Environmental Science and Pollution Research (2022) 29:84312–84324
https://doi.org/10.1007/s11356-022-20872-0

RESEARCH ARTICLE

Scientometric analysis and identification of research trends in microplastic research for 2011–2019

Deepika Sharma[1] · Shreya Jaiswal[1] · Gurjot Kaur[1]

Received: 29 July 2021 / Accepted: 12 May 2022 / Published online: 2 July 2022

Abstract

Microplastic pollution of our environment has seen major data reporting in the last decade. Microplastics produce harmful effects on marine organisms and in humans. Despite the fact that microplastics (MPs) have inert or sublethal toxicity in many circumstances, their long-term presence can have negative ecological consequences. However, there is a paucity of comprehensive literature on the present study and future development trend of MPs in aquatic ecosystems, to our knowledge. In this scientometric study, the literature was evaluated between years 2011 and 2019. The data show increasing importance of microplastics in terms of increase in publication in concurrence of granting funds in this area by major funding agencies. Most research articles were published by authors (~49%) affiliated with Chinese Academy of Sciences. Journals '*Marine Pollution Bulletin*' and '*Environmental Pollution*' were identified as important journals with 273 and 185 research publications, respectively. We have also identified the upcoming research trend and shift from microplastic presence in water to microplastic presence in air. However, in the year 2017, researchers from the UK started publishing more articles in this field with 11 publications with top authors affiliated to University of Plymouth. The journal *Environmental Pollution* has been found to be the leading journal (~20%) addressing the issue of microplastics in the environment. Our co-authorship analysis demonstrated that China (its institutions and authors) is the most collaborative country followed by the USA, together forming top cluster with a link strength of 42. Finally, our analysis provides information about prospective research and emerging trends that can be explored in the coming years.

Keywords Microplastic research · Publication analysis · Scientometry · Co-authorship analysis

Introduction

Microplastics (MPs) are micro-sized synthetic polymer particles that are extremely persistent contaminants of our ecosystem. The direct (physical and chemical) and indirect (organic pollutant leaching from the MP surface) effects of MPs on an organism can be harmful as already shown (Bakir et al. 2012; Catrouillet et al. 2021; Rios et al. 2007; Teuten et al. 2009). MP accumulation has been reported in freshwater, seawater, and terrestrial systems usually through release into the sewage from urban overspills and industrial processes (Bashir et al. 2021; Browne et al. 2011; Lattin et al. 2004; Polis et al. 1997; Thompson et al. 2009; Wagner et al. 2014).

Ingestion of MPs changes biological behaviour such as feeding, reproduction, growth, development, and lifespan of marine organisms (Au et al. 2015; Botterell et al. 2019; Cole et al. 2011; Du et al. 2021; Guzzetti et al. 2018). Similar reports of inflammation and oxidative stress upon MP exposure are now available in humans especially due to heavy usage of synthetic polymers; however, the field is still in its early phase of development (Blackburn & Green 2021; Burgess et al. 2017; Carbery et al. 2018; Dong et al. 2020; Schirinzi et al. 2017). Personal care products such as toothpastes, scrubbers, and glitters are considered sources of microplastics, due to unavoidable usage and result in accumulation of MPs in our environment (Bashir et al. 2021; Praveena et al. 2018; Ustabasi & Baysal 2019).

Recent reports have demonstrated retention of MPs, especially MPs 1–10 μm human A549 human adenocarcinoma lung epithelial cells, resulting in inhibition of cell growth,

Responsible Editor: Philippe Garrigues

✉ Gurjot Kaur
gurjotkaurbains@yahoo.co.in

[1] School of Pharmaceutical Sciences, Shoolini University, Bajhol, Solan 173212, India

alterations in cell shape, oxidative stress, reduction in mucus layer, and even digestive tract disturbance (Goodman et al. 2021; Huang et al. 2021). The ingestion of MPs having sizes between 1 and 10 µm may accumulate in the human body, and due to limited biliary excretion, higher particle concentration may be reached in the gut (Mohamed Nor et al. 2021). Makhdoumi et al. recently showed that PET (polyethylene terephthalate) water bottles contain MPs in the form of fibre (7%) and fragments (93%), with the concentration 8.5 ± 10.2 particles/l (Makhdoumi et al. 2021). A recent toxicological study demonstrated that the small MPs (< 20 mm) do cause oxidative stress and inflammation, while particles < 5 mm can be engulfed by cells and translocated to the respiratory system, the digestive system, and in the skin (Ageel et al. 2022). In addition, MPs caused lymphocyte cytotoxicity and genomic instability at 25, 50, 100, 250, and 500 mg/ml having sizes 10–45 µm, concentrations (Çobanoğlu et al. 2021). Some MP detection studies were also recently reported. Surface absorption via nano-Fe_3O_4-associated magnetization of MPs (Shi et al. 2022), electrocoagulation (Shen et al. 2022), use of natural bioflocculant lysozyme amyloid fibrils (Peydayesh et al. 2021), and coagulation with aluminium hydroxide (Cherniak et al. 2022) are recently reported to effectively remove MPs from water samples.

Therefore, to assess the importance of MPs as a research area and identify the research direction, we analysed the present scientific literature using common scientometric indicators. As scientometric analysis can predict the research performance and involvement of different countries in tackling microplastic pollution, it also highlights the world leaders in this regard.

Methods

Data acquisition and scientometric analysis

We selected SCOPUS as a valid source for retrieval of data used for this scientometric analysis. SCOPUS is one of the main international databases for medical/health sciences, and the terminology included in its thesaurus can be used to search for published research documents on specific research areas. A search with words 'microplastics water pollution' as a descriptor was performed for the years 2011–2019 to retrieve publications that contained these words in publications' titles, keyword lists, and abstracts, a selection criterion in the SCOPUS search box. To avoid discrepancies, we examined the publications by using author ID, PubMed ID, and DOI. The steps were taken to ensure uniformity in the representation of the data and provide better accuracy in records.

To refine the search results to original scientific publications only, document type articles or reviews were selected. Other document types such as book chapter, data paper, proceedings, and abstracts were not included. Once the search was complete, all the documents were selected and data for citation information such as author(s), document title, year, source title, volume, issue, pages, bibliographical information such as affiliations, PubMed ID, DOI, abstract, and keywords, and funding details was exported as CSV files.

