Fate of Microplastics in Wastewater Treatment Plants

Occurrence, Identification, Potential Factors, and Future Perspectives

EDITED BY

Nitin Kumar Singh, Komal Jayaswal, Manish Yadav, and Namita Maharjan

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Fate of Microplastics in Wastewater Treatment Plants

This book covers the various sources, the role of treatment technologies, system-associated factors, and future challenges with reference to microplastics in wastewater treatment plants. It also introduces microplastics, their sources, governing factors, microbial diversity effects, and possible control approaches to minimize the exposure of microplastics to human beings. Modelling and distribution of microplastics, environmental sinks, bioindicators, and microplastics as vector in wastewater treatment units are also discussed.

- Focuses on microplastic pollution, mechanism of removal, treatment technologies, pathways, and fate in wastewater treatment system
- Discusses the factors linked to dispersion, survival, and removal efficiency of microplastics in wastewater treatment systems
- Helps understand 'microplastics removal'-centric sustainability aspects of wastewater treatment systems
- Explores the fate of microplastics in sludge-handling systems
- Incorporates comparative case studies from developed and developing nations

This book is aimed at graduate students and researchers in environmental science and engineering, water resources management, wastewater, and chemical engineering.

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Preface

The ubiquitous presence of microplastics, tiny plastic fragments, has become a pressing environmental concern in recent years. These persistent pollutants contaminate our water resources, raising significant questions about their impact on human health and ecological systems. Wastewater treatment plants are identified as a major pathway for microplastics to enter the environment, acting as both sources and sinks for these microscopic contaminants. With these concerns, this book delves deep into this complex and multifaceted issue. It offers a comprehensive exploration of the presence, behaviour, and removal of microplastics within the wastewater treatment context. This book is designed to serve as a valuable resource for a wide audience, including researchers and academics in environmental science, wastewater treatment, and microplastics research, engineers and practitioners working on wastewater treatment technologies, policymakers, students, and individuals interested in understanding the fate of microplastics in wastewater treatment. This book particularly focuses on key areas such as the presence and characterization of microplastics, health and environmental impacts, bioindicators, removal approaches for microplastics, environmental sinks, and the applications of artificial intelligence and machine learning tools for microplastics detection and/or characterization.

The issue of microplastics in wastewater presents a significant challenge, but also an opportunity for innovation and collaboration. This book aims to contribute to ongoing efforts by providing a comprehensive overview of the current state of knowledge and highlighting promising avenues for future research and action. By working together, we can develop effective solutions to address this challenge and ensure a cleaner and healthier environment for all. The team of editors invites all interested readers to embark on this journey with us, exploring the complex world of microplastics in wastewater and seeking new pathways towards a sustainable future.

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Introduction

Microplastics, which are tiny fragments and fibres measuring less than 5 mm in size, have infiltrated our wastewater treatment systems, posing a silent yet significant threat to human health and ecological well-being. This book delves into the heart of this complex issue and helps readers understand the processes by which these small invaders navigate wastewater treatment plants, as well as the various factors that influence their fate and behaviour. This book is not just a scientific exploration; it is also a call to action for the management of microplastics in wastewater treatment systems. The editors have summarized information covering a wide range of topics, including the characteristics, quantification, and distribution of microplastics, environmental sinks, bioindicators, and microplastics as vectors in wastewater treatment units. By understanding the presence, threats, detection approaches, and potential solutions for removing microplastics within wastewater treatment systems, we aim to collectively work towards a cleaner, healthier future for both ourselves and the environment. The journey of this book begins with the establishment of a scientific foundation and an understanding of the research trends in the context of wastewater treatment, followed by the characterization and quantification aspects of microplastics. Subsequent chapters focus on solutions, case studies, and advancements in the characterization, detection, and monitoring of microplastics using artificial intelligence and machine learning.

The first chapter focuses on the analysis of the microplastics problem through bibliometric analysis, uncovering the extensive research landscape surrounding microplastics in wastewater. Chapters 2–4 highlight the characterization techniques for microplastics and their threats to human health and the environment. Additionally, bioindicators, nature's silent sentinels, are introduced as tools for monitoring microplastic contamination, demonstrating the universality of this issue. In Chapters 5–7, the roles of various microbes and their enzymatic mechanisms, impacts on aquaculture, and investigation approaches in wastewater treatment systems are critically reviewed and presented. Chapter 8 explores the characterization and removal of microplastics at different stages of the treatment process, identifying potential hotspots and inefficiencies. Meanwhile, Chapter 9 highlights the concept of the environmental sink associated with wastewater treatment, emphasizing the need for holistic solutions. In Chapter 10, mass balance and life cycle aspects are also critically discussed for microplastics. Chapters 10 and 12 emphasize the importance of local action by showcasing the unique challenges and potential solutions specific to different contexts. The last two chapters of this book explore the cutting-edge field of machine learning and artificial intelligence in microplastic detection.

