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Research Article

Scientometric Analysis and Visualization of Research on the Effects of Microplastics on Marine Life

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ABSTRACT

The study investigated the effects of microplastics on marine life through scientometric analysis and visualization of research publications. A total of 8,397 scientific documents were collected from the Scopus database covering the years 2013 to 2022 using bibliometric tools. The analysis includes annual scientific production, prolific authors, influential journals, productive institutions, keyword co-occurrences, thematic structures, factorial maps, globally cited publications, research trends, country-wise contributions, international collaborations and funding agencies' roles. The findings revealed that 2022 was the most productive year for publishing, with 3,239 documents. Y. Zhang emerged as the most prolific author in this field, while the Journal of Science of the Total Environment had the highest number of publications. East China Normal University is the most productive institution that contributed the maximum number of publications. The word microplastic is the most frequently used keyword by researchers. The study 'The Physical Impact of Microplastics on Marine Organisms: A Review' by Wright, S. L. *et al*. was a highly cited paper, indicating its significance in the field. The analysis also highlighted the National Natural Science Foundation of China was the major funding agency and China exhibited the strongest international collaboration with the USA. This study provides crucial insights for addressing knowledge gaps, promoting collaboration and guiding evidence-based policies to mitigate the impacts of microplastics on marine ecosystems.

Keywords: Microplastics, Marine life, Scientometric, Visualization, Scopus.

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INTRODUCTION

Microplastics are small plastic particles measuring less than 5 millimeters, which harm ocean and aquatic life worldwide. They can be either intentionally produced on a microscale or result from the breakdown of larger plastic items.[1,2] Their widespread presence in various ecosystems, mainly marine environments, has made them a global environmental issue.[3-5]

Once in the ocean, microplastics are ingested by a wide range of marine organisms, from zooplankton to apex predators like sharks and whales.[6,7] The effects of microplastics on marine life are diverse and multifaceted. Firstly, ingestion can result in physical harm, leading to internal injuries and blockages of the digestive system.[8,9] Microplastics have also been found to adsorb and concentrate toxic pollutants, endangering marine creatures' health and reproductive success. Microplastics also disrupt aquatic food chains, alter behavior and compromise reproductive success in many species.[10-12]

Coral reef is one such significantly affected species disturbing the entire ecosystem, often called the "rainforests of the sea," providing habitat for numerous marine organisms. However, they are particularly vulnerable to rising sea temperatures, ocean acidification and pollution.[13-16]

Rising sea temperatures, driven by climate change, can lead to coral bleaching events, resulting in widespread mortality and loss of habitat for associated species.[17,18]

Higher concentrations of microplastics in coastal sediments are produced due to the intensity of human production activities, than in deep-sea sediments.[19-21] Microplastics come in various shapes, sizes, colors and densities, often associating with pollutants, bacteria and viruses during their production and distribution.[22,23] Environmental forces like monsoons and ocean currents further contribute to their spread and accumulation across different marine regions.

Hence, this study aims to explore research advancements, collaboration patterns, intellectual structures and emerging themes concerning the effects of microplastics on marine life. Such insights can inform policy-making, funding decisions and future research directions.

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LITERATURE REVIEW

Several recent studies have analyzed global microplastic research, considering different periods and aspects of the subject. Bhat *et al.*[24] conducted a global scientometric analysis of microplastic research from 1980 to 2021. It retrieved 8,257 bibliographic records from the Web of Science core collection database. The study found that "microplastics" was not used before 2003, but its use as a pollutant keyword significantly increased since 2004. Statistical analysis revealed a substantial growth in microplastic articles since 2014, with at least 100 articles per year. Leading plastic-producing countries were China, the USA, Germany and Italy. Microplastic research encompasses various disciplines such as environmental sciences, ecology, marine freshwater biology, engineering, chemistry, toxicology and water resources. He *et al.*[25] examined microplastic research in terrestrial systems using data from the Web of Science between 1986 and 2020. It used VOSviewer software to analyse keywords, authors, organizations, countries and journals related to terrestrial microplastics. The study revealed that Science of the Total Environment is the top journal for publishing papers on terrestrial microplastics. It also emphasized the need for standardized protocols to extract and quantify soil microplastics.

Sharma, Jaiswal and Kaur[26] studied microplastic research trends from 2011-2019 using the Scopus database. It reveals that most articles (around 49%) were authored by individuals affiliated with the Chinese Academy of Sciences. The journals 'Marine Pollution Bulletin' and 'Environmental Pollution' were identified as important, with 273 and 185 research publications, respectively. 'Environmental Pollution' was the leading journal (about 20%) focused on microplastics in the environment. Co-authorship analysis revealed that China had the most collaborations followed by the USA, forming the top cluster with a 42-link strength. The study also highlighted potential future research areas and emerging trends. Li *et al.*[27] examined microplastic research trends from 2004 to 2020. They collected 2872 articles from the Web of Science for bibliometric visual analysis using CiteSpace. China and the United States emerged as the top contributors in microplastics research. The study involved researchers from various disciplines, including ecology, chemistry, molecular biology, environmental science and oceanography. Recent research has focused on microplastics' ecological distribution and toxicity and their association with heavy metal pollution. Davtalab, Byčenkienė and Uogintė[28] analysed the research publications from 1990 to 2022 on microplastics, identifying influential countries, authors, institutes, papers and journals. It found a consistent rise in microplastic publications and citations in recent years, with 19 and 35 times increase since 2015. The study was also analyzed thoroughly, revealing significant keywords and clusters to guide future research and capture scholars' attention to crucial topics.

