, depending on specific conditions of parameters, such as particle size/concentration, polymer size/concentration, polymer molecular weight, and velocity gradient or shear rate. These conditions result in varying rates of sedimentation.

> “*Employing coagulation technology in the filtration process can enhance effectiveness in eliminating such MPs, as it facilitates the formation of larger flocs, simplifying the filtration process.*”

4.2 | Filtration Media

The structure and filtration media significantly impact the effectiveness of removing MPs from water. Factors such as porosity, pore size, and surface area directly affect the media's capacity to capture MP particles. Media with smaller pores and larger surface areas are more adept at trapping MPs, especially smaller particles. Moreover, fibrous or layered media, such as activated carbon, nanofibers, or porous membranes, enhance filtration by creating additional barriers for MPs to traverse. The selected filtration media must be appropriate to the specific environmental conditions and consider these various variables to achieve optimal filtration results. Sembiring, Mahapati, and Hidayat (2021b) used cloth filter media to test the performance of capturing MPs in water. The removal efficiency of MPs varied depending on the filter size, with artificial particles ranging from 70 mesh (210−420 μm) to 194, 115, and 57.5 μm, yielding removal rates between 29.8% and 53%, 44.4% and 62.4%, and 62.2% and 89.5%, respectively. For MPs with particles larger than 420 μm (40 meshes), the removal rates ranged from 25% to 40.8%, 42% to 54.2%, and 60.18% to 87.7%, respectively. In addition to filter pore size, the tensile strength and elongation of filter materials should be considered when selecting cloth filters for MP removal. Additionally, other media (e.g., sand) were utilized to mitigate the presence of MPs in water. These filtration methods represent traditional water purification techniques employed since ancient times. Through filtration, water can be purified from sand, silt, turbidity, scale, and other suspended particles. Sand filtration boasts an effective particle size diameter ranging from 0.15 to 0.35 mm and a uniformity factor between 1.5 and 3.0 (Fajar, Sembiring, and Handajani 2022). The effective particle size for trapping in fast filters was greater than 0.55 mm, with a uniformity factor of less than 1.5. The water filtration rate in fast filters varied between 4 and 21 m/h ($100−475\ m^3 \times m^{-2} \times day^{-1}$) and in sand filters varied from 0.1 to 0.4 m/h ($1–8\ m^3 \times m^{-2} \times day^{-1}$) (Abdiyev et al. 2023). A study regarding the development of sand media was also carried out with GO coating. GO can be coated on the sand's surface for enhanced removal of heavy metal and organic dye (Gao et al. 2011; Sreeprasad et al. 2011). Vu and Wu (2022) stated that a thermal method was employed to create GO-coated sand, which was then utilized to eliminate two typical micropollutants, atrazine (ATZ) and atenolol (ATL), from actual groundwater within the context of slow sand filtration. The application of the GO coating altered the surface reflection and elemental composition of the sand, while also decreasing its surface area, pore size, and pore volume. However, it simultaneously increased the sand's ability to remove ATZ and ATL due to the strong attraction between GO and organic compounds. Biochar is an alternative medium that is effective in filtering MPs from water. Substituting activated carbon with biochar, either partially or entirely, has been shown to notably decrease process cost, including regeneration expenses, while maintaining comparable removal efficiency in wastewater treatment plants (Kah et al. 2017). The increasing attention toward utilizing biochar in water/wastewater treatment systems stems from its high adsorption capacity, the cost-effectiveness of the pyrolysis process used to produce it, and its wide local production potential using locally available raw materials. This attention was driven by the prospect of significantly reducing process cost, including regeneration costs, while maintaining the same level of removal efficiency in waste water treatment plant (WWTP) (Inyang and Dickenson 2015). Wang, Sedighi, and Lea-Langton (2020b) stated that biochar filters provide significant capacity for the removal and immobilization of 10 μm–diameter MP spheres (above 95%), which is much larger than that of a similar grain-sized sand filter studied. Furthermore, Amirah Mohd Napi et al. (2023) showed that MP (40–48 μm) removal up to 95.5% was observed with 0.2 g/L MP, which is the lowest concentration tested using granular activated carbon (GAC). The performance reduced with a further increase in MP concentration (up to 1.0 g/L); however, increasing the GAC bed length from 7.5 to 17.5 cm could lead to better removal efficiencies. A comprehensive comprehension of filtration structures and media is crucial for designing efficient filtration systems to combat MP contamination in water. With the ongoing study and development, enhancing the performance and efficiency of filtration technology was attainable, safeguarding water ecosystems and human well-being from the adverse effects of MPs.