Overall, this book highlights that through collaborative efforts and innovative solutions, we can strive towards a cleaner future where our wastewater systems are not conduits for microplastic pollution, but rather effective barriers that protect our environment and our health.

1 Examining the Presence of Microplastics in Wastewater

A Bibliometric Analysis and Overview

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M. Yadav, K. Murugesan, and S.K. Sahu

1.1 INTRODUCTION

Plastics are widely used for various applications in various sectors including personal care, apparel, medical and industrial sectors. This is attributed to their lightweight, stable chemical properties, corrosion resistance, and affordability (Hernandez et al., 2017). According to a forecast, global plastics production was expected to reach 390.7 million tons in 2021, representing an annual growth rate of 4% (GPP, 2023). The escalation of manufacturing and use has led to an unprecedented proliferation of plastic waste and widespread contamination. Most plastics used by consumers are single-use and have limited recycling. Globally, only 9% of plastic waste has been recycled, 12% has been incinerated, and the remaining 79% remains in various ecosystems (Geyer et al., 2017). According to a study (Borrelle et al., 2020), it is expected that around 53 million tons of plastic waste will end up in water bodies by 2030.

Microplastics (MPs) are defined as plastic polymer particles that measure less than 5 mm. The European Commission has recognized MPs as a significant parameter for monitoring and evaluating seawater pollution that arises from plastic debris. The microplastics (MPs) can be classified into two distinct categories, namely primary and secondary microplastics (Auta et al., 2017). Primary microplastics are generated through manufacturing and packaging procedures, and may also be obtained from cosmetic products that serve as exfoliants or pharmaceutical drugs (Mintenig et al., 2017). Over a period of time, plastic waste of larger dimensions found in various environments such as terrestrial, freshwater, and marine undergo a process of degradation, leading to their fragmentation into smaller particles that are less than 5 mm in size (Horton et al., 2017). The microplastics that are most frequently encountered are sourced from diverse plastic materials, such as polyethylene (PE), polypropylene (PP), polyamide (PA), polyvinyl chloride (PVC), polystyrene (PS), and polyethylene

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terephthalate (PET) (Alimi et al., 2018). The emergence of MPs as a significant contaminant has garnered considerable public concern due to its ecological and health impacts, making plastic pollution one of the most critical environmental health issues worldwide (Chae & An, 2017). The extensive use of plastic products globally contributes to the continuous increase in their production each year (Sher et al., 2021).

During the peak period of the COVID-19 pandemic in 2020–2021, the World Health Organization (WHO) recommended the use of face masks to the public and later made it mandatory to minimize the risk of virus transmission (Bhangare et al., 2023). These masks, which are often composed of polymers such as polyethylene (PE), polypropylene (PP), polystyrene (PS), polyurethane (PU), or polycarbonate (PC), have the potential to release microplastic fibers into the environment (Oginni, 2022). Notably, polypropylene, the predominant material used in mask production, degrades rapidly, resulting in the formation of microscopic plastics. However, improper disposal of these masks has become a significant environmental concern, particularly in marine ecosystems, where large quantities of masks have been released from various sources. Ocean Asia reported in 2020 that an estimated one billion masks were discarded into the oceans, basing on an annual production of 52 billion disposable masks. (Xu & Ren, 2021).

Most of these polymers are resistant to degradation by living organisms, necessitating the development of biodegradable substitutes. Existing biodegradable plastics consist of cellulose, polybutylene adipate-co-terephthalate, polybutylene sucrose-co-adipate, po-hydroxyalkanoates, polybutylene succinate, and polylactic acid. However, these plastics often show insufficient decomposition and require a longer decomposition time, only achieving about 90% decomposition under soil conditions (Renzi et al., 2019).

Numerous research investigations worldwide have been dedicated to the study of micro- and nanoplastics. Previous studies have primarily focused on examining various environmental matrices and exploring the fate of microplastics in the environment (Akinpelu & Nchu, 2022). For instance, Papadimitriu and Allinson conducted a study in 2022 to assess the presence of microplastics in marine ecosystems of the Mediterranean Sea. Similarly, Zhou et al. (2022) conducted a comprehensive investigation to evaluate the occurrence of microplastics and nanoplastics in diverse marine environments, encompassing seas, oceans, beaches, bays, gulfs, estuaries, coastlines, and shorelines (Zhou et al., 2022).

The prevalence of microplastics, particularly in the form of primary microplastics, in wastewater is of significant concern. Notably, common food items such as salt, sugar, honey, beer, bottled water, tap water, and fish have been identified as potential sources of plastic contamination, thereby establishing a pathway for microplastic ingestion by individuals (Chang et al., 2020; Zhang et al., 2019). It has been established in previous research that the consumption of contaminated water is a significant route through which microplastics are transmitted from environmental sources to humans (Walker & Fequet, 2023). In a study (Cox et al., 2019), it was revealed that the consumption of food and beverages by an individual could lead to the intake of an estimated 39,000–52,000 numbers of microplastics per year, with variations based on gender and age. Additionally, if bottled water is consumed, this estimate could increase by approximately 90,000 microplastics annually and an additional 4,000 microplastics if tap water is ingested. Owing to their minuscule size, microplastics have the propensity to readily infiltrate hydrological systems and subsequently become integrated into the food chain. However, our current understanding of microplastics remains limited, necessitating urgent research endeavors in this field.