Objectives

The objectives of the study are:

- To explore the annual scientific publications during 2013-22.
- To analyse the most prolific authors, highly influential journals and productive research institutions.
- To visualize the co-occurrence of keywords.
- To evaluate the global collaboration map of the research.
- To analyse research trends and create a factorial map of the research.
- To identify the top funding agency and the highly globally cited publication.

METHODOLOGY

This study analyzed the research publications on microplastics from 2013 to 2022 using evaluative scientometric methods. A total of 8,397 publications were retrieved from the Scopus database using the following keyword. The selected terms have been searched in the fields "article title, abstract and keywords". The search query used was:

((TITLE-ABS-KEY("microplastics") OR TITLE-ABS-KEY ("Microplastic source") OR TITLE-ABS-KEY ("Microplastic effects on marine life")) AND PUBYEAR>2012 AND PUBYEAR<2023 AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SUBJAREA, "ENVI”))). The search was conducted on May 22, 2022.

The data were collected from various types of publications, including articles, reviews, book chapters, conference papers and others. These research papers included full bibliographical details such as publication growth, author profiles, high-ranking journals, significant keywords, affiliations' names and funding agencies. All publications included in the study were in English. The main focus of the study was to analyse trends in publications and citations. The data were downloaded in CSV format for analysis using bibliometric software such as the Bibliometrix package of R Studio[29,30] and VOSviewer.[31] Additionally, Microsoft Excel was used for data analysis and tabulation. The workflow of the study is illustrated in Figure 1.

RESULTS

Annual Scientific Production

The annual trends of scientific production in terms of publications are shown in Figure 2. For over 10 years, researchers have published and indexed 8,397 scientific documents in the Scopus database on the effects of microplastic on marine life. The number of documents has been consistently increasing from 2013 to 2022. The most productive year for publishing documents was

2022, with 3239 (38.58%) publications, followed by 2021, with 2068 (24.63%) published records and the least productive year was 2013, with 18 (0.22%) published records.

Productive Authors

The top 10 authors, ranked according to the highest number of publications, are listed in Table 1, along with total citations, h-index, g-index and publication year. The h-index and g-index functions are implemented in the biblimetrix R package and Bibexcel is used for productivity and citation information from the respective authors. The h-index is calculated based on the analysis of publication data using publications and citations. On the other hand, the g-Index is one of the unique and most significant numbers cited by top g-papers, at least g2. The study reveals that Zhang Y (2016) is the most prolific author in this field, with 270 articles published with 11,996 citations and a g-index of 101. Wang J (2015) is the second-highest author, who contributed 258 articles with 16,979 citations and received a g-index of 124. Among the top 10 authors, Wang Q (2018) has the lowest number of 111 publications and 4515 citations. Regarding the h-index, Wang J and Zhang Y are in 1st and 2nd ranks with an h-index of 71 and 58, respectively.

Highly Productive Journals

The top 10 journals that prefer papers from various sources are enumerated in Table 2. It indicates the high-ranking journals with total publications, citations, h-index, g-index and publisher details. The journal '*Science of the Total Environment*' (Elsevier) had the highest number of publications (1292) with 70,547 citations and received an h-index of 128 and a g-index of 211 in 2014. It is followed by the '*Marine Pollution Bulletin*' (Elsevier Inc.) published the second-highest number of papers (960) with 60,178 citations. The third most productive journal was '*Environmental Pollution*' (Elsevier Ltd.,) which had the highest number of 72,137 total citations and received the highest h-index of 145. Among the top 10 journals in 2014, 'Frontiers in Marine Science' (Frontiers Media S.A.) published the least number of papers (131).

Most Productive Institutions

A total of 5,478 institutions were identified as contributors to the research field. Table 3 lists the top institutions ranked by the number of publications. It was found that East China Normal University had the highest number of publications, with 745 (1.67%), followed by Nanjing University with 535 (1.20%) and Northwest A and F University with 419 (0.94%). The institution with the lowest number of publications among the top 10 is Ocean University of China, with 336 (0.75%) publications. Therefore, the majority of institutions are located in China, indicating that China has been a major target country for research.

