Chapter 23
Bibliometric Analysis of Emerging Trends in Research on Microplastic Pollution in Post-Paris Agreement and Post-COVID-19 Pandemic World

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Abstract Microplastic pollution has emerged as a severe transboundary threat to natural ecosystems, marine environments, and human and nonhuman health. Microplastic pollution and its consequent impacts on natural ecosystems and habitats have attracted the attention of experts, environmentalists, researchers, academia, decision-makers, and the governments across the globe. It is imperative to examine and analyze the existing trends and themes in microplastic pollution-related research. It is also important to identify the most productive countries, organizations, and journals focusing on microplastic pollution and its impacts. The analysis is also needed to pinpoint the keywords and thematic evolution in research on

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microplastic along with the most influential and effective research in the area. This study serves this purpose. The study uses a systematic bibliometric approach to trace out the most productive countries, organizations, sources, and documents on microplastic related research. The study also provides detailed analyses regarding collaborations among countries and organizations in research on microplastic pollution. It also provides a detailed analysis of keywords and thematic evolution regarding microplastic research. This chapter also finds some emerging trends in research regarding the COVID-19 pandemic and microplastic pollution. This chapter pinpoints prospects of research on microplastic pollution and its implications on natural ecosystems, marine environment, human and nonhuman health, and approaches for the effective control and management of microplastic pollution. The conclusion of this analysis also stresses the need for collective strategies and frameworks to manage the microplastic pollution in the COVID-19 outbreak and post-pandemic world.

Keywords Microplastic pollution · Bibliometric analysis · Marine environment · Wastewater · Fresh water · Health effects · COVID-19 and microplastic pollution · Bibliometric analysis

23.1 Introduction

The research on mitigation and adaptation got unprecedented momentum in the wake of the unveiled synthesis report on climate change (IPCC 2014) and the global Paris agreement (UNFCCC 2015). The efforts and policy interventions to reduce Greenhouse Gas (GHG) emissions were a major focus to achieve the targets set in the climate agreement (Ali et al. 2019) and the sustainable development goals (SDGs) (United Nations 2020). In addition to GHG emission control, plastic(s) and microplastic(s) pollution has been a trending area of research that attracted the attention of researchers, experts, and academia all over the globe. Plastic waste has been burgeoning due to an increase in demand for plastic products with an increase in population and economic growth (Ali et al. 2021). The annual global plastic production is about 150 million tons as of 2020. The plastic waste may possibly reach 12 billion metric ton by 2060 (Cox et al. 2019; Zhang et al. 2020). Due to the increase in consumption of plastics, the quantity of plastic items released in the environment is burgeoning. Microplastics are plastic particles less than 5 mm in size. The concept of microplastic was first presented in Thompson et al. (2004). The publications (articles) on the subject started in 2007 and has got momentum in following years.

The plastic items in the environment break down into millions of microplastics. The fragmentation occurs as a result of many routine activities such as mechanical degradation, the physical withering of large items, washing of synthetic textile, chemical degradation, UV degradation, and biological degradation (Horton and

Dixon 2018). The fraction of microplastics in global plastic accumulation is predicted to be 13.2% by 2060 (Sharma et al. 2021). Microplastics are pervasive and harmful pollutants. Microplastics originate from multiple sources, of which the fragmentation of large plastic materials is the primary source. Microplastics are discharged into the environment due to the mismanagement of commercial and industrial wastes. The mechanical processes and UV radiation also release microplastics. Other sources include air pollution, urbanization, ineffective plastic waste management, consumption, and production activities. Microplastics are ubiquitous and affect all kinds of environments due to chemical additives. The connectivity of environments leads to the movement of microplastics. The terrestrial environment is the dominant source of microplastics and contributes more than 70% to marine microplastic debris (Kumar et al. 2021). Besides, the airborne transportation of microplastics carries the microplastics emitted from vehicles and industrial machinery.

The number of studies on microplastic had grown rapidly due to the growing concerns of potential risks related to microplastic exposure. Such risks include marine microplastics, the presence of microplastics in a freshwater system (Reid et al. 2019; Su et al. 2016), soil pollution (Veerasingam et al. 2020), food contamination (Kedzierski et al. 2020; Toussaint et al. 2019), and biological ingestion (Rotjan et al. 2019; Zhong and Li 2020). Lately, much attention has been given to microplastics in aquatic environments (Murphy et al. 2016). Addressing the issue of microplastic pollution is an urgent need as COVID-19 has exacerbated the situation. The rise in global production and consumption of face masks and other personal protective equipment to prevent the transmission of the global pandemic led to huge plastic waste during COVID-19 (De-la-Torre and Aragaw 2021; Patrício Silva et al. 2021). The surgical face masks are made of polymeric materials which are a significant source of microplastic (Kumar et al. 2021). Such plastic particles waste is released into the environment and ends up in oceans posing a threat to aquatic lives.

The chapter fulfills multiple objectives: The first objective of the study is to identify the most productive countries regarding research on microplastic pollution. It also focuses on the quantity of research published and its impact measured by the citation index. The chapter also aims to explore how countries collaborate in research on microplastic pollution. Second objective is to provide a comprehensive analysis of the most productive organization and how these organizations collaborate with other organizations in the field of research on microplastic pollution. The third objective is to examine the most productive journals publishing research on microplastic pollution and its sources, composition, and impacts on human, nonhuman, environments, ecosystems, marine life, and fresh water. The fourth objective is to provide a comprehensive analysis of the most productive and highly influencing research in terms of their citations. The fifth objective is to provide a bibliometric analysis of the most frequently used keywords, thematic evolution, and factorial analysis of conceptual structure(s) of microplastic pollution-related research. The study also provides a comprehensive discussion on microplastic pollution, evolutional analysis of related research, and recent trends in the field of microplastic pollution.

23.2 Methodology for Bibliometric Analysis

23.2.1 Database Selection

The 1st step of a bibliographic study is to select a suitable database to collect the relevant articles published on a specific area of research. In the present bibliometric study, the Scopus database has been chosen to serve this purpose. Another reason to use the Scopus database is that it is larger than the Web of Science (WOS) and also includes the Medline that makes the Scopus far better than Medline (Sweileh 2020). Moreover, it is one of the largest databases with more than 23 thousand journals in every field (Falagas et al. 2008). It is very much convenient to search and export data from the Scopus database. It is also very easy to import and perform analysis on data exported from Scopus. It provides two techniques of search—a basic and advanced search. Complex and long search queries can be carried out to fulfill the goal with high levels of validity. It is worth noting that the Scopus allows the use of terms in titles or titles and abstracts or journal names or authors' names or affiliations (Sweileh 2020), making the search more detailed and comprehensive.

23.2.2 Search Strategy to Retrieve the Required Data

The second important step in a bibliometric study is to construct a reasonable search query that enables the data retrievers possible to gather as many relevant documents as possible but with minimum false-positive search results (Sweileh 2020). Following Sweileh (2020), several articles published as "bibliographic analyses" or "systematic reviews" or "bibliographic analysis" have been reviewed to develop a search query for microplastic pollution. The keywords used were "microplastic pollution" and "microplastic" or "COVID-19" or "surgical masks" or "environmental occurrence" or "sustainable waste management" or "bioremediation" or "single-use plastic" or "biomedical plastic waste" or "nanomaterials" to reach the relevant publications. The search generated 3188 documents including all types of documents from the year 2007 to 2021. The study was limited to only research articles published on microplastic pollution. There were 2617 research articles. Since the articles from the year 2007–2014 were less than 50 in each year, the articles published in these years were excluded from the bibliometric analysis in this study. The analysis is based on 2549 research articles during 2015–2021 till June 6, 2021. Overall, the trend of research in the field of microplastic is on the rise.

23.2.3 Validation of the Search Queries for Retrieval of Relevant Articles/Documents

Validation of the search queries is indispensable to confirm the relevance of the data retrieved from the database. To serve this purpose, two approaches were used. Firstly, following Sweileh (2020), the top 50 articles published in microplastic pollution were reviewed to ensure whether they fit within the scope of microplastic pollution. Using this approach, the false-positive results were excluded from the data file manually. Secondly, following Sweileh et al. (2018) and Sweileh (2020), the actual number of each authors' research articles is compared, through information obtained from Scopus profiles of the authors, with the number of articles obtained by the search query for active authors researching on microplastic pollution. Pearson Correlation Test was carried for this comparison. A robust and significant correlation is deemed to be the confirmation of search query validity (Sweileh 2020; Sweileh et al. 2018). The data was collected from the Scopus database and exported as CSV file. Microsoft Excel, VOSviewer Software program (van Eck and Waltman 2010), and Bibliometrix R-package software were used for data analyses.