At present, bibliometric analysis is widely acknowledged as an alternative approach for assessing scholarly subjects within the domain of library and information science. It has emerged as one of the most popular methodologies for evaluating and predicting research trends in specific areas, as well as for mapping published records that have been identified (Liu et al., 2021). In addition to providing researchers with enhanced access to a broader range of literature, bibliometric analysis fosters collaboration among researchers by bringing them together on a unified platform (Wagner et al., 2015). These inherent advantages underscore the crucial role of bibliometric analysis as a preliminary step in conducting research on topics of regional, national, or international significance. Several researchers have already conducted bibliometric analyses on various subjects, yielding valuable insights. In the present study, we employ a combined approach of bibliometrics and altmetrics to comprehensively analyze microplastics, offering references and recommendations to future researchers and enabling a deeper understanding of the global trends related to microplastics in wastewater. By employing keyword clusters and the altmetric attention score, we identify the research focal points and potential future directions pertaining to microplastics. Additionally, we conduct a systematic review and summary of the contamination status and challenges associated with microplastics, while also providing suggestions for the future focus and perspectives of microplastics research.

1.2 MATERIALS AND METHODS

1.2.1 Data Collection

A systematic and comprehensive literature search was performed to identify pertinent studies focusing on the presence of microplastics in wastewater. Diverse academic databases, including Scopus, Web of Science, PubMed, Lens, and Dimensions, were meticulously queried using appropriate keywords such as "microplastics," "wastewater," "human health," "food chain," "sewage," "effluent," and related terms. Twelve thousand seven hundred and sixty-two articles were retrieved, out of which 6,359 research articles and reviews of various journals of environmental science were evaluated. The time frame for this investigation was from the earliest accessible date i.e., from 1st January 2000, to 15th June 2023, for a period of 23.5 years.

1.2.2 Inclusion and Exclusion Criteria

Studies meeting specific criteria were included in this analysis. Inclusion criteria encompassed investigations that specifically examined the presence of microplastics in wastewater samples and provided comprehensive information regarding its sampling methods, analytical techniques, and reported results. Conversely, studies focusing on other environmental matrices or lacking specific investigations of microplastics in wastewater were excluded from this analysis. Relevant data were meticulously extracted from the selected studies. All the data were downloaded in EndNote, CSV, RefWorks, and RIS format.

1.2.3 Data Analysis Method

To assess the characteristics and trends of the selected documents, a comprehensive bibliometric analysis was conducted, and when feasible, a statistical test (exponential regression) was employed to evaluate significant differences between groups or variables. The data accumulation and analysis were directed in Microsoft Excel 2021, and related graphs were drawn. Bibliometric indicators, including publication output, author, or organizational or country collaborations, citation analysis, and journal distribution, were meticulously examined using appropriate bibliometric software or programming languages VOSviewer (Version 1.6.13). These analyses provided valuable insights into research productivity, collaboration patterns, and the impact of studies within the field of microplastics in wastewater. The cluster analysis by VOSviewer software generates various social network maps, indicating the importance of the size of a node and the thickness of lines (Padilla et al., 2018). Here, the nodes represent the frequency and the lines connecting the nodes symbolize connotations. Different nodes represent various clustering groups (Chang et al., 2022). If the line is thicker, the relationship between nodes will be greater (Gao et al., 2019). Three different types of visualization maps (network, overlay, and density) were derived from VOSviewer and interpreted. The "co-occurrence keywords" is a prominent way to get an idea about the main content of the research field. The extracted data were thoughtfully synthesized to provide a comprehensive overview of the presence of microplastics in wastewater. The synthesized findings were systematically categorized based on geographical locations, sampling methods, analytical techniques employed, and the reported concentrations of microplastics in the environment, food chain, and its impacts on humans. This systematic approach enabled the identification of research gaps, emerging trends, and areas requiring further investigation within the field. The limitations associated with the bibliometric analysis were duly recognized and acknowledged. These limitations included potential biases related to the selection of databases, potential language restrictions, and the exclusion of unpublished or non-peer-reviewed sources. The scope of this analysis was strictly limited to the selected studies, and any inherent limitations or biases within the individual studies were thoughtfully considered during the interpretation of the results.

1.3 RESULTS AND DISCUSSIONS

The present investigation entails a thorough bibliometric analysis aimed at scrutinizing the prevalence of microplastics in wastewater and presenting a synopsis of the existing research in this domain. The objective of the study was to ascertain the primary research patterns, notable authors, impact journals, and noteworthy research clusters linked to microplastics in wastewater. The findings of our analysis indicate a consistent rise in the quantity of literature pertaining to microplastics in wastewater during the last 10 years. The increasing trend indicates that scholars are gaining greater cognizance of the prospective hazards and ecological consequences linked with microplastics present in wastewater.