The electronic search was performed on 29 November 2019, and record of articles (original and review) with a total of 947 publications was retrieved. No restriction based on language of articles was made although only a small percentage of total articles was non-English (< 5%). Refined search with word combination 'microplastics air pollution' with document type 'article or review' was also performed to assess the reporting of scientific advancement in microplastics in air pollution. Search resulted in 41 articles. This refined search for the years 2011–2019 was performed to identify the forthcoming trends in microplastics pollution in these recent years. Indicators, publications between 2011 and 2019, journal wise publications, country-wise publications, top funding agencies, top research institutions, and top ten publications based on citations and most prolific authors were obtained by analysis of raw data in the CSV files and plotted into graphs or indexed in tables. For example, the total number of publications was plotted against the years from 2011 to 2019 as shown in Fig. 1. In the similar way, author affiliations and funding agencies were plotted against the total number of publications for these years.

The data for number of publications in top ten journals were plotted in the pie chart, and percentage proportions were calculated to give a percentage-based evaluation in comparison to total publications. Data for country-wise publications were plotted in the map using the Maps tool of MS Excel, and top ten countries were colour graded (dark to light blue) to visualize the number of research publications for the countries. The networking analysis was done based on different countries, organizations, and authors. The data were selected according to the collaboration of countries, organizations, or authors with each other.

Visualization and representation of bibliometric networks were done through VOSviewer, wherein network visualization and mapping were performed with the original CSV data files containing the required bibliometric data. Minimum number of documents were fixed to threshold values at which number of countries, organizations, and authors lead to the minimum collaboration followed by manually set to top ten authors/organizations/countries, respectively, to attain optimal results. A network graph was generated after analysis and visualization by the software Pajek. Briefly, files obtained from VOSviewer were used to generate network graph in the Pajek program. Parameters like minimum

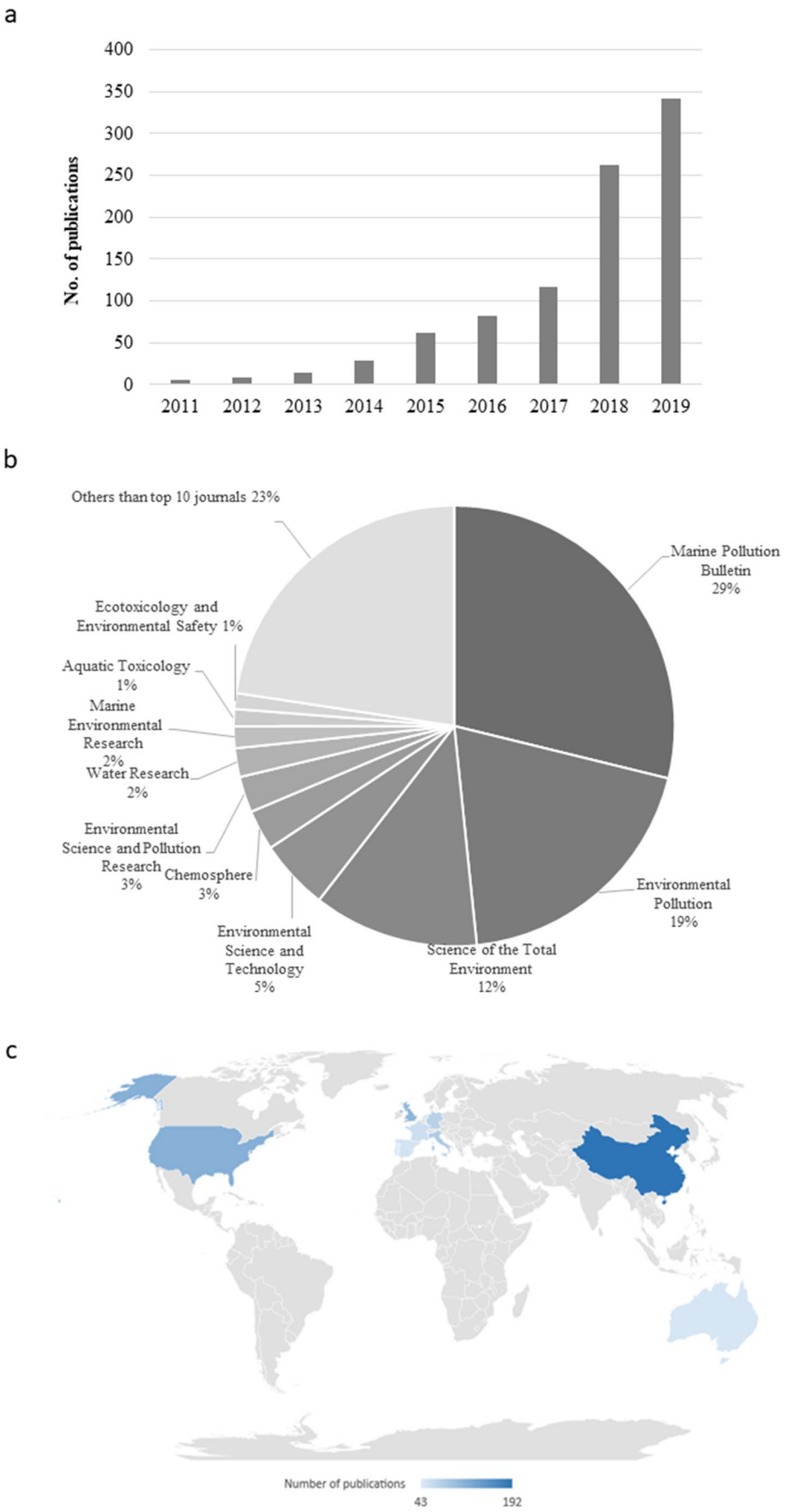

Fig. 1 Publication metrics for journals and countries. **a** Publications per year. Year-wise publication count for search term 'microplastics water pollution' between 2011 and 2019 in original research articles and review articles is obtained and plotted into a bar graph. **b** Journal-wise publications. The pie chart of top ten journals with their percentage proportions are obtained by indexing publications based on publishing journal for the search term 'microplastic water pollution' for the years 2011–2019. **c** Publications per country. Country-wise number of publications for search term 'microplastics water pollution' was collected and plotted into a map chart using the Maps tool of MS Excel for the years 2011 to 2019

number of documents and number of authors/organizations/countries were set manually limiting to top 10 to obtain optimal results.

In the visualized network graph, lines represent connection between countries/organizations/authors, while the linewidth indicates the strength of their association. Circle represents a particular country, organization, or author, and the size of the circle represents the number of documents and citations. The colour of the circles represents the cluster that is identified to work together through the literature analysis.

Results and discussion

An analysis of SCOPUS database for the years 2011–2019 using research and review publications for search terms 'microplastics water pollution' and 'microplastics air pollution' was performed. The numbers of publications are categorized according to funding agencies, author affiliations, publications per year, and journals on the topics. This type of scientometric analysis has not been performed previously for the microplastic research field.