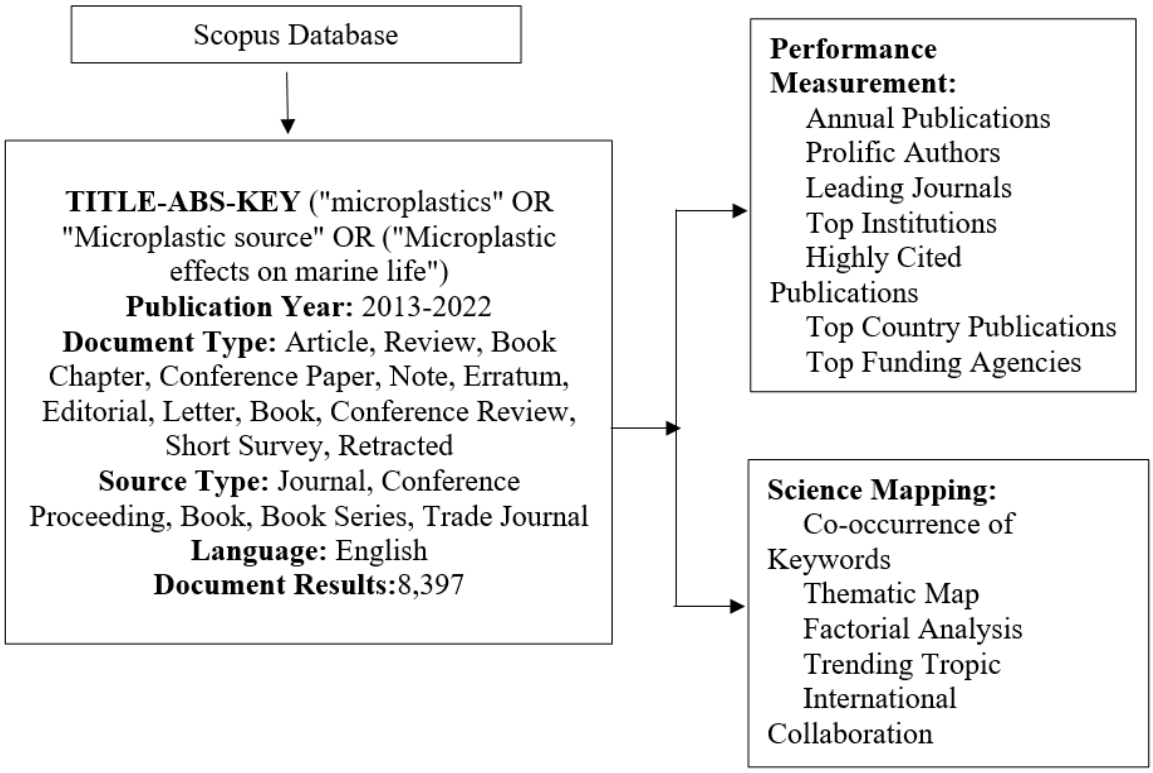

Figure 1: Workflow of the study.

Co-Occurrences of Keywords

The network visualization map, developed using VOS viewer, allows the study of keyword co-occurrence in research publications. The co-occurrences represent the number of articles in which each keyword is observed. The keywords were divided into clusters and the color of a keyword circle indicates its cluster affiliation. It formed 5 clusters: red, green, blue, yellow and purple. Out of 38,691 keywords, 9,574 met the threshold by taking the minimum number of at least 3 documents. From these 9,574 keywords, only 100 were selected for interconnected analysis, resulting in 5 clusters, 4,644 links and a total link strength of 150,638. Notably, the most frequently used keywords were 'microplastic' (7,365 times and 62,637 TLS), 'water pollutant' (3,902 times and 39452 TLS), 'particle size' (1,998 times and 21,415TLS) and 'polypropylene' (1,382 times and 15,155 TLS), as shown in Figure 3.

Thematic Map

A thematic map depicts typological themes using density (Y-axis) and centrality (X-axis). Figure 4 shows the map with three representative labels per theme. Centrality indicates topic importance, while density reflects development. Bubbles represent themes. The map consists of four quadrants:

- Motor themes (upper-right)
- Basic themes (lower-right)
- Emerging or declining themes (lower-left)
- Niche topics (upper-left)

In the upper-right quadrant, motor themes include microplastics, nanoplastics and adsorption, highlighting their importance and development in research. In the lower-right quadrant, microplastic, plastic pollution and pollution are basic themes, signifying significance but limited development. Moving to the upper-left quadrant, microplastic pollution, wastewater and abundance are niche themes. This quadrant shows highly specialized subjects designated by a high density but low centrality. Finally, in the underdeveloped themes section, plastics, ecotoxicology and human health represent themes indicating an emerging or declining status.

Factorial Analysis

The factorial analysis is used to map the conceptual structure of a framework using multiple correspondences of keywords. This study comprises 50 words and identifies 3 clusters of documents that reveal familiar concepts in Figure 5. The three clusters that emerged are red, blue and green. Cluster 1 (red) encompasses concepts such as microplastic, plastic, microplastics, environmental monitoring, plastics, article, water pollutants, water pollutants, chemicals, plastic waste, polymers, polyethylene, particle size, marine ecosystem pollution, microplastic pollution, water, Fourier transform infrared spectroscopy, humans, polypropylene, marine environment, concentration composition, unclassified drugs, sediment, polypropylenes, concentration parameters, humans, water pollution, chemistry, pollution and priority journals. Cluster 2 (blue) introduces concepts such as nonhuman, controlled studies, toxicity, animals, polystyrene, bioaccumulation and analysis. Cluster 3 (green) focuses on the word polystyrenes and polystyrene derivatives, which refer to the effects of microplastics on marine life.