4.3 | Flow Rate Filtration

The filtration rate plays a crucial role in the efficiency and effectiveness of MP filtration in water. Variations in the filtration rate can influence the removal efficiency of MPs, energy consumption, and the durability of membranes or filtration media. A filtration rate that is too high may lead to excessive hydraulic pressure, potentially causing damage such as cracks, tears, or blockages in the membrane or filtration media. This, in turn, diminishes the efficacy and longevity of the filtration equipment. Kwon et al. (2022) explained that a higher flow rate can decrease the efficiency of removing MPs because the MPs, which are larger than the pores of the fibers, are extracted. In addition, higher flow rates can increase drag forces on the MPs, leading to improved transport of MPs from agglomerations formed in the MP mixing zone (Rullander et al. 2023). Meanwhile, Ahfir et al. (2017) investigated the retention and transport of suspended particles in coarse sand columns with a diameter-to-particle ratio of approximately 36 at low flow rates. The study revealed that particles larger than 20 μm were entirely retained by the porous media. Insufficient filtration rates may diminish MP removal efficiency by limiting the contact duration between MP particles and the membrane or filtration media. Consequently, this may lead to prolonged retention times and necessitate treating larger volumes of water to achieve the desired reduction rate. The MP reduction efficiency is 85%–97% with flow rates ranging from 4 to 10 m/h (Fajar, Sembiring, and Handajani 2022). Previous research indicated a 96% reduction efficiency in MPs sized at 200 μm when the flow rate reached 4 m^3/m^2-h (Sembiring, Fajar, and Handajani 2021a). An excessively high filtration rate may demand more energy to uphold a steady hydraulic pressure, whereas an overly low rate could lead to reduced energy consumption but necessitate longer operation durations. Additionally, the flow rate level influences the increment in head loss, an aspect that lacks thorough study. Optimal filtration rate selection can enhance efficiency, prolong filtration equipment lifespan, and diminish overall energy usage, thereby promoting the successful and sustainable removal of MPs from water.

5 | Limitations and Future Outlook

This study provides a bibliometric overview of the worldwide research emphasis and advancement of MP filtration in wastewater treatment. Nonetheless, the search terms "Microplastic AND removal AND Filtration OR Filtering OR Filter OR Separate" employed in the title and abstract may restrict the acquired data. Articles lacking specific keywords in their titles or abstracts were omitted, indicating a need for more inclusive methodologies. Overcoming these limitations may be possible with the integration of advanced technologies such as artificial intelligence and big data into bibliometric analysis. Despite the promising advancements in filtration technology for MP reduction in water, a notable research gap persists. Country co-authorship analysis indicates insufficient research on MP filtration in water within African nations and Southeast Asian countries such as Malaysia and Indonesia. Moreover, by conducting bibliometric mapping of author keywords, it becomes apparent that the prevailing direction in MP filtration research within wastewater treatment centers around utilizing coagulation technology to adsorb MPs, advancing ultrafiltration to capture nanoparticle-sized MPs, integrating multiple filtration media, and discerning key factors affecting filtration efficacy. Consequently, there is a call for researchers to broaden their investigations in the future by exploring appropriate technologies and optimal operational parameters for various underrepresented wastewater types, including agricultural, pig farm, aquaculture, and reservoir wastewater. Furthermore, a comprehensive and adaptable filtration strategy tailored to the unique traits of MPs found in aquatic environments is required. Hence, a thorough comprehension of these MPs is crucial for devising efficient filtration systems aimed at safeguarding aquatic ecosystems and human well-being.

> *"This study provides a bibliometric overview of the worldwide research emphasis and advancement of MP filtration in wastewater treatment."*

6 | Conclusion

Filtration technology presents an effective method for treating MP contaminants in wastewater. This review emphasizes the current research focus and prospects concerning MP filtration in wastewater treatment, utilizing bibliometric approaches and examining factors influencing filtration performance. Keyword analysis reveals frequent occurrences of terms such as coagulation, removal efficiency, wastewater, and associated factors such as MP type and size, concentration, filtration media, and water flow rate. This underscores the current global study's emphasis on reducing MPs in water treatment through filtration methods.

The filtration method can only capture plastic particles sized between 10 and 20 μm, making the coagulation method a potentially more efficient option for MP removal. Additionally, employing multiple filter media with smaller pore sizes can enhance filtration effectiveness, albeit requiring consideration of water flow rates during the filtration process. Addressing the existing gaps in this field warrants comprehensive future studies to explore advancements in filter media aimed at reducing MPs of smaller sizes at different water flow rates.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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