Microplastics in water pollution

An analysis of the total number of publications between the years 2011 and 2019 using the search term 'microplastics water pollution' demonstrated that while only 6 research publications (reviews and research articles) were published in the year 2011, an increase in the number of publications was observed over the years. A significant rise in the publication was observed for 2017 with 117 publications. In 2019, 342 published articles were retrieved, the highest number of articles to date in the field. Interestingly, the rise in research publications has been sharper after 2015 (62 publications) (Fig. 1a).

The publication trend in the years 2011 (6 publications) and 2012 (9 publications) displays that these years were the initial stages for research on microplastics in water pollution. A review titled 'Microplastics in the marine environment' published in the year 2011 is indexed as the top article with the most citations (1240) during 2011–2019 (Table 1). The high number of citations of this article indicates its role in shaping the research associated with MP detection in seawater and effects on marine life. This publication and few more publications in the years 2011–2014 helped define the field resulting in a massive increase in publications in the next 4 years (2015–2019) (Table 1). In all years, a rise was observed in publications per year indicating increasing number of scientist and their contributions in the field culminating into 342 research publications in 2019. We expect this number to further rise exponentially in the coming decade.

Indexing of the total number of publications according to journals for the search term 'microplastic water pollution'

Table 1 List of the top articles published during 2011–2019 based on citation count. Listed are top ten articles published during the selected years. Type of article, year of publishing, and total citations as on 22–11-2019 are also given

Article	Type	Year of publishing	Citation count
Andrady, Anthony L. Microplastics in the marine environment. *Marine Pollution Bulletin* 62.8: 1596–1605	Review	2011	1240
Cole, Matthew, et al. Microplastics as contaminants in the marine environment: a review. *Marine Pollution Bulletin* 62.12: 2588–2597	Review	2011	976
Eriksen, Marcus, et al. Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. *PloS one* 9.12: e111913	Research	2014	852
Hidalgo-Ruz, Valeria, et al. Microplastics in the marine environment: a review of the methods used for identification and quantification. *Environmental Science & Technology* 46.6: 3060–3075	Review	2012	814
Lusher, A. L., Matthew Mchugh, and R. C. Thompson. Occurrence of microplastics in the gastrointestinal tract of pelagic and demersal fish from the English Channel. *Marine Pollution Bulletin* 67.1–2: 94–99	Research	2013	495
Eerkes-Medrano, Dafne, Richard C. Thompson, and David C. Aldridge. Microplastics in freshwater systems: a review of the emerging threats, identification of knowledge gaps and prioritisation of research needs. *Water Research* 75: 63–82	Review	2015	419
Eriksen, Marcus, et al. Microplastic pollution in the surface waters of the Laurentian Great Lakes. *Marine Pollution Bulletin* 77.1–2: 177–182	Research	2013	413
Van Cauwenberghe, Lisbeth, and Colin R. Janssen. Microplastics in bivalves cultured for human consumption. *Environmental Pollution* 193: 65–70	Research	2014	410
Claessens, Michiel, et al. Occurrence and distribution of microplastics in marine sediments along the Belgian coast. *Marine Pollution Bulletin* 62.10: 2199–2204	Research	2011	406
Gall, Sarah C., and Richard C. Thompson. The impact of debris on marine life. *Marine Pollution Bulletin* 92.1–2 (2015): 170–179	Research	2015	389

demonstrated that the journal '*Marine Pollution Bulletin*' published the highest number of research publications (273 research publications) as shown in Fig. 1b. '*Environmental Pollution*' ranked second with 185 research publications and '*Science of the Total Environment*' ranked third with 115 publications. The *Environmental Science and Technology* journal also made it to top ten with 49 research publications. Based on the analysis of journal category, it is possible to describe which journal is publishing the most articles in that particular field. Interestingly, '*Marine Pollution Bulletin*' with impact factor 3.750 published 273 publications in the field of microplastics in water pollution than '*Environmental Pollution*' with impact factor 6.792 (185), its closest rival (Fig. 1b). Although these journals published a considerable fraction of research articles in the field, none of their publications made it to the top ten publications of 2011–2019 (Table 1).

The total number of publications per country for search term 'microplastics water pollution' for the year 2011–2019 demonstrated that China led with 192 research publications. The USA ranked second with 117 research publications, and the UK ranked third with 110 research publications, while Portugal ranked the last among top ten countries with 43 research publications. There is a considerable difference in the number of research publications between the first and the last countries on the list (Fig. 1c; Suppl Table 4). The highest number of publications by research scientists of China indicates higher awareness among Chinese scientists about the presence of microplastics in water. The number of articles published by China was four times greater than Portugal. Data supports that a contribution by many countries is being made in this field in the recent years and there is an increase in their involvement in the research on microplastic water pollution.

The highest number of research publications (177 research publications) was sponsored by the four funding agencies of China in the field of 'microplastic water pollution' during 2011–2019. The National Natural Science Foundation of China (NNSFC) supported 109 research publications, while its closest competitor, the National Basic Research Program of China (NBRPC), financially supported only 32 publications in the field. In addition, while 34 publications were sponsored by two funding agencies of the European Union (ERDF and EC) and 29 were sponsored by Fundação para a Ciência e a Tecnologia (FPCT) Portugal, only 9 research publications were sponsored by the Germany-based funding agency Bundesministerium für Bildung und Forschung or BFBUF (Fig. 2a). Interestingly, most research was sponsored by Chinese agencies (177 research publications) as compared to all other agencies together (115 research publications). This confirms an active role and support of Chinese funding agencies in the field. Figure 2b shows the affiliation-wise research articles

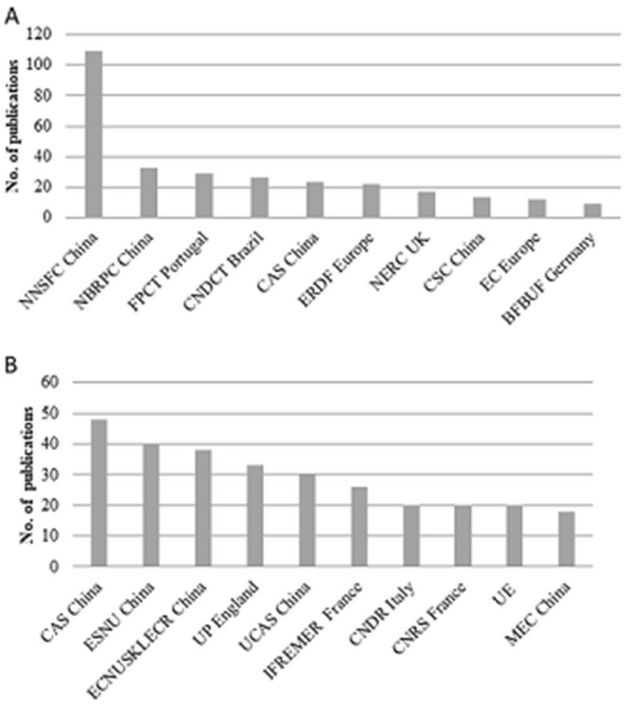

Fig. 2 The top ten funding agencies and author affiliations in the field during 2011–2019. **a** Research publications were indexed based on their sponsoring agencies as listed in individual publications. Full names of funding agencies are mentioned in Supplementary Table 1. **b** Top ten author affiliations obtained using search term 'microplastic water pollution'. Full author affiliations are mentioned in Supplementary Table 2