Most Globally Cited Publications

The top 10 globally cited papers are shown in Table 4. It includes information on authors, specialized journals, year of publication, total citations and the average number of citations per year for each article. The paper entitled 'The physical impact of microplastics on marine organisms: a review' by Wright SL *et al.* (2013), published in *Environmental Pollution*, received the highest citations (2382), with an average of 216.55 citations per year and a total normalized citation of 3.59. It is followed by the article titled 'Microplastics in Freshwater and Terrestrial Environments: Evaluating the Current Understanding to Identify the Knowledge Gaps and Future Research Priorities' by Horton AA *et al.* (2017) and published in *Science of the Total Environment*, which received 1588 citations, with an average of 226.86 citations per year and a normalized total citation of 7.71.

The article 'Microplastic Ingestion by Zooplankton' by Cole M (2013), published in *Environmental Science and Technology*, secured the third rank with 1543 citations, an average of 140.27 citations per year and a normalized total citation of 2.32. Lastly, the article 'The impact of debris on marine life,' authored by Gall SC, obtained the lowest ranking on the list with 1147 citations, averaging 127.44 per year.

Research Trends

Figure 6 depicts the trend of microplastics as a topic of interest based on the author's keywords from 2013 to 2022. Furthermore, Year q1, year med and year q3 represent different periods. A

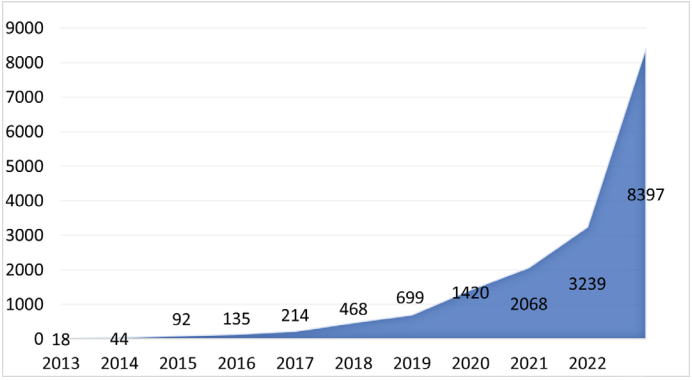

Figure 2: Annual trends of articles published from 2013 to 2022. Source(s): Figure by authors.

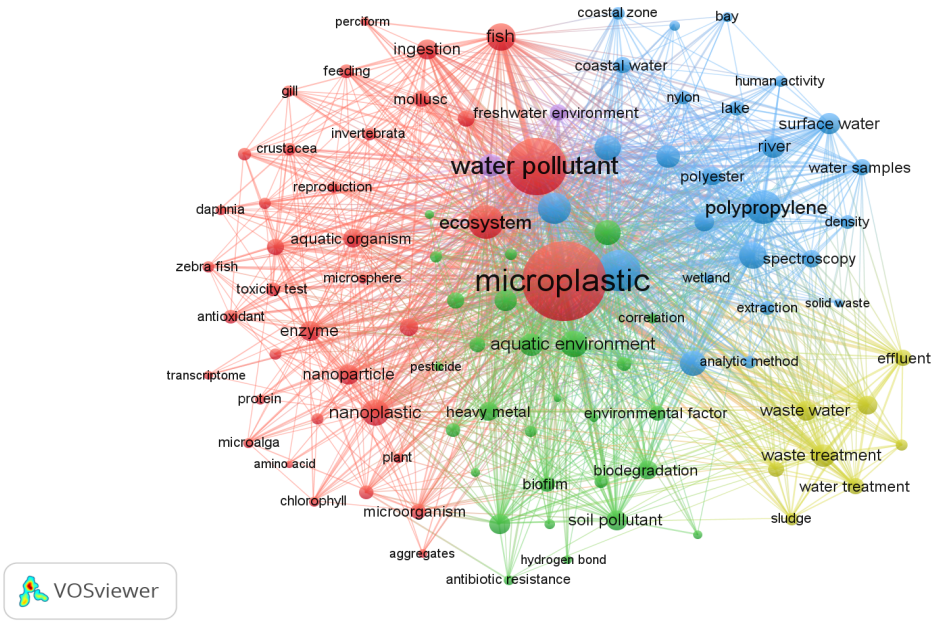

Figure 3: Keyword co-occurrence network. Source(s): Figure by authors.