23.3 Results of the Bibliometric Analysis

Bibliometric analysis of the articles published on microplastic pollution during 2015–2021 shows that 2549 research documents are published in 354 journals till June 6, 2021, as classified in the Scopus database. It is evident that the research publications on microplastic pollution have been increasing over the years, and it got momentum after the Paris agreement as to the sources of pollution, and its impacts on human life, natural environments, and ecosystems have attracted the attention of the experts and researchers in succeeding years. The number of research documents on microplastic pollution increased by 82% from 2015 to 2016. This increasing trend also got momentum in subsequent years as it increased to 105.5% during the 2019–20 period. This trend is still likely to continue as 619 research articles have been published in less than 6 months in 2016. Articles published in 2015 have the highest mean total citations per article (MTCA) of 192.2 and mean total citation per year (MTCY) of 32.03 as articles published in 2015 got a maximum of 6 years (see Table 23.1).

Table 23.1 The number of research articles on microplastic pollution published during 2015–2021 (June 6, 2021)

Year	*N*	MTCA	MTCY	CY
2015	50	192.20	32.03	6
2016	91	127.43	25.49	5
2017	141	102.68	25.67	4
2018	258	63.53	21.18	3
2019	455	31.08	15.54	2
2020	935	10.31	10.31	1
2021	619	1.59		0

N: total number of documents published in a country; *MTCA:* Mean TC per article; *MTCY:* mean TC per year; *CY:* citable years

23.3.1 Most Productive Countries in Microplastic Pollution Research

23.3.1.1 Bibliometric Analysis of the Most Productive Countries in Research on Microplastic Pollution

Bibliographic analysis of countries with at least one publication concluded 122 countries globally. Out of these countries, 47 are meeting the threshold of at least five publications during the sampled period with 1840 research articles published in these countries. More than 80% of these articles on microplastic pollution were published in the top 20 countries listed in Table 23.2. China is a leading county with 356 research articles which is 23% of 1501 articles published in the top 20 countries, whereas the United States, Germany, and the United Kingdom stand 2nd, 3rd, and 4th, subsequently, in the top 20 nations published on microplastic pollution. Out of 47 countries with at least five documents, the top 4 countries published more than 41% of the total published during 2015–2021 which is more than 51% published in the top 20 countries.

It concluded seven clusters with China as the leading country. The data retrieved from the Scopus database indicates that out of 122 countries in which the microplastic-related research documents published, 51 countries met the criteria of a minimum of four documents. The overlay visualization of the TLS of the bibliographic coupling with other countries is displayed in Fig. 23.1.

23.3.1.2 Bibliometric Coupling Analysis Based on Countries

Figure 23.1 displays the bibliometric coupling analysis of top 20 countries. The analysis has been carried out, and the network is visualized by VOS-viewer software. The nodes, in Fig. 23.1, indicate countries. The larger the node, the greater the influence of the node (respective country) on other nodes (other countries), whereas the line shows the mutual relationship between the nodes (countries). The different colors in Fig. 23.1 represent the years. The bibliographic coupling analysis based on

Table 23.2 Bibliometric analysis of top 20 countries publishing research on microplastic pollution

R	Country	*N*	*N* (%)	TC	TC/N	TLS
1	China	356	23.7	10810	30.4	520623
2	United States	158	10.5	7913	50.1	303563
3	Germany	128	8.5	7074	55.3	258253
4	United Kingdom	123	8.2	8672	70.5	273158
5	Italy	89	5.9	3461	38.9	175929
6	Spain	79	5.3	2177	27.6	145412
7	Netherlands	60	4.0	4583	76.4	138698
8	France	54	3.6	4519	83.7	166968
9	India	54	3.6	860	15.9	118729
10	South Korea	52	3.5	1575	30.3	82412
11	Australia	51	3.4	2034	39.9	96202
12	Canada	44	2.9	1405	31.9	73999
13	Brazil	43	2.9	1559	36.3	101524
14	Portugal	41	2.7	2482	60.5	106788
15	Norway	34	2.3	728	21.4	58548
16	Denmark	30	2.0	1199	40.0	58493
17	Hong Kong	30	2.0	1714	57.1	62030
18	Japan	28	1.9	449	16.0	51066
19	Turkey	24	1.6	618	25.8	42045
20	Iran	23	1.5	634	27.6	57241

N: total number of research articles published in a country; *N (%)*: percentage of each country's research papers published in top 20 countries; *TC*: total citations of a country; *TC/N*: total citations per document; *TLS*: total link strength

the top 20 countries' weight ranking reveals that the top 5 most influencing countries are China, the United States, Germany, the United Kingdom, and Italy with TLS of 520623, 303563, 273158, 258253, and 175929, respectively. It is also notable that the proportion of TLS for these countries in the top 20 countries has been 17.8, 10.4, 9.3, 8.8, and 6%, respectively. The coupling analysis unveils that China, the United States, Germany, the United Kingdom, and Italy cite many the same literature on microplastic pollution. It means the research on microplastic pollution in these countries has the same literature reference foundation.

23.3.1.3 Bibliographic Analysis of Country Collaboration on Microplastic Pollution

Figure 23.2 represents the country's collaboration on microplastic pollution research all over the globe. The analysis reveals 1466 entries of collaborations among countries with a maximum of 60 to 1 collaboration. China has the lead in collaboration on microplastic pollution-related research having 10.57% of total collaborations globally. China and the United States are the top collaborating countries with 60 collaborations which are 4.09% of total collaborations globally. Among the top 20

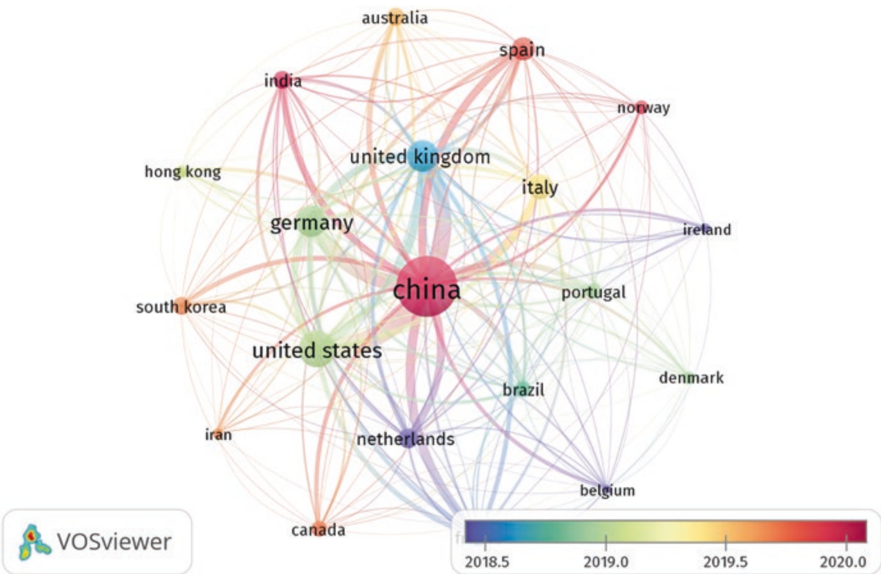

Fig. 23.1 Bibliographic coupling analysis of top 20 countries

No.	From-To	*f*	%
1	China-USA	60	4.09
2	China-Australia	28	1.91
3	China-Hong Kong	26	1.77
4	USA-Canada	21	1.43
5	China-United Kingdom	17	1.16
6	United Kingdom-Netherlands	17	1.16
7	USA-Australia	17	1.16
8	USA-United Kingdom	17	1.16
9	United Kingdom-Australia	15	1.02
10	China-Germany	14	0.95
11	Italy-Spain	14	0.95
12	Spain-Portugal	14	0.95
13	Italy-United Kingdom	13	0.89
14	Netherlands-Mexico	13	0.89
15	USA-Netherlands	12	0.82
16	France-Belgium	11	0.75
17	Germany-Norway	11	0.75
18	Germany-United Kingdom	11	0.75
19	Spain-France	11	0.75
20	China-Canada	10	0.68