count. While 48 research articles were published by authors affiliated with the Chinese Academy of Sciences, 40 research articles were published by authors affiliated with East China Normal University. Thirty-three and twenty-six research articles were published by the authors affiliated to the University of Plymouth and the University of France, respectively. The analysis resulted in a total of 174 research articles published by authors affiliated with the different Institutes of China, i.e. CAS China, ESNU China, UCAS China, and MEC China (Fig. 2). Data shows that the highest numbers of authors were affiliated with Chinese Academy of Sciences (48 research publications), while the authors affiliated to the Ministry of Education China contributed 18 research publications.

Co-authorship of a publication is the involvement of two or more countries, authors, or organizations for any research article. Total link strength signifies the bond between different authors with other researchers from other parts of the world. Figure 3a shows the co-authorship cluster between the research departments or laboratories/organizations on microplastic water pollution between 2011 and 2019. It is based on analysis of collaboration of authors of different laboratories/organizations in the world. Publication count

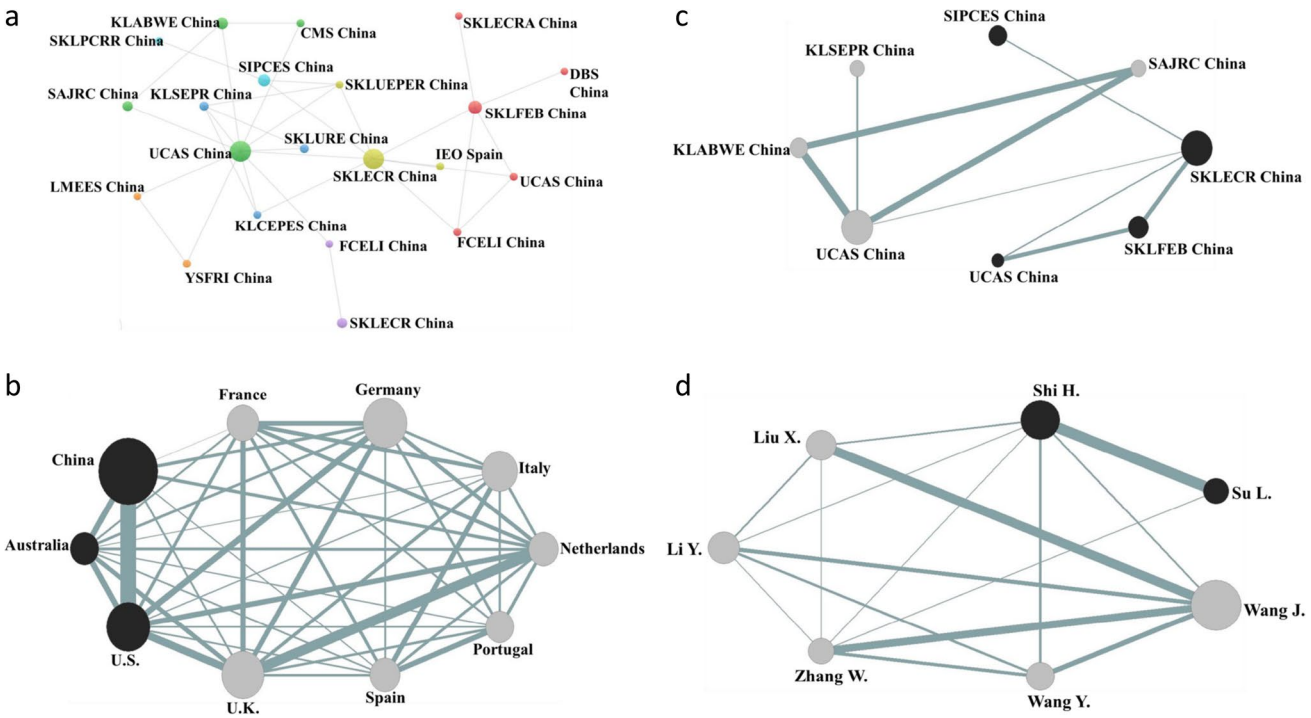

Fig. 3 Scientific collaborations. **a** Collaborations between top 35 research laboratories/organizations. 21 research laboratories/organizations showed the largest network. The full names of the research laboratories/organizations are listed in Supplementary Table 3. **b** Collaborating countries. **c** The top 8 collaborating organizations. Visualizations were performed using VOSviewer and Pajek based on citation, number of documents, and total link strength with the direct collaborators shown as part of one-color cluster. **d** The co-authorship analysis based on authors. Top 10 authors were selected from which only 7 showed collaboration and participation in cluster/s as shown in the figure

varied from 38 to 5 documents, whereas citation count ranged from 1784 to 9. Centro de Estudios Avanzados en Zonas Áridas or CEAZA, Chile, is the top cited organization having 7 published documents with citation count of 1784 and total link strength of 10, but this organization is not visible in the cluster as it has not collaborated with other laboratories/organizations. Therefore, State Key Laboratory of Estuarine and Coastal Research, East China Normal University or SKLECR, China, with 37 published documents, citation count of 1423, and link strength of 18 formed the largest cluster and showing its connection with UCAS, China, majorly and also with many other laboratories/organizations. The figure shows that 21 organizations have varying connections with each other in general with UCAS, China, having maximum connections of link strength of 36. It was noted that changing the parameter of the selected number of organizations limiting to only top 10 organizations decreased the link strength from 36 to 24 previous link strength with 35 organizations.