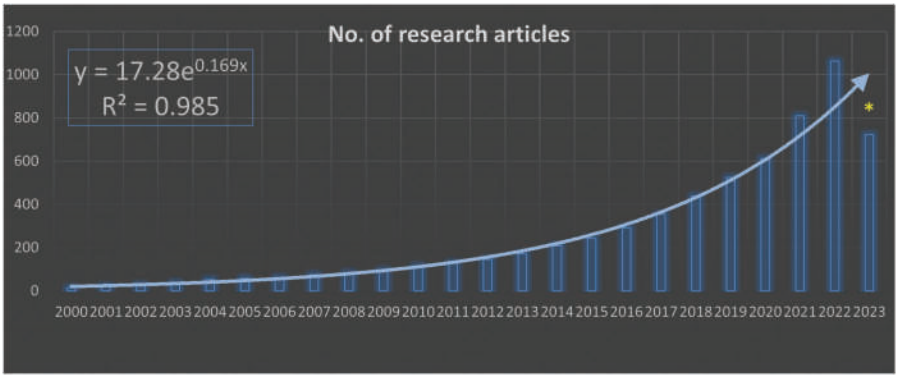

FIGURE 1.1 Literature growth-trend of "microplastic"- and "wastewater"-related research from 2000 to 2023. *Data are for 6 months (from 1st January to 15th June 2023).

1.3.1 PUBLICATION TRENDS AND GROWTH

The findings of our analysis indicate a consistent rise in the quantity of literature pertaining to microplastics in wastewater during the last ten years. The observed expansion (Figure 1.1) denotes an increasing curiosity and acknowledgment of the significance of investigating microplastic pollution in wastewater within academic circles. The increasing trend of published articles from January 1, 2000, to June 15, 2023 ($R^2 = 0.985$) indicates that scholars are gaining greater cognizance of the prospective hazards and ecological consequences linked with microplastics present in wastewater. However, the number of articles published from 2000 to 2010 is almost 642, but will reach 3,121 in the next decade, that is, from 2011 to 2020. The total number of articles published in 2022 on the topic of microplastics and wastewater was 1,062, while in the year 2023, it was 723 within 6 months.

1.3.2 KEY RESEARCH TOPICS AND CLUSTERS

Utilizing the method of keyword co-occurrence analysis, the present research article aims to shed light on the significant research themes and groupings that emerge within the domain of microplastics in wastewater. By examining the patterns of keyword co-occurrence, a comprehensive understanding of the interrelationships between various research topics can be achieved. In this study, a set of predetermined criteria was employed to select the keywords for analysis. Specifically, keywords with a co-occurrence frequency equal to or greater than 150 were considered, resulting in a pool of 23,046 keywords for evaluation. Notably, only 145 keywords met this threshold, reflecting the selectivity of the analysis and ensuring the inclusion of meaningful and relevant terms. The results of the analysis revealed the presence of distinct research clusters that encapsulate several prominent research themes. These clusters encompass a range of topics, including "wastewater treatment," "microplastic characterization," "microplastic fate and transport," "impact on aquatic ecosystems," and "health implications." The identification of these clusters emphasizes the interdisciplinary nature of microplastic research, highlighting the necessity of fostering collaboration among scholars from diverse fields.

TABLE 1.1
Summary and Analysis of Top Co-occurrence Keywords Based on "Microplastic" and "Wastewater"

Co-occurrence Keywords	Occurrences	Total Link Strength
Microplastic	3,003	55,806
Plastic	2,637	55,627
Water pollutant	2,020	46,217
Plastic waste	2,127	45,073
Environmental monitoring	2,025	40,668
Chemical water pollutants	1,989	45,442
Marine environments	1,762	38,849
Polyethylene	1,328	35,691
Controlled study	1,266	28,487
Sediment	1,021	25,676

To further examine the strength and significance of the identified clusters, a cluster density analysis was conducted based on the acquired data. The density of keyword co-occurrence within the clusters, the term "microplastic," notably, exhibited the highest link strength, occurring 3,003 times and demonstrating a link strength of 55,806. This observation underscores the central role of microplastic-related research within the broader context of the investigated domain. Additionally, Table 1.1 presents the top ten keywords with their corresponding occurrence frequencies and link strengths. These keywords provide insights into the most prominent and influential terms within the analyzed dataset, further contributing to our understanding of the research landscape surrounding microplastics in wastewater. By employing rigorous criteria and analyzing a substantial number of keywords, the study provides a comprehensive overview of the research landscape and offers valuable insights for future investigations in this domain. However, the number of co-occurrences of "treatment method" and "human physiology" is less than 40.