Note: f = frequency; % = percentage of total global country collaborations

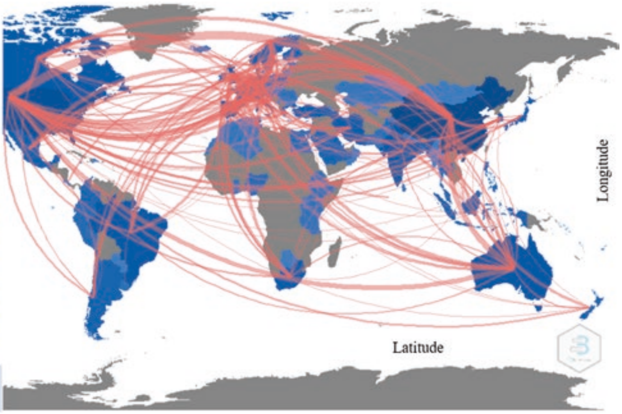

Fig. 23.2 Country collaboration map on microplastic pollution around the world

collaborating countries, China has the most effective collaboration with six major collaborations in the top 20 collaborations. Out of the top 20 collaborations, the top 3 collaborations come from China to the United States, Australia, and Hong Kong. The 4th leading collaboration on microplastic pollution-related research is between the United States and Canada with the frequency of 21 which is 1.43% of the collaboration worldwide. The United States has collaboration with four countries including Canada, Australia, United Kingdom, and the Netherlands. The United Kingdom has also been one of the leading countries in research on microplastic pollution in the world.

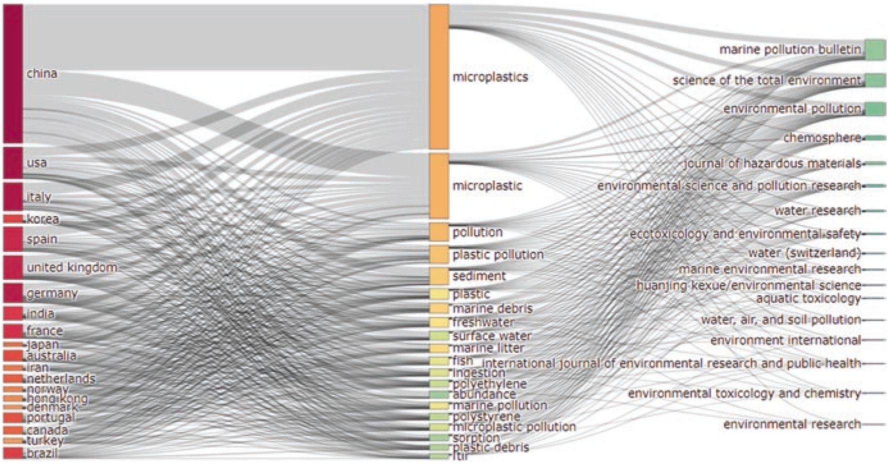

Fig. 23.3 Three-factor analysis of countries, keywords, and sources

23.3.1.4 Three-Factor Analysis of Countries, Keywords, and Sources

Figure 23.3 represents a three-factor analysis of the relationship among countries (left), keywords (middle), and the sources (journals) (right). The analysis shows that the top 20 countries all published "microplastics"-related research in the top 3 journals: *Marine Pollution Bulletin, Science of the Total Environment, and Environmental Pollution*. China has the lead in published "microplastics" and "microplastic"-related research articles followed by the United States and Italy.

23.3.2 The Most Productive Organizations/Institutions

23.3.2.1 Bibliometric Analysis of the Most Productive Organizations

Bibliographic analysis of organization shows that 15 out of 3588 organizations all over the globe meet the threshold of minimum five documents of an organization with four clusters. Table 23.3 summarizes the bibliographic analysis of the 15 organizations/institutions/universities publishing five or more than five documents. The analysis reveals that the University of Chinese Academy of Science (UCAS) has been a leading institution with 32 publications and a TLS of 6462 followed by the East China Normal University (ECNU), Shanghai, China, with 21 publications on microplastic pollution with 4988 TLS. However, publications from ECNU are leading in TC and TC/N of 3188 and 151.81 as compared to that of UCAS having 1743 TCs and 54.47 TC/N. It is interesting to note that 12 out of 15 top organizations are from China. Two institutions from South Korea and one organization from the Netherlands are included in the top 15 institutions publishing research on microplastic pollution.

Table 23.3 Top organizations publishing research on microplastic pollution

R	Organizations	Cluster	*N*	TC	TC/N	TLS
1	University of Chinese Academy of Sciences, Beijing, 100049 China	2	32	1743	54.47	6462
2	State Key Laboratory of Estuarine and Coastal Research, East China Normal University, Shanghai, China	1	21	3188	151.81	4988
3	College of Natural Resources and Environment, Northwest A&F University, Yangling, Shaanxi, China	3	9	125	13.89	1529
4	State Key Laboratory of Freshwater Ecology and Biotechnology, Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan, China	1	8	869	108.63	2762
5	Wageningen Marine Research, Ijmuiden, Netherlands	2	7	873	124.71	1581
6	Key Laboratory of Plant Nutrition and the Agro-Environment in Northwest China, Ministry of Agriculture, Yangling, Shaanxi, China	2	6	12	2.00	1227
7	Shanghai Institute of Pollution Control and Ecological Security, Shanghai, China	2	6	24	4.00	701
8	University of Chinese Academy of Sciences, Beijing, 100039 China	1	6	563	93.83	2281
9	Agro-Environmental Protection Institute, Ministry of Agriculture of China, Tianjin, China	3	5	5	1.00	316
10	Guangdong Laboratory for Lingnan Modern Agriculture, South China Agricultural University, Guangzhou, China	1	5	5	1.00	1413
11	Key Laboratory of Aquatic Botany and Watershed Ecology, Wuhan Botanical Garden, Chinese Academy of Sciences, Wuhan, China	4	5	789	157.80	2527
12	Key Laboratory of Soil Environment and Pollution Remediation, Institute of Soil Science, Chinese Academy of Sciences, Nanjing, China	2	5	267	53.40	410
13	Laboratory for Marine Ecology and Environmental Science, Qingdao National Laboratory for Marine Science and Technology, Qingdao, China	1	5	316	63.20	1834
14	Oil and Pops Research Group, Korea Institute of Ocean Science and Technology, Geoje, South Korea	1	5	161	32.20	1036
15	Sino-Africa Joint Research Center, Chinese Academy of Sciences, Wuhan, China	4	5	789	157.80	2527

R: rank of the organization; *N*: total number of research articles published on microplastic; *TCs*: total citations; *TC/N*: total citation per document; *TLS:* total link strength

23.3.2.2 Bibliographic Coupling Analysis Based on Organizations

Figure 23.4 shows the bibliographic coupling analysis based on organizations. Nodes in Fig. 23.4 represent the organizations, and lines indicated the collaboration links. The thickness of the lines shows the total link strength of an organization on other organization(s). The visualization of the estimates of the overall strength of the bibliographic coupling links with other organizations shows that the CAS Beijing, China, is also leading in the collaboration with other organizations. The CAS has the strongest collaboration network with East China Normal University with a link strength of 1382.