Figure 3b shows co-authorship analysis based on countries. China is leading with 396 documents with the citation count of 6022 and total link strength of 82, followed by the USA with 221 documents, 8455 citation count, and total link strength of 123. Germany is closely following with 216 documents, 7188 citation count, and total strength link of 84, followed by the UK having the most citation count of 11,803 having 200 documents with link strength of 105. Our cluster analysis is based on only top 10 countries having maximum citation and research documents. In this networking, top 10 published documents ranging from 396 to 92 were selected along with citation range from 11,803 to 2393 and total range of link strength from 123 to 52 as mentioned in Table 2 (a). Figure 3b shows the collaboration between top research laboratories/organizations. It should be noted that some of them have strong connections with some laboratories but no connections with any other research laboratories. The University of Chinese Academy of Sciences, China or UCAS had the strongest connection with two organizations, viz. KLABWE, China, with 12 published documents (306 citation count and link strength of 20) and SAJRC, China, with 9 published documents (294 citation count and total link strength of 18). UCAS has 38 research documents with 617 citations and total link strength of 24 followed by SKLECR, China, with 37 published documents with 1423 citation and link strength of 11 followed by other research laboratories/organizations. CEAZA, Chile, has the highest citation count, i.e. 1784, but it is not visible in

Table 2 The top 10 countries and organizations based on total link strength, number of citations, and numbers of documents are listed. The data is visualized in Fig. 6

a

S. no	Country	Documents	Citations	Total link strength
1	USA	221	8455	123
2	UK	200	11,803	105
3	Netherlands	102	4248	94
4	Germany	216	7188	84
5	China	396	6022	82
6	France	118	5874	73
7	Australia	96	3283	69
8	Spain	103	2393	64
9	Italy	145	3497	56
10	Portugal	92	3369	52

b

S. no	Research laboratories	Documents	Citations	Total link strength
1	UCAS China	38	617	24
2	KLABWE China	12	306	20
3	SAJRC China	9	294	18
4	SKLFEB China	16	549	12
5	SKLECR China	37	1423	11
6	UCAS China (different address)	6	242	8
7	CEAZA Chile	7	1784	6
8	ESMOI Chile	7	994	6
9	KLSEPR China	8	143	3
10	SIPCES China	13	85	2

the cluster, as there was no collaboration with other laboratories/organizations. In this networking, top 10 published documents ranging from 38 to 6 were selected along with citation range from 1784 to 85 and range of link strength from 24 to 2 as mentioned in Table 2 (b).

The co-authorship analysis in Fig. 2d is based on the authors who contributed majorly on the topic of microplastic water pollution. The cluster demonstrated that author Wang J. has the greatest number of published collaborative documents, i.e. 57 with citation count of 1080 and total link strength of 33, followed by Shi H. having 34 published documents with 1341 citation count and total link strength of 22. In addition, the network cluster shows that few authors have more network connection as well as citations than others. Wang J. has a strong network as is visible with his line connection with three other authors (Fig. 3d; Suppl Table 5). The network consisted of the top 10 authors ranging from 57 to 15 publications along with citations ranging from 1341 to 81 and link strength from 33 to 12 as mentioned in the table in Fig. 3d.

Upcoming research trend: microplastics in air pollution

During our extensive literature analysis, we came across recent publications on microplastic presence in air. As MPs are micro-sized particles that could easily be present in air (as dust) and inhaled by workers during manufacturing and processing in industry, we assessed whether this could be an upcoming research trend. We performed a SCOPUS data collection with search term 'microplastic air pollution' and analysed the obtained results.

A significant change is observed for the number of publications obtained using the search term 'microplastic air pollution' for the indicated time period. While for the years 2011, 2014, and 2015, only one article was published, no article linking microplastics to air pollution were published in 2012, 2013, and 2016. A rapid increase in the number of publications per year is observed after 2016; i.e., 7 research articles were published in 2017, 8 research articles in 2018, and 23 research articles in 2019 (Fig. 4a). As is visible from the data in Fig. 4a, microplastics have not been previously studied in the context of air pollution. One article was published in 2011 titled 'Presence and partitioning properties of the flame retardants pentabromotoluene, pentabromoethylbenzene and hexabromobenzene near suspected source zones in Norway' that showed brominated flame retardants used as fireproof-plastics, having the same properties of the organic pollutants. This paper described the presence of these pollutants in air coupled to low-density solids such as microplastics (Arp et al. 2011). Similarly, 2014 and 2015 also showed 1 publication each in this research area. The article titled