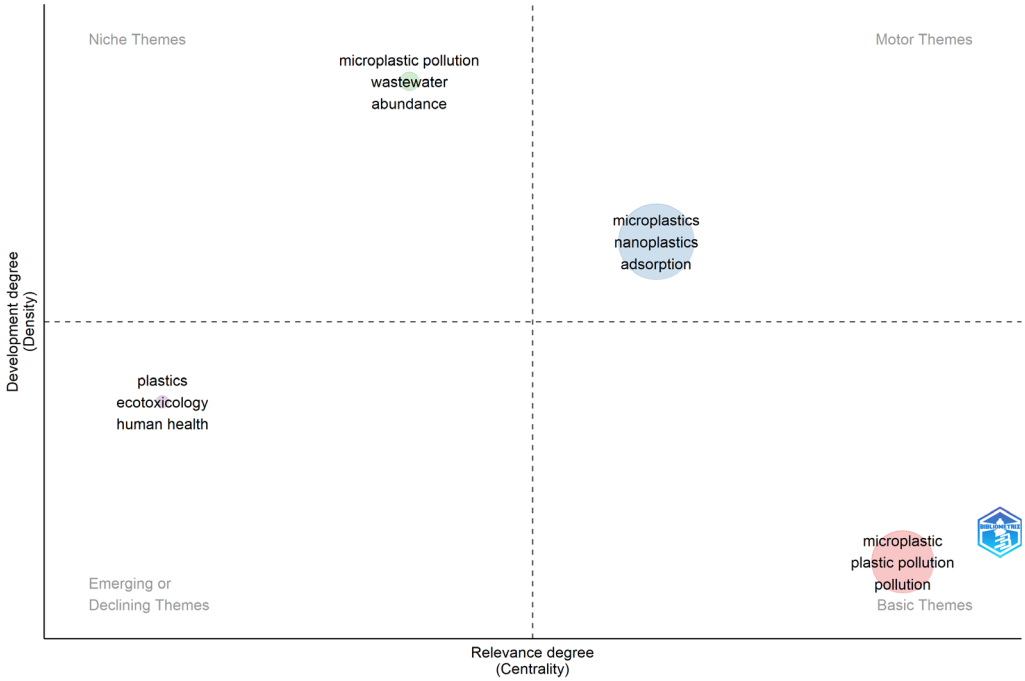

Figure 4: Thematic map representation of author keywords.

bubble represents a trending topic, indicating that at least one document on that topic was published in a given year. The bubble size is proportional to the number of articles published on that topic during the corresponding period. The figure reveals that ten keywords have trended for two to three consecutive years, while eight have trended for four to five years. The keyword 'mytilus edulis' appeared 6 times between 2014 and 2017, 'microbeads' appeared 51 times between 2018 and 2020 and 'polystyrene microplastics' appeared 71 times between 2021 and 2022, respectively.

Country Scientific Production

The scientific production of research on microplastic effects on marine life across various countries from 2013-2022 is displayed in Table 5. The analysis indicates the top 20 productive countries contributed significantly to this field. China emerged as the leading

Table 1: Prolific author's productivity.

Authors	NP	TC	*h*_index	*g*_index	PY_start
Zhang Y	270	11996	58	101	2016
Wang J	258	16979	71	124	2015
Li Y	192	7807	50	83	2018
Wang Y	190	6099	41	70	2015
Wang X	165	6301	43	74	2017
Liu Y	154	5461	42	69	2018
Li J	151	10468	48	101	2015
Wang Z	121	4544	38	64	2018
Zhao Y	112	7053	45	83	2016
Wang Q	111	4515	35	65	2018

NP= "Number of Publications", PY= "Publication Year" and TC= "Total Citations".

Table 2: Top journals preferred for publication.

Journals	Publisher	NP	TC	*h*_index	*g*_index	PY_start
Science of the Total Environment.	Elsevier	1292	70547	128	211	2014
Marine Pollution Bulletin.	Elsevier Inc.	960	60178	120	208	2013
Environmental Pollution.	Elsevier Ltd.	847	72137	145	237	2013
Journal of Hazardous Materials.	Elsevier	555	22399	79	113	2015
Chemosphere	Elsevier Ltd.	505	21677	74	125	2015
Environmental Science and Technology.	American Chemical Society	308	41483	102	201	2013
Environmental Science and Pollution Research.	Springer Science + Business Media	257	8937	47	85	2015
Water Research	Elsevier Ltd.	251	22593	72	147	2015
Ecotoxicology and Environmental Safety.	Academic Press Inc.	141	5553	41	71	2017
Frontiers in Marine Science.	Frontiers Media S.A.	131	3001	26	52	2014

NP= "Number of Publications", PY= "Publication Year" and TC= "Total Citations".

Table 3: Top 10 productive institutions.

Rank	Institution	Country	Articles (%)
1	East China Normal University.	China	745 (1.67%)
2	Nanjing University.	China	535 (1.20%)
3	Northwest A and F University.	China	419 (0.94%)
4	Beijing Normal University.	China	395 (0.89%)
5	Nankai University.	China	367 (0.82%)
6	South China Agricultural University.	China	367 (0.82%)
7	University Of Aveiro.	Portugal	361 (0.81%)
8	Tongji University.	China	350 (0.79%)
9	Zhejiang University.	China	339 (0.76%)
10	Ocean University of China.	China	336 (0.75%)