Previous studies on the treatment of "microplastics" and its effects on human physiology have primarily concentrated on the current processes utilized in sewage treatment plants and drinking water treatment facilities (Ma et al., 2019; Liu et al., 2021). Additionally, investigations have been conducted on the potential presence and impact of microplastics within the human body (Schwabl et al., 2019; Vianello et al., 2019). In subsequent times, this approach may gain widespread acceptance, and the associated focal areas may pertain to conventional ecological remediation methodologies like engineered wetlands, biodegradation (involving insects capable of consuming and decomposing plastics), and photocatalytic technology besides plastic human physiology.

1.3.3 INFLUENTIAL COUNTRY, INSTITUTIONS, AND AUTHORS

1.3.3.1 Dominant Countries in Microplastics Research

A comprehensive investigation was conducted to identify the countries and institutions that have significantly contributed to the field of microplastics in wastewater research. The study employed a rigorous criterion that required a minimum number of documents from a country, with at least 120 articles and 2,000 citations, to be included in the analysis. Out of the 149 countries that publish journals on microplastics and wastewater, only 20 countries met these established thresholds. China emerged as the most prominent country in this research domain, securing the top rank and contributing to 30% of the global research output. Following China, the United States, the United Kingdom, Germany, and Australia were among the top-ranking countries, all fulfilling the aforementioned criteria. The findings also revealed strong linkages between these countries (Figure 1.2a), indicating collaborative efforts and information exchange within the global research community. Furthermore, cooperation studies are centered between China and South Korea, Japan, the United States, Australia, India, and Hong Kong. The United Kingdom, Canada, Turkey, Germany, the Netherlands, and Norway have rather tight research ties. France also established more collaboration with Spain, Italy, Portugal, and Brazil than with any other country.

Furthermore, the analysis aimed to identify the most notable authors and institutions in the field of microplastics in wastewater. Once again, China demonstrated its predominance in this regard. The same entities mentioned earlier, namely China, the United States, the United Kingdom, Germany, and Australia, were found to have made significant contributions to this realm of research (Figure 1.2b). These contributions have played a crucial role in advancing our understanding of microplastic

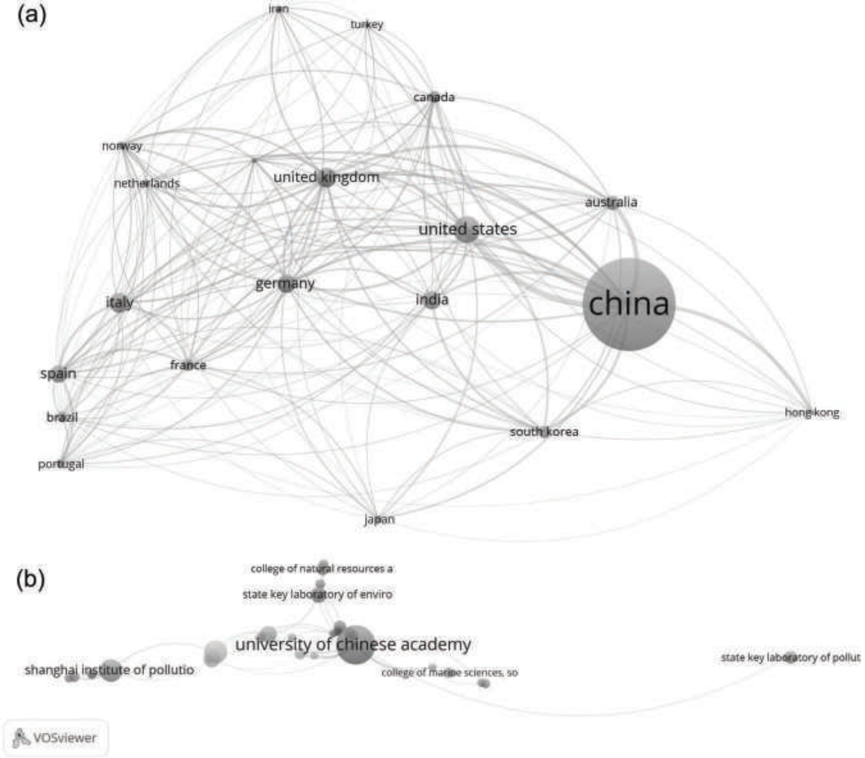

FIGURE 1.2 Network visualization map of top 20 productive countries. (a) Collaboration networks map, (b) cluster analysis map.

pollution in wastewater. The academic achievements of the individuals associated with these entities have had a substantial impact on the trajectory of the field and have influenced subsequent inquiries.

1.3.3.2 Pioneering Institutions in Microplastics Study

In addition to assessing countries and authors, the study also focused on identifying institutions that have actively contributed to the research on microplastics in wastewater (Table 1.2). Using a criterion of a minimum of 20 documents and 100 citations, out of the 12,690 organizations publishing journals on this topic, only 29 institutes met the established thresholds. These institutions represent a select group that has consistently produced substantial research output and garnered significant recognition within the scientific community. The findings of this research article highlight the global landscape of microplastics in wastewater research, emphasizing the prominent role of China, along with other influential countries such as the United States, the United Kingdom, Germany, and Australia. The study also acknowledges the significant contributions made by specific authors and institutions in advancing the knowledge in this critical area of study.