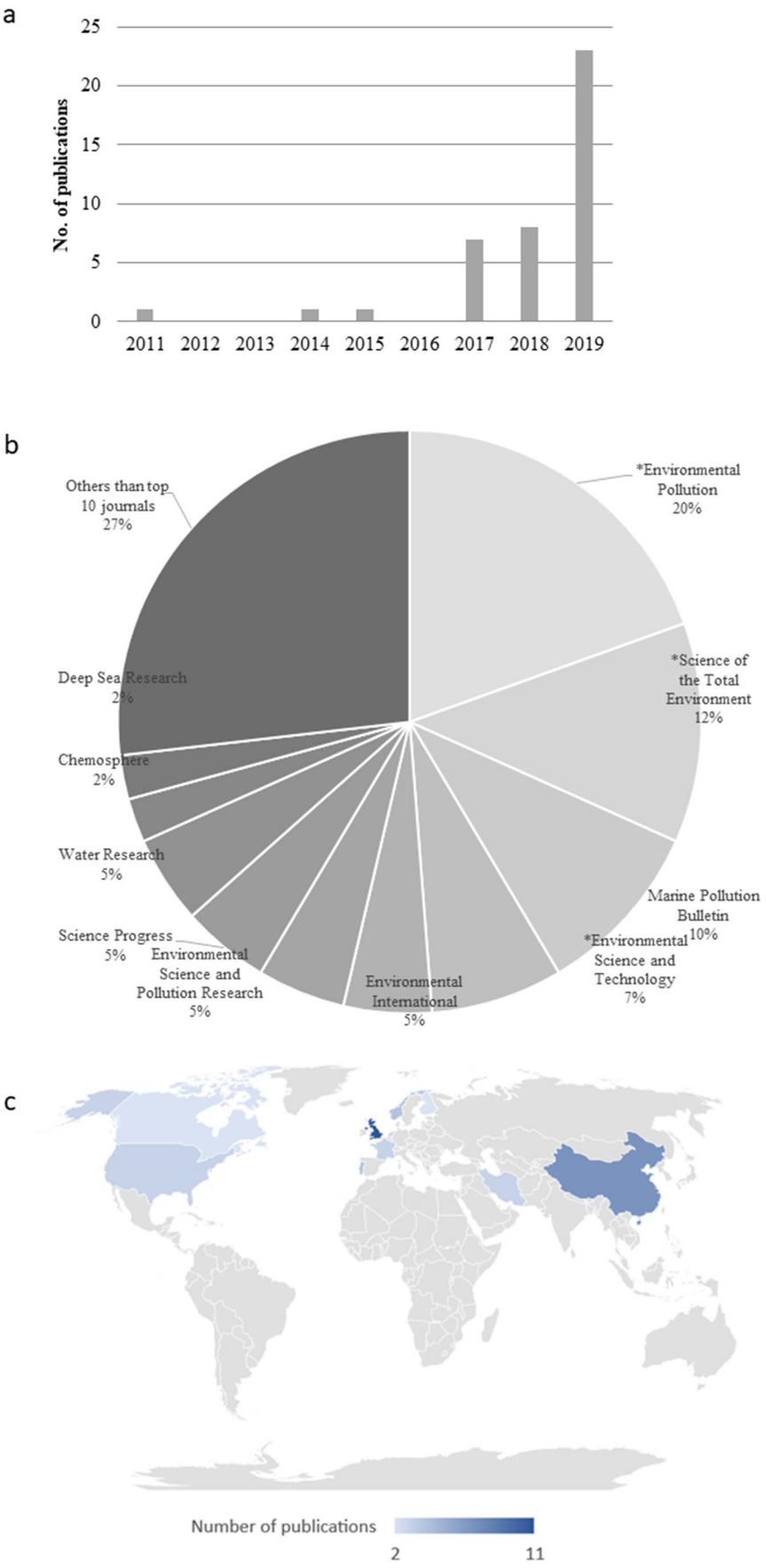

Fig. 4 Publication metrics for journals and countries for microplastic air pollution. **a** Publications per year. Year-wise publication count for search term 'microplastics air pollution' between 2011 and 2019 in original research articles and review articles was obtained and plotted into a bar graph. **b** Journal-wise publications. The pie chart of top ten journals with their percentage proportions are obtained based on publishing Journal for the search term 'microplastic air pollution' for the years 2011–2019. *Journals that were common between top ten journals for both the search terms. **c** Country-wise publications. Top ten countries were identified on the basis of publication count for search term 'microplastic air pollution' for the years 2011–2019 and plotted into a map chart using the Maps tool of MS Excel. *Countries that were common between top ten countries for both the search terms

'A new analytical approach for monitoring microplastics in marine sediments' published in 2014 described a study on extraction and identification of microplastics from marine sediments and displayed background contamination of blank samples with three to five microplastic fibres after 5 days of exposure to lab air (Nuelle et al. 2014), while the article titled 'Using a forensic science approach to minimize environmental contamination and to identify microfibres in marine sediments' published in 2015 confirmed the above finding by demonstrating the presence of MP fibres in the air (Woodall et al. 2015). No publications were published in 2012, 2013, and 2016 in this research area. It seems that the early publications between 2011 and 2015 defined the research direction resulting in a considerable increase in the number of publications in this field in the later years (23 research articles in 2019).

For the search term 'microplastic air pollution', the journal *Environmental Pollution* published the highest number of research publications (8 research publications) as shown in Fig. 4a. *Science of the Total Environment* ranked second, and journal *Marine Pollution Bulletin* ranked third with 5 and 4 research publications, respectively, for the indicated years. Based on the analysis of journal category, it is possible to describe which journal is publishing the most articles in that particular field. *Environmental Pollution* with impact factor 5.714 published 8 times more research publications on this search term than the closest rival, *Chemosphere* with impact factor 5.108.

The total number of publications per country for search term 'microplastic air pollution' presented the UK as the current leader with 11 research articles while China ranked second with 7 research articles and Norway as third with 4 research articles (Fig. 4c). Out of the top ten countries, six countries were common between the fields when search was performed for 'microplastics water pollution' and 'microplastics air pollution', shown by the asterisk in the figure. Our data suggests that participation of countries in the research area of microplastics associated with air pollution is increasing. Interestingly, the UK has the highest number of research publications in the research area, shifting places with China, while Norway, a new entry, has 4 research publications. France, Netherlands, and the USA published equal number of the research articles in this area (3 research articles).

Figure 5a describes the top ten funding agencies that sponsored research publications in the field of microplastic air pollution for the years 2011–2019. We observed that four agencies (indicated by asterisk) funded research publications in both the areas of research. Chinese funding agencies sponsored the research in both areas (microplastic air pollution and microplastic water pollution). The highest number of research publications was sponsored by the Chinese funding agencies (total 8 research publications), which

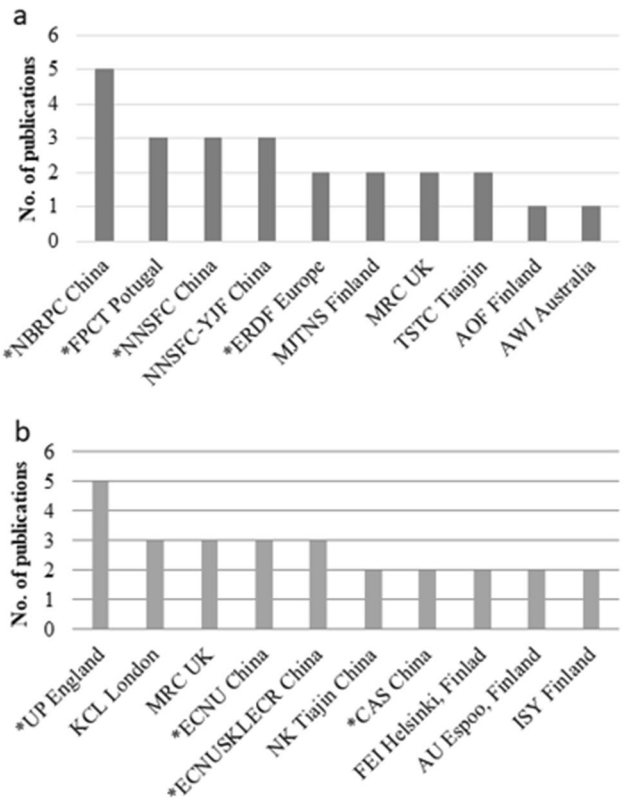

Fig. 5 The top 10 funding agencies and author affiliation were plotted into the bar graphs for the years 2011–2019. *Funding agencies that were common between top ten agencies for both the search terms. **b** Funding agencies were indexed according to number of research publications in the field of 'microplastic air pollution' to obtain the top ten agencies. Full names of funding agencies are given in Supplementary Table 1. **b** The data was compiled based on top ten affiliations for the search term 'microplastic air pollution' for the years 2011–2019. Full affiliations are mentioned in Supplementary Table 2

are 8 times greater than the number of research publications funded by Australian funding agency (only 1 research publication). This data suggests that Chinese funding agencies are supporting the upcoming research trend in microplastics research substantially more than other countries. An analysis of total number of research articles for the top ten author affiliations using the search term 'microplastics air pollution' for 2011–2019 (Fig. 5b) shows an overlap with earlier data on microplastics water pollution research. Four institutions (indicated by asterisk in the figure) published research articles in both fields. The rest published research articles only on the search term 'microplastics air pollution'. The highest numbers of research articles (5 publications) were published by the authors affiliated with the University of Plymouth. Data shows that most publications are published by the authors affiliated with the Chinese (10) and Finnish (6) institutions.