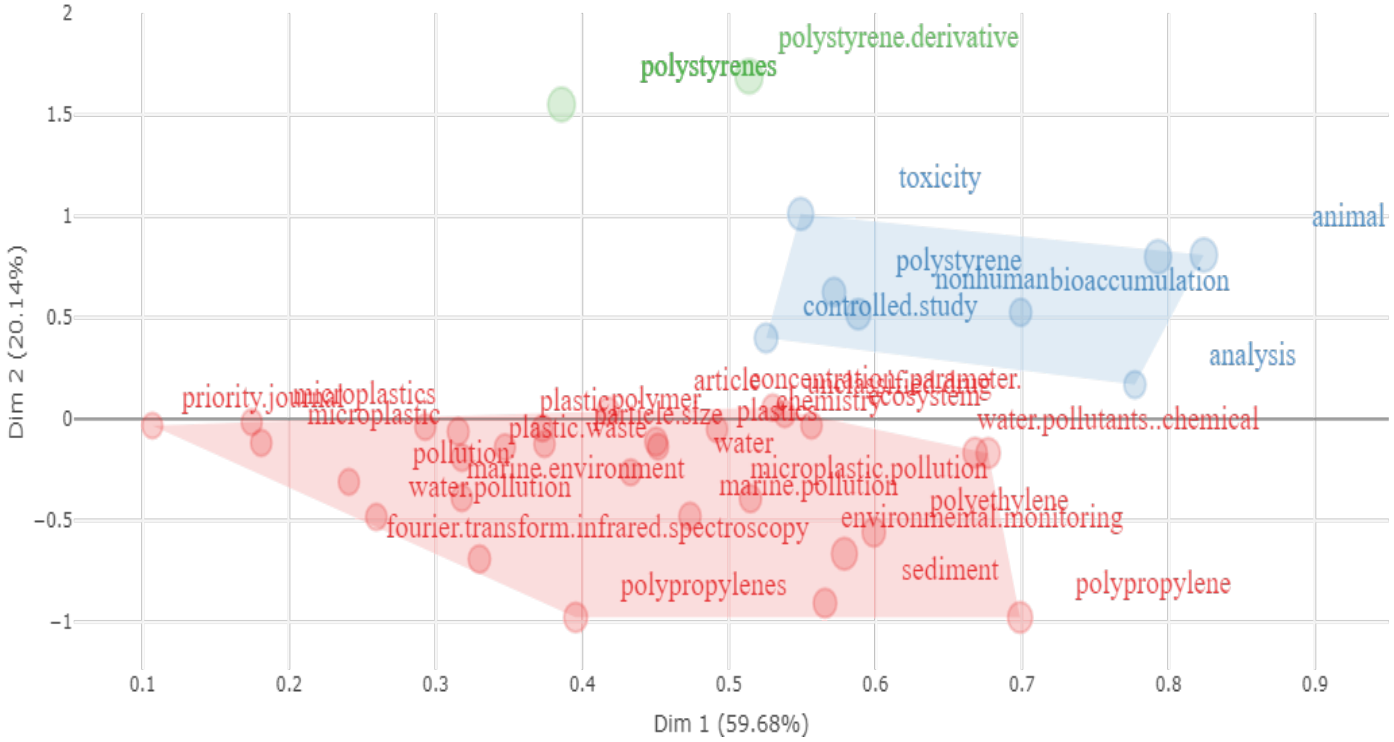

Figure 5: Factorial analysis map (keyword plus).

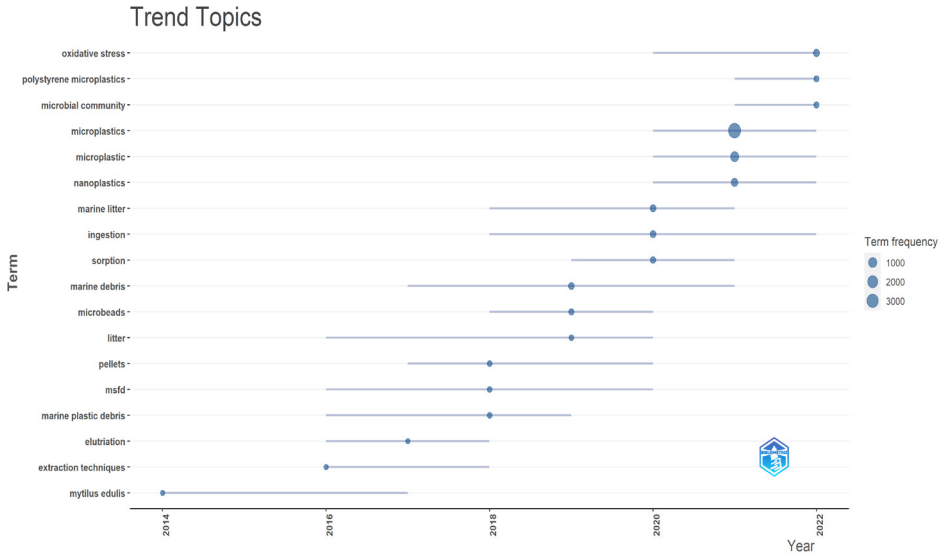

Figure 6: Trend topics (author's keywords). Source(s): Figure by authors.

contributor with an impressive 17313(37.02%) publications and 121,130 citations, followed by Italy with 2884(6.17%) publications and 17,527 citations. The USA secured the third position with 2300(4.92%) publications and 21,263 citations, while Germany follows closely behind with 2045(4.38%) publications and 23,690 citations. At the bottom of the list, Sweden has contributed the lowest number of publications, with 410(0.88%) publications and 3,960 citations. The analysis reveals China as the most productive country in terms of both publications and citations in the domain.