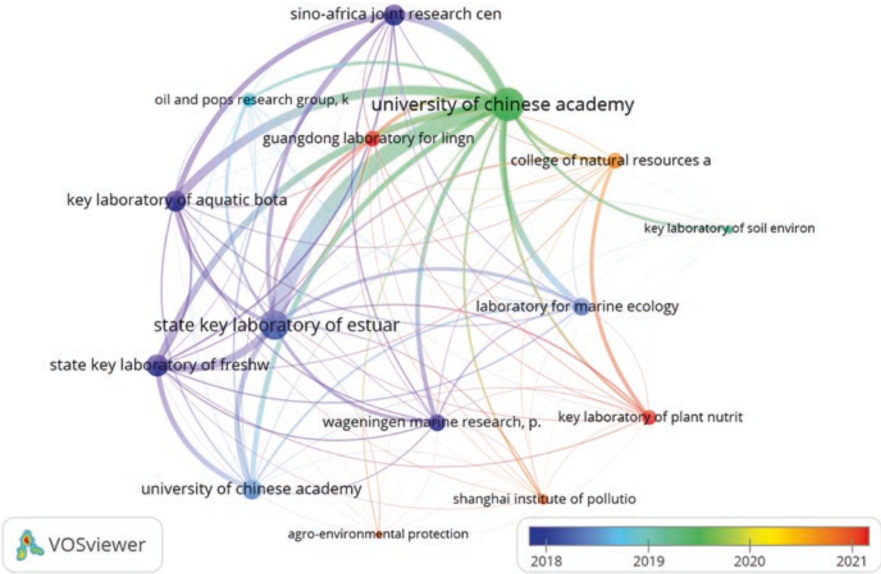

Fig. 23.4 Bibliographic coupling analysis based on organizations

23.3.3 The Most Productive Journals in Research on Microplastic Pollution

23.3.3.1 Bibliometric Analysis of Top 20 Journals Based on Published Articles on Microplastic Pollution

A bibliometric analysis of 2581 microplastic pollution-related publications published in 2015–2021 in 350 journals was carried out. The study finds out an average year from publication, average citation per document, and average citation per year per document of total articles published during the selected period as 1.54, 30.02, and 8.17, respectively. The analyzation of the top 20 journals publishing microplastic pollution-related research traced out that 1972 research articles published in these top 20 journals. The summary of the analysis is given in Fig. 23.5, and Table 23.4 shows the visual presentation of bibliographic coupling of the sources. Out of 1972 plastic pollution-related publications, *Marine Pollution Bulletin (MPB)* ranks first with 520 articles with 26.4% of the documents published in the top 20 journals during 2015–2021. The 2nd ranked journal is *Science of the Total Environment (STOTEN)* with 397 documents (20.1% of 1945) followed by *Environmental Pollution (EnP)* with 385 research articles related to pollution research producing 19.5% of the documents published in the top 20 journals during the selected period. Analysis of year-wise publications shows a higher number of documents published in *MPB* in each year from 2015 to 2021. It is interesting to note that 2/3 of the research papers have been published in the top 3 journals. *EnP*

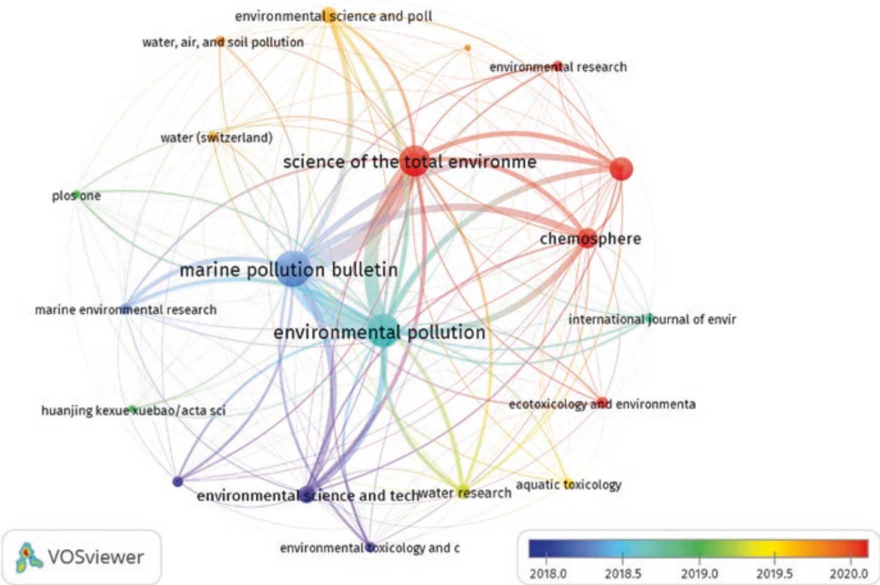

Fig. 23.5 Bibliographic coupling analysis of the sources

is a leading journal with respect to number of total citations (TCs) of 18452 followed by *MPB* with 15666 and *STOTEN* with 10382 TCs.

MPB is a leading journal started in 1970 with a 7.9 cite score and 4.049 impact factor (IF). It publishes research related to "rational use of maritime and marine resources."[1] Moreover, it also focuses on publishing research on marine pollution, effluent disposal, and pollution control. Since 1972, the journal *STOTEN* with a 10.5 cite score and 6.55 IF primarily focuses on research related to the total environment interfacing with "atmosphere, lithosphere, hydrosphere, biosphere, and anthroposphere."[2] In recent years, the journal has been publishing research related to nanomaterials, microplastics, and other emerging contaminants. *EnP* has been publishing documents focusing on environmental pollution and its impacts on ecosystems and human health. The journal has increased its publications and its quality of research published and increased the cite score and IF to 10.8 and 6.79, respectively.

[1] https://www.journals.elsevier.com/marine-pollution-bulletin

[2] https://www.journals.elsevier.com/science-of-the-total-environment

Table 23.4 Source dynamics of top 20 journals publishing articles on plastic pollution

R	Sources	*N* (%)	*N*	2015	2016	2017	2018	2019	2020	2021	H-Index	G-Index	TC	TC/N
1	Marine Pollution Bulletin	26.4	520	18	22	49	70	114	174	73	77	123	15666	30
2	Science of the Total Environment	20.1	397	0	3	4	32	72	160	126	67	102	10382	26
3	Environmental Pollution	19.5	385	8	22	28	60	78	113	76	58	86	18458	48
4	Journal of Hazardous Materials	6.3	124	0	0	0	2	5	37	80	38	78	1254	10
5	Chemosphere	6.0	118	1	3	2	5	19	41	47	27	48	2357	20
6	Environmental Science and Technology	4.5	89	3	5	13	11	19	32	6	24	45	6103	69
7	Environmental Science and Pollution Research	2.9	57	1	1	6	2	6	21	20	21	34	1192	21
8	Water Research	2.6	52	0	3	3	5	7	21	13	15	30	2984	57
9	Ecotoxicology and Environmental Safety	1.8	36	0	0	1	3	4	19	9	15	26	696	19
10	Water (Switzerland)	1.2	24	0	0	0	4	4	11	5	13	20	215	9
11	Environment International	1.1	21	0	0	1	0	4	14	2	13	17	846	40
12	Marine Environmental Research	1.1	21	2	3	1	1	1	8	5	10	16	1447	69
13	Scientific Reports	1.0	19	1	1	4	2	4	5	2	9	15	1553	82
14	Aquatic Toxicology	0.9	18	0	0	0	5	3	5	5	9	14	567	32
15	Environmental Toxicology and Chemistry	0.8	16	2	4	1	1	2	2	4	8	13	975	61
16	Plos One	0.8	16	0	1	0	2	1	10	2	8	13	320	20
17	Water Air and Soil Pollution	0.8	16	0	0	1	2	2	6	5	7	11	127	8
18	Huanjing Kexue/Environmental Science	0.8	15	0	0	0	0	4	7	4	6	11	133	9
19	Environmental Research	0.7	14	0	1	0	1	0	4	8	6	11	133	10
20	International Journal of Environmental Research and Public Health	0.7	14	0	0	1	5	1	5	2	6	10	262	19
Total publication[a]			1972	36	69	115	213	350	695	494				

Note: *R*: rank of the quantity ranking of the top 20 journals during 2015–2021 (May 30, 2021)
[a]Total publication per year by top 20 journals publishing papers on plastic pollution