Co-authorship cluster analysis to assess scientific collaboration of different organizations working together in the field

of microplastic air pollution between 2011 and 2019 demonstrated that 5 organizations are collaborating out of initial 107 organizations used for the analysis (Fig. 6a). There is only 1 published document by every organization whereas citation count ranges from 33 to 4 with link strength of 4.

Network analysis based on countries demonstrated that the top cluster is formed by the USA and the UK having link strength 2. The UK has the greatest number of documents, i.e. 13 with citation of 478 and having link strength of 8, followed by the USA having 6 documents with citation of 212 and link strength of 3. Out of 10, only 8 are showing the connection in the network cluster and few of them are also having no network connection with the other countries. This network analysis utilized documents ranging from 13 to 2, citation number ranging from 478 to 15, and link strength ranging from 8 to 1 (Fig. 6b). For assessing collaboration between organizations, organizations with highest research articles, citations, and total link strength were selected and visualized. Interestingly, only four organizations out of the top ten organizations formed network of collaboration with each other. The clusters shown in Fig. 6c as all 4 organizations have the same citation, same number of published documents, and link strength. Department of Forestry, Wildlife and Fisheries, Center for Environmental Biotechnology or CEB, USA, having citation 33 and link strength 3 followed by Marine Biology and Ecology Research Centre, University of Plymouth, Devon, or MBERC, UK, having citation 33 and link strength 3. School of Applied Sciences, Edinburgh Napier University or SAS-ENU, Scotland, having citation 33 and link strength 3, followed by St. Abbs Marine Station, St. Abbs or SAMS, UK, with citation 33 and link strength having 3. In this network, the top 10 published documents were selected, where citation range is from 33 to 1 and link strength from 3 to 1. During the preparation of the network, it has been noted that there is only 1 published document by every organization where only 4 organizations collaborated in this work (Fig. 6c). The top 10 countries and organizations with the total number of citations, documents, and total link strength are listed in Table 3.

The co-authorship analysis for microplastic air pollution showed that author Li D. had 3 published documents, citation count of 9, and total link strength of 10, followed by Liu K. and Wang X. with same number of published documents, citation count, and link strength, followed by 2 other authors which formed the cluster network. Out of the top 10, 5 showed scientific collaboration. In this networking, top

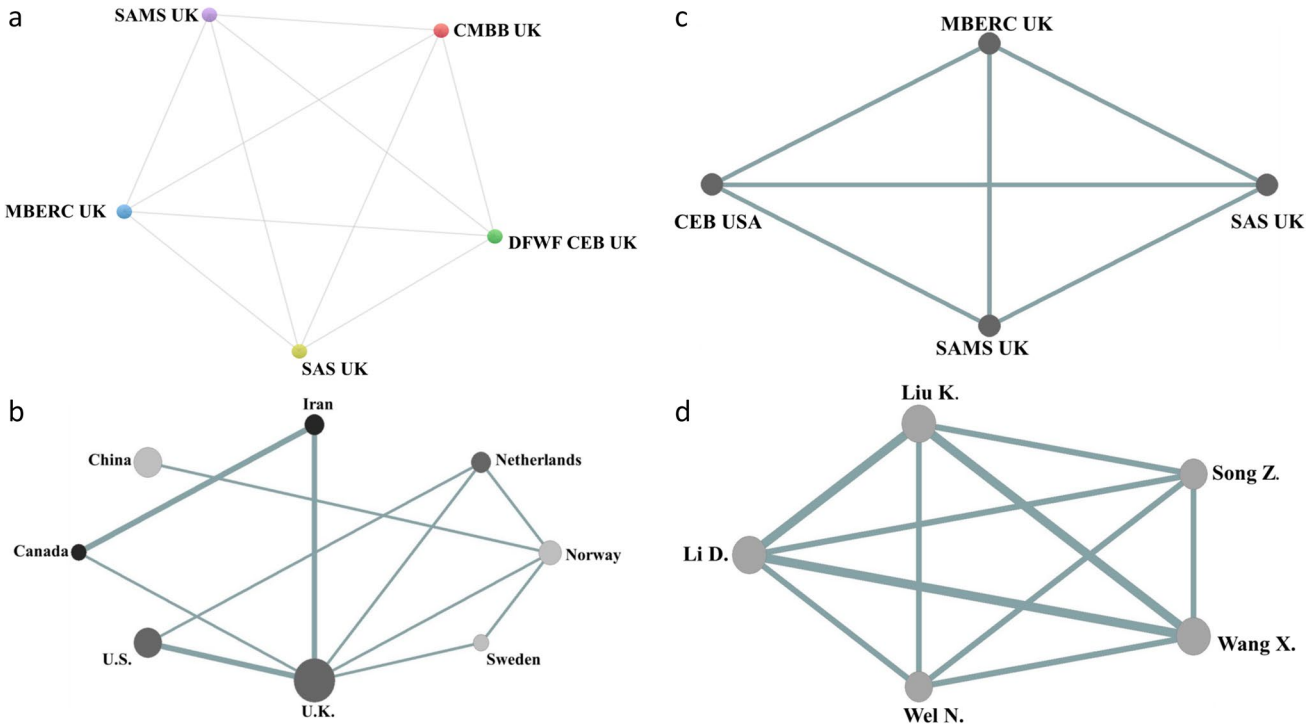

Fig. 6 Scientific collaborations. The network analysis based on the countries and organizations based on the search term 'microplastic air pollution' from years 2011 to 2019. **a** Between organizations. They have only 1 published document and they show equal collaboration with other 4 organizations. The full names of the research laboratories/organizations are listed in Supplementary Table 3. **b** Between top 10 countries were chosen based on citation, number of documents, and total link strength however only 8 are collaborating. **c** Between top organizations. **d** For top authors. The width indicates the strong connection of the network between different authors. Only 5 authors showed collaboration with each other. The network is obtained using the search term 'microplastic air pollution' for years 2011–2019 and analysis and visualization using VOSviewer and Pajek

Table 3 The top ten collaborative organizations and countries. The table lists the top collaborating organizations and countries during 2011–2019 based on total link strength, number of citations, and numbers of documents. The full names of research laboratories/departments are given in Supplementary Table 3

a

S. no	Country	Documents	Citations	Total link strength
1	UK	13	478	8
2	Iran	3	27	4
3	Norway	4	47	4
4	Canada	2	15	3
5	Netherlands	3	61	3
6	USA	6	212	3
7	Sweden	2	34	2
8	China	6	16	1
9	France	3	326	1
10	Germany	4	278	1

b

S. no	Research laboratory/department	Publications	Citations	Total link strength
1	CEB USA	1	33	3
2	DGS Sweden	1	4	3
3	DLS WI	1	4	3
4	DNSE Iran	1	1	1
5	MFRC Ireland	1	4	3
6	MBERC UK	1	4	3
7	MBERC UK (different address)	1	33	3
8	SAS UK	1	33	3
9	SAMS UK	1	33	3
10	TC Canada	1	1	1

10 published documents ranging from 4 to 2 were selected along with citation range from 174 to 2 and range of link strength from 10 to 0. Link strength 0 indicated that they have no collaboration with other authors (Fig. 6d).