International Collaboration

The collaboration world map in Figure 7 shows the authors' country-based affiliation, with colors indicating the strength level of the relationship. Light colors represent a weak relationship, while dark colors indicate a stronger relationship. Gray indicates no connection. Mathematically, an edge in a network (or graph) refers to a connection between two nodes (or vertices). In this case, the countries serve as the nodes and the cooperation between them serves as the edges. The map reveals that the top 10 most frequent

Table 4: Top 10 highly cited papers.

Author	Title	Source	Year	Total Citations	TC per Year	Normalized TC
Wright S.L.	The physical impacts of microplastics on marine organisms: a review.	Environmental Pollution.	2013	2382	216.55	3.59
Horton A.A.	Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities.	Science of the Total Environment.	2017	1588	226.86	7.71
Cole M.	Microplastic Ingestion by Zooplankton.	Environmental Science and Technology.	2013	1543	140.27	2.32
Eerkes-Medrano D.	Microplastics in freshwater systems: a review of the emerging threats, identification of knowledge gaps and prioritisation of research needs.	Water Research.	2015	1458	162	4.64
Wright S.L.	Plastic and Human Health: A Micro Issue?	Environmental Science and Technology.	2017	1292	184.57	6.27
Auta H.S.	Distribution and importance of microplastics in the marine environment: A review of the sources, fate, effects and potential solutions.	Environment International.	2017	1249	178.43	6.07
Lusher A.L.	Occurrence of microplastics in the gastrointestinal tract of pelagic and demersal fish from the English Channel.	Marine Pollution Bulletin.	2013	1223	111.18	1.84
Alimi O.S.	Microplastics and Nanoplastics in Aquatic Environments: Aggregation, Deposition and Enhanced Contaminant Transport.	Environmental Science and Technology.	2018	1169	194.83	8.2
Van Cauwenberghe L.	Microplastics in bivalves cultured for human consumption.	Environmental Pollution.	2014	1166	116.6	3.02
Gall S.C.	The impact of debris on marine life.	Marine Pollution Bulletin.	2015	1147	127.44	3.65

TC= "Total Citations".

research collaborations involve China and the USA (221 articles), followed by China and Australia (131 articles), China and Hong Kong (76 articles), China and the UK (65 articles), China and Canada (61 articles), China and Korea (55 articles), Spain and Portugal (55 articles), the USA and Canada (54 articles) and the USA and the UK (53 articles). Among these collaborations, the least frequent was between China and Germany, with 49 articles.

Funding Agencies

A total of 160 funding agencies have been identified in the Scopus database. Table 6 lists the top 10 highly productive

Table 5: Top 20 country-wise scientific production.

Country	Articles	TC	Country	Articles	TC
China	17313(37.02%)	121130	Canada	1013(2.17%)	12506
Italy	2884(6.17%)	17527	Brazil	963(2.06%)	7379
USA	2300(4.92%)	21263	Portugal	963(2.06%)	12274
Germany	2045(4.38%)	23690	Indonesia	638(1.37%)	1670
Spain	1810(3.87%)	11698	Netherlands	617(1.32%)	14587
India	1531(3.28%)	8332	Japan	606(1.30%)	3032
United Kingdom	1529(3.27%)	29936	Iran	517(1.11%)	5590
France	1365(2.92%)	14602	Norway	484(1.04%)	4773
South Korea	1240(2.66%)	10841	Turkey	435(0.93%)	2254
Australia	1152(2.47%)	11560	Sweden	410(0.88%)	3960

TC= "Total Citations".