23.3.3.2 Bibliometric Analysis of Topmost Cited Microplastic-Related Research Documents

Bibliometric analysis of the top 20 most cited research articles is summarized in Table 23.5. The mean value and range of TCs of the top 20 most cited journals are 427 TCs and 322–553 TCs. The most cite document also ranked 1st in the top 20 with the highest number of total citations 553 and 92 TCs per year is (Murphy et al. 2016) published in *Environmental Science and Technology.* The article examines the microplastic sources in the aquatic environment. Murphy et al. (2016) show that despite the efficient removal rates of microplastics using modern treatment technology, even a modest amount of microplastic per liter of effluent is being released into the environment and results in a huge amount of microplastic discharge. The second-ranked document with 552 TCs and 92 TCs per year is Sussarellu et al. (2016). The authors provide groundbreaking data on microplastic impacts providing help for the prediction of ecological effects on marine ecosystems. The study examines how exposure to polystyrene microplastics affects reproduction in oysters. The analysis reveals that microplastics cause feeding modifications, and reproductive disruptions in oysters also have a considerable effect on offspring. The study provides that strong reasons to believe that microplastics entered the marine environment are the source of concern, especially for filter feeders. Wright and Kelly (2017) (ranked 4th) examine how exposure to microplastic through diet and inhalation occurs and harms human health. The researchers review multidisciplinary scientific literature, gauge human health effects of microplastics, and outline some emergent areas of future research. Examining the accretion, particle toxicity, and chemical and microbial hazards, the corresponding existing fields reveal potential particle, chemical, and microbial hazards. The review anticipates chronic exposure to be a great source of concern. Van Sebille et al. 2015 (ranked 3rd) study the impact of microplastics debris in the ocean surface on marine life. The estimates reveal that in 2014, the accrued number of microplastic particles ranges between 15 and 51 trillion particles, weighing between 93,000 and 326,000 metric tons which makes it only approximately 1% of global plastic waste estimated entering the ocean in 2010.

The most of the top 20 studies consider municipal wastewater effluent as one of the major pathways for microplastic entrance into the aquatic environment, for instance, considering the engorgement that municipal wastewater treatment plants (WWTPs) are the major conduits of microplastic to the environment. Carr et al. 2016 (ranked 5th) investigate waste discharges from tertiary and secondary plants. The authors also probed the influent loads, particle size/type, transportation, and confiscation at WTPs. The researchers find out that existing wastewater treatment processes are effective in removing microplastic pollutants exerting into municipal WWTPs. The analysis does not unveil tertiary effluent as a significant source of microplastics as the latter is successfully removed during skimming and settling treatment processes. Mintenig et al. 2017 (ranked 8th) identified microplastic in effluents from four tertiary and eight secondary WWTPs. The polymer was identified of all microplastics down to the size of 20 μm through Micro-FTIR imaging. Microplastic was determined in all effluents of analyzed WWTPs. About 97% of

Table 23.5 Top 20 most global cited articles on microplastic pollution

R	Author(s)	Focus	TC	TC/Y	NTC
1	Murphy et al. (2016)	Examine how wastewater treatments work as a source of microplastic pollution in the aquatic environment	553	92	4
2	Sussarellu et al. (2016)	Assessment of the impact of polystyrene microspheres on the physiology of the Pacific oyster	552	92	4
3	Van Sebille et al. (2015)	The study represents the global estimates of microplastic abundance and mass using the largest dataset.	551	79	3
4	Wright and Kelly (2017)	Focuses on how microplastics affect human health	538	108	5
5	Carr et al. (2016)	Investigates the effluent discharge from seven tertiary and one secondary plant to examine microplastic in municipal wastewater treatment plants (WWTPs)	477	80	4
6	Avio et al. (2015)	The study analyzed how polyethylene (PE) and polystyrene (PS) microplastics adsorb pyrene.	470	67	2
7	Van Cauwenberghe et al. (2015a)	The study detects microplastics mussels and lugworms living in natural conditions.	456	65	2
8	Mintenig et al. (2017)	Identifies microplastic in effluents of WWTPs	420	84	4
9	Van Cauwenberghe et al. (2015b)	Reviews techniques, occurrence, and effects of microplastics in sediments	414	59	2
10	Klein et al. (2015)	Studies occurrence and special distribution of microplastic in the aquatic environment	408	58	2
11	Dris et al. (2015)	Investigates microplastic pollution in the urban environment	403	58	2
12	Brennecke et al. (2016)	Provides a deeper understanding of the microplastic vector for heavy metal contamination in the marine environment	393	66	3
13	Napper and Thompson (2016)	Examine the synthetic microplastic fibers released from washing machines	382	64	3
14	Lusher et al. (2015)	Analysis of microplastic in surface and subsurface samples from Arctic polar waters	369	53	2
15	Reid et al. (2019)	Discuss 12 major emerging threats to freshwater biodiversity	365	122	12
16	Su et al. (2016)	The occurrence of microplastics in the freshwater environment	354	59	3
17	Avio et al. (2017)	Attempted to examine plastic and microplastic pollutions in the oceans and emerging threats	347	69	3
18	Lei et al. (2018)	The study finds out how microplastics cause intestinal damage and other negative effects in *zebrafish Danio rerio* and *nematode Caenorhabditis elegans.*	346	87	5
19	Mason et al. (2016)	Detection of microplastic in municipal WWTPs	334	56	3
20	Leslie et al. (2017)	The study represents concentration data for the emerging contaminants in WWTPs, freshwater, and marine systems.	322	64	3

R: ranking of the papers based on citations; *TC*: total citations of the article(s); *Y*: number of year(s); *NTC*: normalized TC microplastic was removed with installed tertiary treatment. WWTP was found a possible source of microplastic but also the as sink as the latter was also detected in sewage sludge. Mason et al. 2016 (ranked 19th), analyzing the 17 different facilities across the United States, found fibers and fragments to be the most common type of particle within the affluent, but some fibers might be originated from nonplastic sources. The authors also observed inter- and intra-facility variation in discharge concentrations. Moreover, variations in the relative proportions of particle types were also observed. Leslie et al. 2017 (ranked 20th) clarified that treated municipal wastewater and solids were critical sources of microplastic pollution. "Riverine-suspended particulate matter" was found enriched in microplastic. Moreover, similar microplastic intensities were found in canal and treated wastewater. The authors observed that filter feeders and other benthos amassed microplastics in their bodies, and estuarine sediments were highly infested with microplastics.

Avio et al. 2015 (ranked 6th) examined the bioavailability and toxicological risk posed by the pollutants and examined how polyethylene and polystyrene microplastics effectively absorb pyrene. Further, pyrene absorbed on microplastics is readily available for mussels. It is also found that microplastics have several impacts on molecular and cellular pathways. Moreover, Avio et al. (2015) observe potential toxicological risks arising from virgin and contaminated microplastics. Van Cauwenberghe et al. (2015a) (ranked 7th) discussed the results of the study in the context of possible risks due to possible transfer of adsorbed pollutants detecting microplastics in mussels and lugworms living in natural habitats. The authors collected two species of marine invertebrates representing different feeding strategies from six locations along the French-Belgian-Dutch coastline. In addition, laboratory experiments were conducted to examine likely harmful impacts on ingestion and translocation of microplastic on the energy metabolism of the selected species. The analysis found microplastics in all collected organisms. It is also found that mussels and lugworms are exposed to high concentrations but no significant negative impact on the overall energy budget of the organisms. In another analysis, Van Cauwenberghe et al. (2015b) (ranked 9th) reviewed the technique, occurrence, and effects of microplastics in sediments and stressed the need for standardization and harmonization of abstraction techniques, occurrence, distribution, and impacts.

Klein et al. 2015 (ranked 10th), analyzing all sediments containing microplastic particles by infrared spectroscopy, found polyethylene, polypropylene, and polystyrene in abundance. Moreover, emerging pollution of inland river sediments with microplastic, and the rivers are vectors of transportation of microplastics into the ocean. Microplastic contaminations in urban areas are a source of great concern. Aspired from this argument, Dris et al. 2015 (ranked 11th) investigate the microplastic contamination in urban apartments and surface water in the continental environment. The pioneering study on the urban environment confirmed the microplastic in sewage, freshwater, and total atmospheric fallout and provided robust information on the type and size of the distribution of microplastics.

Most of the studies focus on the analysis of microplastics and their impressions on the marine environment, and the prevalence of microplastics in freshwater has been less explored. Reid et al. 2019 (ranked 15th) document 12 evolving intimidations to freshwater biodiversity including emerging contaminants, engineered nanomaterials, and micropollutants. Su et al. 2016 (ranked 16th) investigate microplastic pollution levels of freshwaters examining the Chinese Taihu Lake. The study found that abundance of microplastics in planktons was the highest in freshwater lakes worldwide. The prevalence of the highest levels of microplastics is found not only in water but also in organisms in the China's third largest lake. Lei et al. 2018 (ranked 18th) used zebrafish Danio rerio and nematode Caenorhabditis elegans as model organisms for microplastic exposure in freshwater pelagic and benthic environments. The researchers examined the toxic impacts of five common types of microplastics including polyethylene, polypropylene, polyvinyl chloride, and polystyrene. The results show that microplastic particles cause intestinal damage and other negative effects in organisms. The toxicity of microplastics is closely reliant on their size rather than composition.