Overlay cooperation networks between nations reveal scientific production and collaboration tendencies. This study examined the average number of publications each year from January 1, 2019, through June 15, 2023, the most active period. The cooperation networks of 33 of the 149 nations with at least 50 papers were examined. Each nation is a node in the overlay collaboration networks, and node connections reflect country partnerships. Countries with more annual publications tend to collaborate more. The size of each node is proportional to the total number of publications during the most prolific era to find nations with at least 50 papers. It identifies the

TABLE 1.2
Top Five Institutes Conducting Research on "Microplastic" and "Wastewater"

Rank	Organization	Number (% Global Contribution)
1	University of Chinese Academy of Sciences, Beijing, China	106 (1.67)
2	State Key Laboratory of Estuarine and Coastal Research, East China Normal University, Shanghai, China	48 (0.75)
3	Shanghai Institute of Pollution Control and Ecological Security, Shanghai, China	46 (0.72)
4	State Key Laboratory of Freshwater Ecology and Biotechnology, Chinese Academy of Sciences, Wuhan, China	30 (0.47)
5	State Key Laboratory of Environmental Criteria and Risk Assessment, Chinese Research Academy of Environmental Sciences, Beijing, China	27 (0.42)

United States, China, the United Kingdom, the Netherlands, South Korea, Australia, and India as important stakeholders with strong collaborative strengths.

1.3.3.3 Cited Research Works and Their Impact

Investigating the global scientific contribution, it is revealed that only 67 out of 149 countries fulfilled the criteria of a minimum of 30 papers and 500 citations per nation (Table 1.4). This indicates that a considerable number of countries have yet to achieve substantial scientific output in terms of paper publication and citations. Interestingly, China, which is the major research contributor, did not surpass the average number of papers per nation. This suggests that China's research output is not significantly higher than that of other countries on average. However, it is worth noting that the University of Chinese Academy of Sciences in Beijing, China, ranked first in publishing research articles, with a total of 106 papers contributing to 1.67% of global research output. In contrast, among the top 15 countries, the Netherlands exhibited the highest citation rate per article, with an impressive average of 114.34 citations per paper, as shown in Table 1.3. This underscores the influential and esteemed nature of the scientific work conducted in the Netherlands. The United Kingdom closely followed with an average citation rate of 98.66, further emphasizing the quality and impact of their research output. These findings highlight the varying levels of scientific productivity and impact across nations, with some countries meeting the minimum thresholds, while others have room for improvement. Citation rates of the Netherlands and the UK demonstrate their scientific achievements. These nations have produced scientifically significant research. However, the study provides useful insights into global scientific contribution and emphasizes the necessity of research and innovation for global scientific understanding.

TABLE 1.3
Summary of Top 15 Country Distribution with Citation Time

Country	No. of Articles	Citations	Average Nos. of Citations per Article	Total Linkage Strength
China	1,915	72,162	37.68	773
United States	483	25,317	52.42	574
United Kingdom	350	34,531	98.66	441
Germany	316	18,928	59.90	365
Australia	247	13,664	55.32	350
India	319	11,296	35.41	335
Spain	314	10,754	34.25	282
Italy	353	13,350	37.82	275
France	196	12,570	64.13	258
Canada	191	11,293	59.13	223
Norway	127	8,940	70.39	218
South Korea	203	8,487	41.81	207
Netherlands	118	13,492	114.34	183
Portugal	147	5,533	37.64	159
Brazil	172	6,023	35.02	156

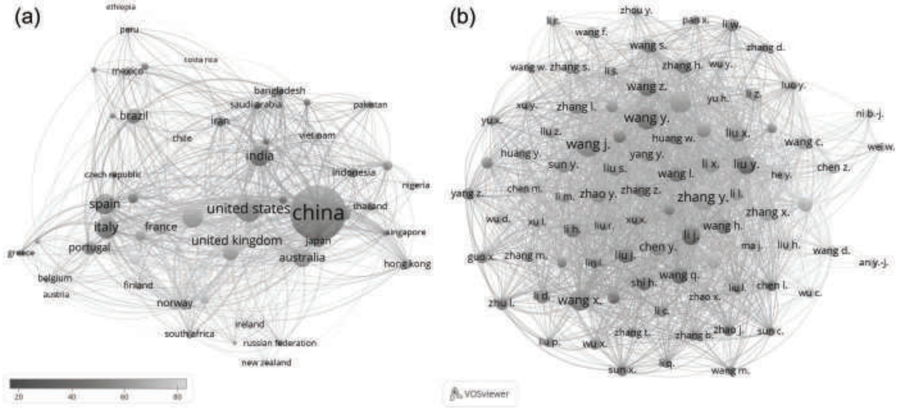

FIGURE 1.3 (a) Overlay collaboration networks among the most productive countries with average citations per year of published articles. (b) Cluster analysis of authors highly cited in the field of microplastic in wastewater during the period of 2000–2023 (till June 15, 2023).