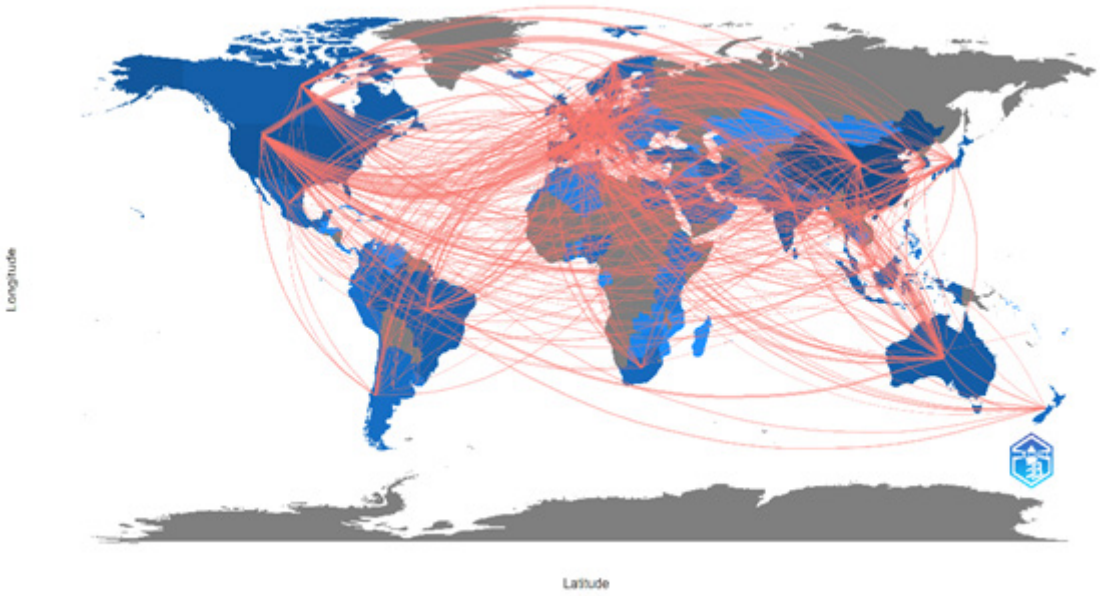

Figure 7: Top ten most collaborative countries.

funding agencies based on the number of research projects they have financed. The National Natural Science Foundation of China (China) contributed the highest number of publications, with 1842(17.10%), followed by the National Key Research and Development Program of China (China) with 556 (5.16%) publications and the Fundamental Research Funds for the Central Universities (China) with 215 (2.00%) publications. Among the top 10 agencies, the Bundesministerium für Bildung und Forschung (Germany) has the lowest number of publications, with 138 (1.29%). It has been observed that the top funding agencies are from China, Portugal, Belgium, South Korea, Switzerland and Germany.

DISCUSSION

This comprehensive analysis provides valuable insights into the research landscape concerning the effects of microplastics on marine life. The results reveal critical information, including publication trends, most productive authors, leading journals, prolific institutions, thematic structures and global collaborations.

The increasing trend in scientific publications over the past decade reflects the growing concern and interest in microplastic pollution and its impacts on marine ecosystems. Identifying prolific authors and institutions provides valuable information about the leading contributors to this field of research. Authors such as Zhang Y and Wang J have made substantial contributions, indicating their expertise and influence in the field. Similarly, institutions like East China Normal University and Nanjing University have emerged as key hubs of research activity in this

Table 6: Top 10 funding agencies.

Rank	Funding Agency	Country	NP (%)
1	National Natural Science Foundation of China.	China	1842(17.10%)
2	National Key Research and Development Program of China.	China	556(5.16%)
3	Fundamental Research Funds for the Central Universities.	China	215(2.00%)
4	Chinese Academy of Sciences.	China	187(1.74%)
5	Fundação para a Ciência e a Tecnologia	Portugal	175(1.63%)
6	European Regional Development Fund.	Belgium	173(1.61%)
7	European Commission.	Belgium	161(1.50%)
8	National Research Foundation of Korea.	South Korea	154(1.43%)
9	Horizon 2020 Framework Programme.	Switzerland	146(1.36%)
10	Bundesministerium für Bildung und Forschung.	Germany	138(1.29%)

NP= "Number of Publications".

domain. The concentration of research output in institutions from China highlights the country's investment in scientific research and its commitment to addressing environmental issues. Collaboration among researchers from different countries can facilitate knowledge exchange and accelerate scientific progress.

The preference for specific journals, such as Science of the Total Environment, Marine Pollution Bulletin and Environmental Pollution, highlights the significance of this research topic. These journals serve research findings and shape scientific discourse and policymakers.

The co-occurrence of keywords and thematic analysis provides valuable insights into the key themes and emerging trends within the literature. The keywords such as "microplastic," "water pollutant," and "particle size" focus on understanding microplastic contamination in marine life. Furthermore, thematic mapping highlights the dynamic nature of research themes such as microplastic pollution, nanoplastics and adsorption, which emerge as central areas of investigation of the research. Additionally, factorial analysis highlights the conceptual structure of research, identifying distinct clusters of keywords and their interrelationships. It provides a comprehensive overview of the underlying frameworks guiding research in this field.

The analysis of globally cited publications highlights seminal contributions to the literature, such as the review by Wright *et al.* (2013) on the physical impact of microplastics on marine organisms. These highly cited papers are foundational works that have influenced the research directions and policies. Research trends identified through the author's keyword analysis offer insight into emerging research areas and priorities.

Lastly, examining funding agencies shows the financial support structures for research in this field. The dominance of Chinese funding agencies reflects strategic investments in addressing environmental challenges and promoting scientific innovation.

CONCLUSION

This study provides a comprehensive overview of research trends, collaboration patterns and thematic developments in microplastics and their effects on marine life. The findings highlight the growing scientific interest in addressing this environmental issue and emphasize the potential for collaboration and knowledge sharing among researchers, policymakers and stakeholders. By addressing knowledge gaps, promoting interdisciplinary collaboration and informing evidence-based policies, the scientific community can play a crucial role in mitigating the effects of microplastics and protecting the health of marine ecosystems for future generations.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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