There is only a single study examining the interaction between different classes of pollutants. Brennecke et al. 2016 (ranked 12th) attempted to examine the interactions between the two different classes of pollutants – heavy metal and microplastics. The authors examined the adsorption of two heavy metals leached from antifouling paints to virgin polystyrene beads and aged polyvinyl chloride fragments in seawater during the experimental manipulation of 14 days. The analysis showed a significant interaction between the microplastics and heavy metal showing implications its repercussions for marine life and environment. According to Napper and Thompson (2016) (ranked 13th), the release of synthetic microplastic plastic fibers is potentially a vital source of microplastic into the environment. It is also found that fiber release varied according to wash treatment with a variety of convoluted interactions, and it was concluded that washing clothing can a vital conduit of microplastic into the aquatic habitats.

In a pioneer study to examine microplastics in Arctic waters, Lusher et al. (2015) (ranked 14th) found microplastics in surface and subsurface samples in Arctic region. But the origins and corridors through which microplastic reached the Arctic region remained vague. The study recommended further research to develop a deeper comprehension of the microplastic sources and their impact on the environment. Avio et al. (2017) (ranked 17th) pointed out that plastic pollution has increased worldwide and a foremost risk to the marine environment. It has become ubiquitous, but there is a dire need for quantifiable estimates on the global abundance and weight of floating plastics particularly in the Southern Hemisphere and distant regions of the world. Even some large-scale convergence zones of plastic debris have been discovered, yet immediate standardized common methodologies are imperative to measure and quantify plastic in seawater and sediments. Moreover, plastic contamination has been affecting marine species that call for a more integrated ecological risk evaluation of these materials on a priority basis.

Bibliographic coupling of the documents shows that only 24 research articles fulfill the threshold level of a minimum of 300 citations. Estimations of the total strength of the bibliographic coupling links of the top 20 documents with other documents indicated two clusters of documents (Fig. 23.6).

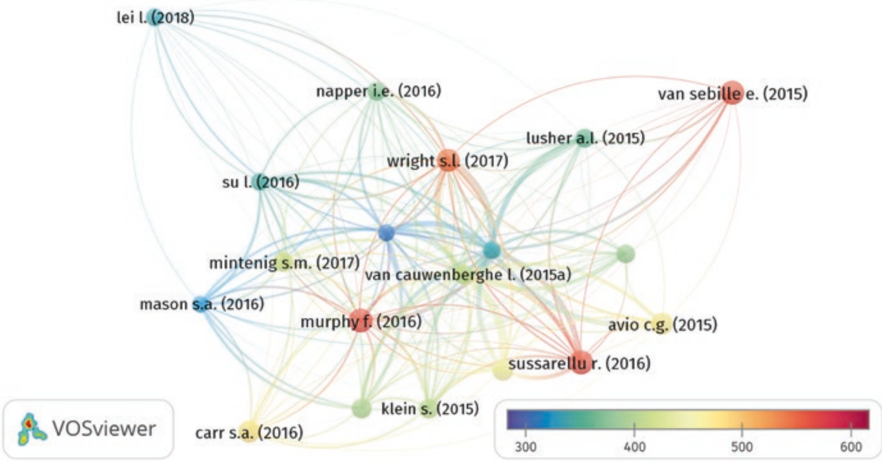

Fig. 23.6 Bibliographic coupling of documents

23.3.4 Bibliometric Analysis of Keywords, Thematic Evolution, and Factorial Analysis of Conceptual Structure

Out of 3262 author keywords, 139 met the threshold level of a minimum of 50 appearances. The visualization of the keyword clusters in Fig. 23.7 unveiled three major clusters. Cluster 1 mainly contains the words microplastic, microplastics, microplastic pollution, and composition and structure of microplastic pollution with microplastics as the most used word. Cluster 2 focuses on environmental monitoring, water pollutants, marine pollution, marine environment, geological sediments, sediments, plastic pollutions, and their impacts on the marine environment, whereas cluster 3 comprises the keywords related to impacts of organic pollutants, nanoparticles, ingestion and ingestion rate, toxicity, and their impacts on humans, nonhumans, and marine life. Risk assessment of exposure to microplastic pollution is also included in cluster 3.

Thematic evolutional analysis shows a very detailed process of evolution of keywords used and themes that emerged during the 2015–2021 period. The 7-year sampled period has been divided into four slices in 2015–2016, 2017–2018, 2019–2020, and 2021 to have a deeper insight into the thematic evolution of microplastic pollution-related research. Figures 23.8 and 23.9 show the visualized results of the thematic analysis. In 2015–2016, the researchers focused on microplastic, marine litter, persistent organic pollutants (POPs), abundance, plastic ingestion, and polystyrene. The research on polystyrene has been an emerging field in microplastic research in 2015–2016 as it can be seen in Fig. 23.9a. Research themes regarding microplastics, sediments, plastic ingestion, and polystyrene have the major themes attracting the attention of the researchers in Slice 2 (2017–2018) (Figs. 23.8 and 23.9b). The themes related to Fourier Transform Infrared (FTIR) spectroscopy,