1.3.3.4 Leading Authors and Their Contributions

When assessing authors who have actively contributed to the research on microplastics in wastewater, using a criterion of a minimum of 30 documents and 80 citations, out of the 14,480 authors, only 93 met the established thresholds (Table 1.4 and Figure 1.3). The findings reveal that J. Wang, affiliated with an institution in China, has emerged as the predominant author in terms of the number of publications on the topic under investigation. Table 1.4, a crucial component of this research, displays the distribution of publications among different authors and their corresponding link strengths. Link strength is a measure that indicates the impact and influence of an author's work within the scientific community. Higher link strength signifies a greater citation rate, recognition within the field, and potential to shape future research directions in the field. The dominance of J. Wang, in terms of publications and link strength, underscores their expertise, productivity, and influence in the research area. It also suggests that their work has gathered substantial attention and recognition from peers and scholars worldwide. However, the article entitled published by Hidalgo-Ruz and his research group is the most cited article in the journal *Environmental Science and Technology,* focusing on "microplastics in the marine environment" with citation of 2,734 times (Table 1.5), based on sampling and analysis method (Hidalgo-Ruz et al., 2012). The foremost areas of research which are cited more includes, the examination of microplastics for human consumption (Van Cauwenberghe & Janssen, 2014), the evaluation of the impact of debris on marine life (Gall & Thompson, 2015), the analysis of microplastics in the aquatic environment (Murphy et al., 2016), the identification of the source of microplastics in the environment (Dris et al., 2016), and transportation and ultimate destiny of microplastic in wastewater treatment plants (Liu et al., 2021). The topics also covered the global inventory of small floating plastic debris (Van Sebille et al., 2015), recommendations and categorization framework for plastic debris (Hartmann et al., 2019), microplastics in marine pollution caused by facial cleansers (Fendall & Sewell et al., 2009), and microplastic pollution in lakes (Free et al., 2014).

TABLE 1.4
Top 10 Authors of Various Countries with Their Publications and Citations

Rank	Author	Country	No. of doc.	Total doc of Country	% Country Wise	Total Doc.	% Globally	Total Citations	Total Link Strength
1	Wang, J.	China	148	1,915	7.73	6,359	2.33	8,080	752
2	Carr, S.A.	United States	102	483	21.12	6,359	1.60	6,917	537
3	Van Sebille, E.	United Kingdom	90	350	25.71	6,359	1.42	6,132	413
4	Funck, M.	Germany	86	316	27.22	6,359	1.35	4,630	345
5	Galafassi, S.	Australia	99	247	40.08	6,359	1.56	4,084	330
6	Sharma, S.	India	71	319	22.26	6,359	1.12	2,703	328
7	Paul-Pont, I.	Spain	101	314	32.17	6,359	1.59	3,003	272
8	Avio, C.G.	Italy	82	353	23.23	6,359	1.29	2,529	256
9	Dris, R.	France	73	196	37.24	6,359	1.15	2,898	238
10	Alimi, O.S.	Canada	79	191	41.36	6,359	1.24	3,122	226

TABLE 1.5
Most Cited Articles Published during the Period of 2000–2023 (till June 15, 2023) on "Microplastic" and "Wastewater"

Rank	Article	Journal	Main Research Interest	Citations
1	Hidalgo-Ruz et al. (2012)	*Environmental Science and Technology*	Microplastics in the marine environment	2,734
2	Van Cauwenberghe and Janssen (2014)	*Environmental Pollution*	Microplastics for human consumption	1,185
3	Gall and Thompson (2015)	*Marine Pollution Bulletin*	Impact of debris on marine life	1,170
4	Murphy et al. (2016)	*Environmental Science and Technology*	Microplastics in the aquatic environment	1,066
5	Dris et al. (2016)	*Marine Pollution Bulletin*	A source of microplastics in the environment	1,024
6	Carr et al. (2016)	*Water Research*	Transport and fate of microplastic particles in wastewater treatment plants	988
7	Van Sebille et al. (2015)	*Environmental Research Letters*	Global inventory of small floating plastic debris	951
8	Hartmann et al. (2019)	*Environmental Science and Technology*	Recommendations for and categorization framework for plastic debris	918
9	Fendall and Sewell (2009)	*Marine Pollution Bulletin*	Microplastics in marine pollution by facial cleansers	904
10	Free et al. (2014)	*Marine Pollution Bulletin*	Microplastic pollution in lakes	863

1.3.4 JOURNALS AND PUBLICATION OUTLETS

The present study aimed to identify the key journals that have made significant contributions to the field of microplastics in wastewater research. These journals play a pivotal role in disseminating research findings and fostering scientific discourse within this particular domain. Analyzing the publication channels enables scholars to determine the most relevant periodicals for sharing their research while also empowering decision-makers and interested parties to access the most up-to-date information on microplastics in wastewater. Through a comprehensive analysis, it was found that the journal *Marine Pollution Bulletin* emerged as the primary publication outlet for research on microplastics in wastewater, with a notable number of articles published (376). This journal holds an h-index value of 193, indicating a significant impact and influence within the scientific community. The findings suggest that researchers in this field have recognized *Marine Pollution Bulletin* as a reputable platform for disseminating their work and engaging in scientific discussions.