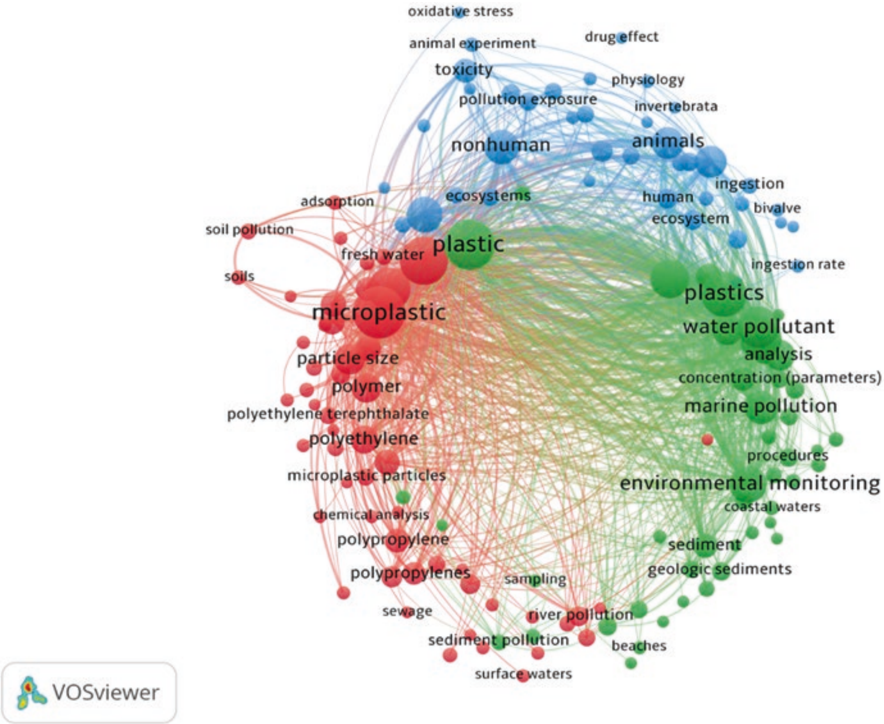

Fig. 23.7 Bibliographic visualization of keyword clusters

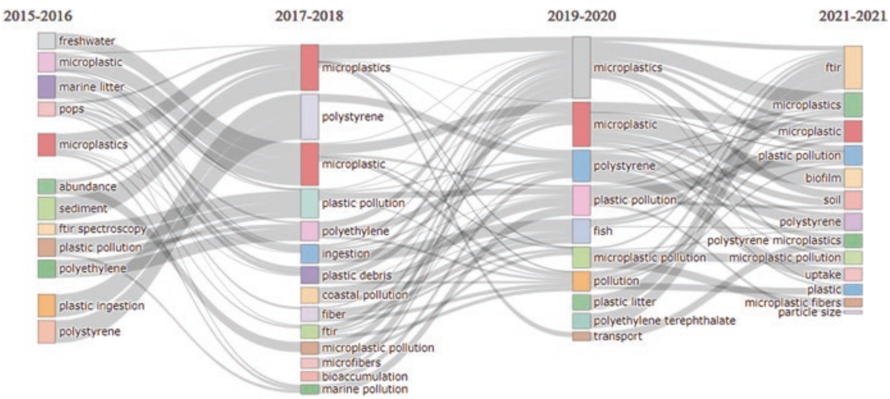

Fig. 23.8 Thematic evolution analysis

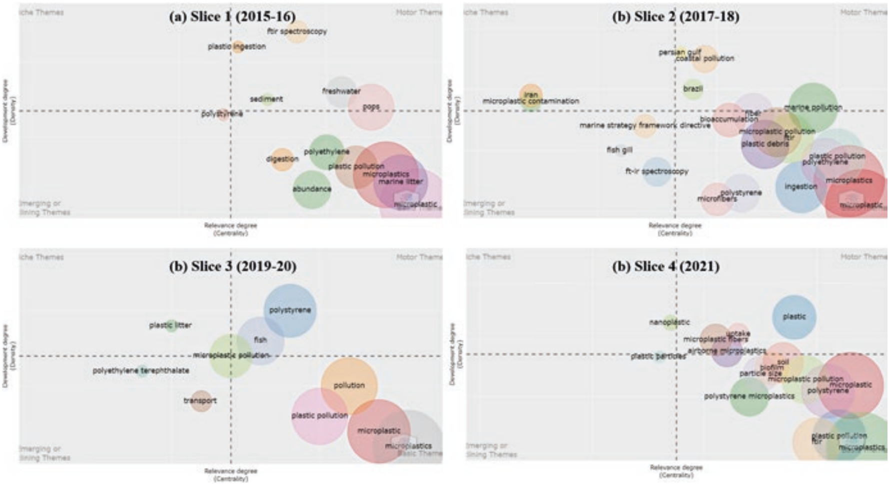

Fig. 23.9 Thematic evolution of the research on microplastic pollution: slice-wise analysis

polyethylene, microplastic debris, coastal pollution, microplastic pollution, microfibers, bioaccumulation of microplastic, and marine pollution increased in Slice 3 (2019–2020). Microplastic pollution has been the central theme of research in the same slice, whereas polyethylene terephthalate and transport have been the emerging field of research in Slice 3 (Fig. 23.9(3)). In Slice 4, the FTIR spectroscopy, microplastic(s), and plastic pollution have been leading themes of research in microplastic pollution research. FTIR spectroscopy has been an extensively used technology in research on microplastic pollution (Veerasingam et al. 2020).

Factorial analysis of conceptual structure of microplastic pollution (Fig. 23.10)-related research shows that major latest research on microplastic pollution research mainly focuses on FTIR spectroscopy, sediment, polypropylene(s), sediment(s), river pollution (fresh water), and polyethylene and is focused on microplastic research in China. Keywords and thematic analysis show that microplastic(s), microplastic pollution, marine litter, microplastic contamination, polystyrene microplastics, FTIR, ingestion, bioaccumulation, coastal pollution, pops, and analysis of particle size have been major themes of interest for the microplastic pollution-related research.

23.4 Discussion

The bibliographic analysis of the research articles published shows that the research on microplastic pollution got momentum after the publication of synthesis report on climate change (IPCC 2014) and the global Paris agreement (UNFCCC 2015).

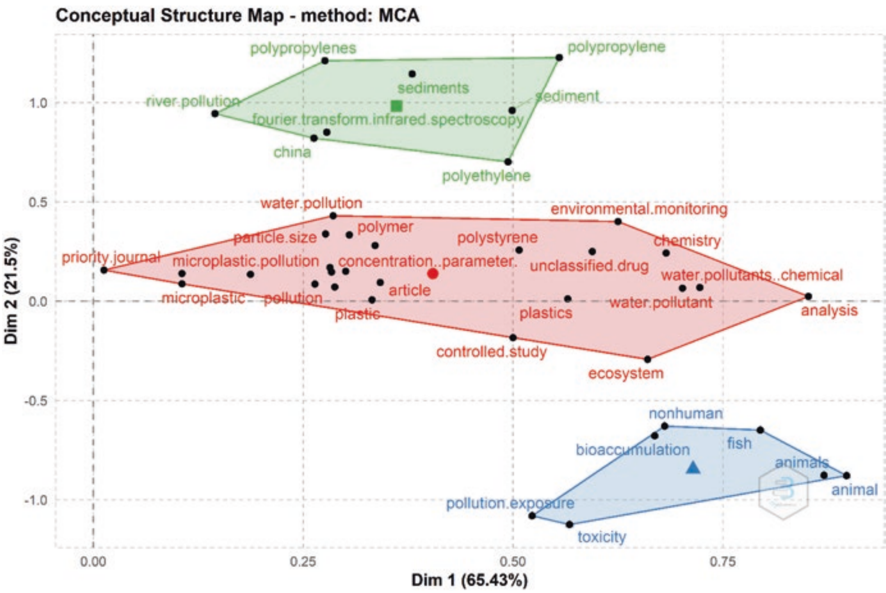

Fig. 23.10 Factorial analysis (conceptual structure map)

Moreover, the collective commitment of the global economies to sustainable development goals (SDGs) (United Nations 2020) also contributed to this momentum. The number of articles increased by 1770% in 2020 as compared to published in 2015, whereas this number of documents published on microplastic pollution is higher at 1138% in 2021 (on June 6, 2021) as compared to those published in 2015. The number of publications in less than 6 months of 2021 is higher than in 2015. However, it is likely to be much higher by the end of 2021. The results of the current study are in agreement with that in Sorensen and Jovanović (2021). The number of publications increased 2323.1% from 2009 to 2019 (Sorensen and Jovanović 2021).

The bibliometric analysis of the most productive countries shows that China is leading and the most effective country out of 122 countries in terms of research article publications on microplastic pollution during 2015–2021 followed by the United States and Germany, respectively. He et al. (2020) also find these three countries the most productive countries in research on microplastics in terrestrial ecosystems. Moreover, based on bibliographic coupling analysis of countries, China is also found to be more productive and collaborating with other countries. A bibliometric mapping and analysis of the management of plastic waste (de Sousa 2021) find a significant increase in research publications on plastic pollution, and China is found to be the most influencing in research articles published on plastic pollution. Moreover, analysis of the top organizations conducting and producing research on microplastic reveals the Chinese organizations/institutions having the lead in this research area as 12 of 15 top organizations have been publishing articles on microplastic pollution. It is important to note that 113 out of 130 research articles published in top 15 organizations worldwide are produced by the Chinese organizations/institutions which makes 86.92% of total publications by top 15 organizations. In addition, the Chinese organizations are also leading research impact measured by TC per research document published. The UCAC has the lead in publishing articles on microplastic pollution. This analysis produces the similar results as in de Sousa (2021) and He et al. (2020) which also find Chinese authors and organizations/institutions leading in the plastic pollution-related research. The analysis of the most productive journals reveals *MPB, STOTEN,* and *EnP* are deemed to be the top 3 productive journals in microplastic pollution-related research. He et al. (2020) also find these three journals leading the research related to microplastics in terrestrial ecosystems, but the ranking of these journals is *STOTEN, EnP,* and *MPB* as 1st, 2nd, and 3rd, respectively. The results of the current study are also supported by Pauna et al. (2019) and Sorensen and Jovanović (2021) that *MPB* has published the most documents on microplastic pollution. Pauna et al. (2019) conducted a bibliometric network analysis of global scientific literature on "marine microplastics."