Following the journal *Marine Pollution Bulletin*, two other journals such as *Environmental Pollution* and *Science of the Total Environment* were identified as influential publication venues for research on "microplastics in wastewater." While the number of articles published in these journals was slightly lower than *Marine*

Pollution Bulletin, their significance in advancing knowledge in this area should not be overlooked. Moreover, it is worth noting that *Environmental Science and Technology*, despite publishing a comparatively smaller number of articles (239), demonstrated the highest h-index among the identified journals. This indicates that the research published in this journal has had a substantial impact and has been widely cited within the scientific community. *Environmental Science and Technology* continues to serve as an important resource for researchers and interested stakeholders seeking the latest advancements and insights on "microplastics in wastewater."

This detailed study underscores global concerns about the impact of microplastic contamination on human health through the food chain. The prevalence of microplastics in various food sources and their potential health impacts highlight the urgent need for further studies, risk assessments, and containment techniques. International collaboration and standardized approaches are needed to create effective solutions to reduce microplastic pollution and protect human health. Further research on the toxicity, fate, and transport of microplastics is needed to develop evidence-based laws and policies to address this growing environmental and health concern. To date, very little research has been conducted worldwide on the impact of microplastics on human health in the food chain. Initially, researchers from 53 countries started working in this research area, of which only 13 countries are actively doing research in this area and are now publishing at least five articles per year. China and India are two prolific countries in this research area. M. Wu and W. Huang from Hunan University, China, J.-J. Guo from Jinan University, China, R. Qi, X. Chang, and L. Yang from the University of Chinese Academy of Sciences, China, M. Kumar from CSIR-Indian Institute of Toxicology Research, Lucknow, India (Kumar et al., 2021), A.C. Vivekanand from KTH Royal Institute of Technology, Sweden, in collaboration with M.J. Taherzadeh from the Indian Institute of Technology Roorkee, India are some of the top researchers in this field. There is still a lot of work to be done in this area in the future as it is an emerging field of research.

1.4 CONCLUSION

This bibliometric study shows that microplastics have increased significantly in wastewater studies. The amount of literature on this topic has steadily increased over the period of 2000–2023 ($R^2 = 0.985$), indicating a growing interest for microplastic pollution studies in wastewater. The study also highlights the leading countries and institutions in this research area, as well as the geographical distribution of scientific production. Keywords and concurrent clusters showed the importance of microplastics in the research areas of wastewater. The most frequently studied topics were the characterization of microplastics, origin and routes of contamination, treatment and removal, and their environmental impact. The result shows the complexity of microplastic pollution in wastewater and underlines the need for a comprehensive investigation. The present analysis revealed research gaps that require further investigation. Since the methods for collecting, separating, and assessing microplastics differ, uniform standards could increase comparability and ensure research coherence, consistency, and reliability of the data. Although wastewater research focuses on primary microplastics, secondary microplastics are rarely studied. Microplastics have been found in many foods, but little is known about their bioaccumulation and health risks. Future studies should focus on the health risks of microplastics in wastewater, assessing their hazards and exploring ways to reduce them. Long-term studies are needed to determine the impact of microplastics in wastewater on aquatic ecosystems and the environment, which will help to develop effective management and mitigation methods. There are few comprehensive studies on the management and elimination of microplastics in wastewater. Effective remediation requires further research.

Global collaboration in research is possible, especially among leading research nations like China, the United States, and the United Kingdom, as well as emerging academic regions. A significant number of countries (129 out of 149) have limited studies on microplastics, pointing out the global disparity in research and its untapped potential. It is crucial to bolster research capabilities in these overlooked nations. Top institutions from these regions can play a role in establishing new research centers. Expert researchers like J. Wang offer valuable guidance in the field. Their methods could benefit newcomers. Frequently cited studies shed light on research priorities and areas of interest. There's an urgent need to delve into the origins of microplastics, their effects in unexplored regions, and ways to counteract them. For better precision in results, future studies should refine the methodologies proposed by Hidalgo-Ruz et al. (2012). Even though countries like the Netherlands and the United Kingdom aren't major contributors in terms of volume, their high citation indices underline the significance of research quality. Comprehensive studies on microplastics, spanning environmental, health, and engineering domains, are essential. Publishing this research in esteemed journals can help shape policies and best practices.

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AUTHORS' CONTRIBUTIONS

S.K. Sahu and K. Murugesan came up with the idea for the article; B.S. Panda, R.K. Sethi, and M. Yadav conducted the literature survey; S.S. Pati, B.S. Panda, and A. Sahu conducted the data collection and analysis; and K. Murugesan and S.K. Sahu have critically revised the work. All authors read and approved the final manuscript.

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