Bibliometric analysis of the topmost cited microplastic-related research articles shows that some studies focused on sources of microplastic waste in the marine environment. For instance, Murphy et al. (2016) concluded that despite efficient removal of plastic waste from the wastewater, the effluents have been discharged and causing accumulation into the environment. Sussarellu et al. (2016), using a groundbreaking data on microplastic impacts, found microplastics affecting the reproduction in oysters. Wright and Kelly (2017) anticipates that chronic exposure to accumulated particle toxicity and chemical and microbial hazards affect human health. Some of the studies focused on the analysis of accumulation of microplastic debris in marine environments. For instance, Van Sebille et al. (2015) traced out how microplastic particles accumulated in the shapes of plastic marine debris. Most of the top research documents attempt to explore how municipal wastewater effluents work as a conduit of microplastic into the aquatic environment. Carr et al. (2016) find out that existing wastewater treatment processes are effective in the removal of microplastics from WWTPs through tertiary plants. Mintenig et al. (2017) focused on FRIR imaging to identify the size of the microplastics in tertiary and secondary WWTPs. Mason et al. (2016) observed inter- and intra-facility variation in discharge concentrations. Leslie et al. (2017) detected microplastic concentration in freshwaters such as canal water and treated water. Some studies attempted to examine toxical risks in marine inhabitants. Virgin and contaminated microplastics pose potential toxicological risks to marine mussels (Avio et al. 2015). In another study, Van Cauwenberghe et al. (2015a) reveal that mussels and lugworms are exposed to a high concentration of principle laboratory experiment but no significant impact on the organism's overall energy budget. Klein et al. (2015) find polyethylene, polypropylene, and polystyrene in abundance in river shore sediments. A pioneering study on the urban environment, Dris et al. (2015) confirm the existence of microplastic in sewage and fresh water. Su et al. (2016), Lei et al. (2018), and Reid et al. (2019) analyze microplastic pollution and its impact on freshwater. Brennecke et al. (2016) explore the interaction between heavy metals and microplastics. Synthetic microplastic plastic fibers are also a critical and potential source of microplastic into the environment (Napper and Thompson 2016). It is also imperative to analyze the microplastic in Arctic waters. Lusher et al. (2015) serve this purpose and found surface and subsurface samples, but the origins and pathways of microplastics to Arctic region still need to be explored. Pauna et al. (2019) unveiled that the research on marine microplastic primarily focused on toxicology and environmental chemistry. Pauna et al. (2019) stressed the need of adoption of interdisciplinary perspectives in marine microplastics-related research.

Since the inception of the COVID-19 pandemic, the problems related to plastic and microplastic pollution have increased enormously. In the wake of the COVID-19 pandemic and the preventive measures recommended by the World Health Organization (WHO) to slow down the infection, transmission has been a great source of plastic pollution. A substantial increase in the use and production of face masks and other elements such as gloves, face protectors, protective suits, and safety shoes manufactured with polymeric material including antiviral textiles has been ending as microplastic pools (Ardusso et al. 2021). In recent research, the consequent increase in plastic and microplastic pollutions due to the pandemic and issues related to it has attracted the attention of environmental researchers and experts.

The research themes and trends have shifted to COVID-19 and pollution. The unprecedented increase in the production of face masks during the COVID-19 pandemic has emerged as a new environmental challenge globally (Aragaw 2020). Disposable face masks (DFMs) have been used to slow down the transmission rate of COVID-19. Consequently, extensive use of single-use DMCs is playing a critical role in microplastic pollution. This is another source of concern amid the COVID-19 pandemic for the researchers and communities warranting the measures and policy interventions to address the microplastic pollution in pandemic situations (Fadare and Okoffo 2020). Chowdhury et al. (2021) also assert that face masks are a considerable nonrecyclable plastic material. Moreover, it is also a source of concern that wearing masks poses microplastic inhalation risk, and reusing the masks increases the risk (Li et al. 2021). Anastopoulos and Pashalidis (2021) analyze the role of face masks and subsequent mask-driven microplastic as pollutant carriers in the hydrosphere, biosphere, etc. Single-use face masks enter the uncontrolled environment, and safe disposal of the masks has been a challenging issue. Single-use surgical face masks can act as dye carriers (Anastopoulos and Pashalidis 2021).

Moreover, unprecedented and increased use of the PPEs during COVID-19 pandemic situations has worsened the plastic pollution issues in the marine environment (De-la-Torre et al. 2021; De-la-Torre and Aragaw 2021). It is stressed to address the key research needs regarding the occurrence and abundance of PPEs, sources, fate, and drivers of PPEs, PPE as sources of microplastics and vectors of invasive species and pathogens and source and vector of chemical pollutants in the marine environment (De-la-Torre and Aragaw 2021). Torres and De-la-Torre (2021) stress the need of using biodegradable face masks as an alternative to reduce non-biodegradable plastic waste pollution. In a recent study, Ardusso et al. (2021) provide reflections and perspectives on how the pandemic causing aggravated plastic pollution on beaches and coastal environments consequently would be increasing devastation to the marine environments and ecosystems.

23.5 Conclusion

The research on microplastic pollution, its composition, and its impact on natural environments, ecosystems, marine environments, and human health has shown increasing trends since the global Paris agreement to deal with climate change and global warming. This chapter primarily focused on identifying the most productive countries, organizations/institutions, research journals, the most productive research articles, author keywords, and the evolution of various research themes during the sampled period of 2015–2021. The bibliometric analysis concluded China, the United States, and Germany the most productive in producing research on microplastic pollution. In addition, these countries are also found to be more productive and effective in terms of collaboration in the field of research on microplastic pollution. The analysis of the most productive organizations/institutions has revealed that the Chinese organizations/institutions are the most productive in research on microplastic pollution. The UCAS has been the leading organization/institution in producing research on microplastic pollution.

While analyzing the major sources (journals) publishing research on microplastic pollution and its composition, sources, and impacts on natural environments, ecosystems, human and nonhuman life, and marine environments, the journals *Marine Pollution Bulletin, Science of the Total Environment,* and *Environmental Pollution* have been the leading journals in the research area. The examination of the best papers in terms of research influence measured by the total citation per research article shows that the top publications focused mainly on marine environments, sources of the microplastic pollution, the composition of microplastic, and their impacts on natural environments and ecosystems with a special concentration on its impacts on human and nonhuman health. Most of the productive research articles addressed the microplastic pollutions in marine environments and fresh waters. Some studies focused on microplastic pollutants in wastewaters. The author keyword and thematic evolution analysis show that the frequent keywords and themes in research during the sampled period have been microplastic(s), plastic(s), water pollutants, concentration, particle size, polyethylene, polymer, polypropylene, sentiments pollution, coastal waters, fresh waters, plastic ingestion, bioaccumulation, marine pollution, FTIR, polystyrene microplastics, to name a few. A new research area that emerged in microplastic pollution-related research has been the microplastic pollution in the COVID-19 pandemic since the inception of the global pandemic. The recent studies in this area are primarily focused on COVID-19 and microplastic pollution, face masks, PPEs, and plastic wastes during COVID-19.

However, a few studies have focused on the strategies and policy frameworks to control microplastic pollution. The focus of the researcher has the identification of the microplastic(s), their composition, sources, conduits, and their impacts on the natural environments, ecosystems, human and nonhuman health, and marine life. The current bibliometric analysis finds it imperative to represent multiple research prospects that can be useful in setting future research trends on strategies to control and effectively manage the microplastic(s) pollution and issues related to it. An important future research area may be the analysis of microplastic pollution in far-off regions such Arctic region. It is important to examine the sources, conduits, and composition of microplastic pollution in far-off areas such as the Artic region. Moreover, it is also pivotal to evaluate the measures to control microplastic pollution and frame out strategies to deal with it in the less developed and developing countries. There is a need to adopt hybrid approaches to manage fresh water as crucial ecosystems for human life as well as essential hotspots of biodiversity and ecological function. Future research may focus on bridging the gaps between conservation of biodiversity and accelerated rate of species endangerment and stimulate the efforts to reverse the global trends in freshwater degradation (Reid et al. 2019).

It is imperative to put forth resources and strategies to mobilize and increase awareness on COVID-19 prevention, but it is also indispensable to increase public awareness on the use and disposal of the waste and its management. It is also imperative to direct research to look for eco-friendly alternatives along with enhanced effective waste management systems. The future research directions are likely to focus on the development of waste management systems, framing, and implementation of strategies for integrated coastal management. Since the COVID-19 pandemic has been adversely affecting all economies on the globe, the collective global strategies toward the developments in environmental research on COVID-19 and post-pandemic would be productive to deal with the various global environmental risks.

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