An analysis of total number of research articles published in the area of 'microplastic water pollution' and 'microplastic air pollution' displayed Shi H. has published the highest number of the articles in the 'microplastic water pollution' with 25 research publications. Thompson, R.C., ranked second with 24 research publications. Interestingly, he ranked first in publications on the microplastic air pollution with 4 research publications. Data also supports that only two authors (Thompson, R.C. and Li, D.) published articles in both the research areas. The remaining authors published research only in one field (Table 4).

It can be assumed that microplastic fragmentation and increasing levels are directly proportional to plastic usage and thus to increasing plastic production. Therefore, it is unsurprising that a higher number of publications are published in recent years to study the MP production and its effects. These increases in MP levels can be directly correlated to the use of plastics in cosmetics, surgical face masks, toothpaste, and food containers, and thus, MPs release into our ecosystems (Aragaw 2020; Fadare et al. 2020; Praveena et al. 2018; Ustabasi & Baysal 2019). In addition, many recent reports have presented data on organic pollutants such

Table 4 Comparison between publications. Listed table shows the comparison between the publications published by different authors in the areas of 'microplastic water pollution' and 'microplastic air pollution' during 2011–2019

Author	Publication count	
	'Microplastics water pollution'	'Microplastics air pollution'
Shi, H	25	
Thompson, R.C	24	4
Su, L	14	
Shim, W.J	13	
Wu, C	13	
Galgani, F	12	
Guerranti, C	12	
Koelmans, A.A	12	
Li, D	12	3
Turra, A	12	
Kelly, F.J		3
Liu, K		3
Wang, X		3
Koistinen, A		2
Rhodes, C.J		2
Setälä, O		2
Song, Z		2
Talvitie, J		2

as polycyclic aromatic hydrocarbons adsorbed on the MP surface (Gao et al. 2019; Li et al. 2020). It is speculated that adsorption of these pollutants on the MP surface may result in increased retention of these chemicals in the environment and thus pose as a risk to humans. Furthermore, MPs have been recently found in human stool (Schwabl et al. 2019) as well as mineral water bottles (Schymanski et al. 2018) demanding more research on health effects in humans. These important findings are also the cause of increasing number of publications in recent years.

Conclusions

Due to the current increase in microplastics pollution due to rapid industrial development and plastic use, it is important that the scientific community establishes a better understanding of plastic effect on our ecosystem and human health. To aid the scientists working in this emerging field, we have attempted a scientometry study in the field of microplastics with respect to its pollution. Our method provides a scientific tool to know about the current status of research in this particular field and supports an increase in scientific contributions to further the understanding of the emerging field. It can be assumed that scientists are increasingly aware about current microplastic pollution. Our study identified the journal and country-wise publications, publications per year, and top authors, focusing on research on the microplastics water pollution and air pollution for 2011–2019. Many countries and funding agencies are now participating in this research. We have demonstrated that scientific interest in this field is rapidly increasing. Interestingly, China is leading the microplastics water pollution field as visible from the publication data, possibly due to higher funding opportunities. In addition, some journals (*Atmospheric Environment*) and author affiliations (University of Plymouth, UK) outperformed other journals in publishing field-related research. We have also identified a shift in research trend towards the presence of microplastic in air and its impact on human health. Although the field is comparatively new, our analysis does provide information about prospective research area in the next years. Due to increase in the production of the microplastics, the future research should be focused on mechanistic studies, i.e. exposure, uptake, and fate of microplastics in humans and our ecosystem.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11356-022-20872-0.

Author contribution Gurjot Kaur conceptualized the study. Gurjot Kaur collected the data. Deepika Sharma and Shreya Jaiswal equally contributed to this study by analysing the data and scientific literature and producing the final figures and tables. Deepika Sharma and Gurjot Kaur wrote the first draft together. Gurjot Kaur edited and refined the final draft.

Data availability Yes.

Declarations

Ethics approval and consent to participate Not applicable.

Consent to publication Not applicable.

Competing interests The authors declare no competing interests.

References

Ageel HK, Harrad S, Abdallah MAE (2022) Occurrence, human exposure, and risk of microplastics in the indoor environment. Environ Sci Process Impacts 24:17–31

Aragaw TA (2020) Surgical face masks as a potential source for microplastic pollution in the COVID-19 scenario. J Mar Pollut Bull 159:111517

Arp HP, Moskeland T, Andersson PL, Nyholm JR (2011) Presence and partitioning properties of the flame retardants pentabromotoluene, pentabromoethylbenzene and hexabromobenzene near suspected source zones in Norway. J Environ Monit 13:505–513

Au SY, Bruce TF, Bridges WC, Klaine SJ (2015) Responses of Hyalella azteca to acute and chronic microplastic exposures. Environ Toxicol Chem 34:2564–2572

Bakir A, Rowland SJ, Thompson RC (2012) Competitive sorption of persistent organic pollutants onto microplastics in the marine environment. Mar Pollut Bull 64:2782–2789

Bashir SM, Kimiko S, Mak C-W, Fang JK-H, Gonçalves D (2021) Personal care and cosmetic products as a potential source of environmental contamination by microplastics in a densely populated Asian city. J Front Mar Sci 8:604

Blackburn K, Green D (2022) The potential effects of microplastics on human health: What is known and what is unknown. Ambio 51:518–530

Botterell ZL, Beaumont N, Dorrington T, Steinke M, Thompson RC, Lindeque PK (2019) Bioavailability and effects of microplastics on marine zooplankton: a review. Environ Pollut 245:98–110

Browne MA, Crump P, Niven SJ, Teuten E, Tonkin A, Galloway T, Thompson R (2011) Accumulation of microplastic on shorelines woldwide: sources and sinks. Environ Sci Technol 45:9175–9179

Burgess RM, Ho KT, Mallos NJ, Leonard GH, Hidalgo-Ruz V, Cook AM, Christman K (2017) Microplastics in the aquatic environment—perspectives on the scope of the problem. Environ Toxicol Chem 36:2259–2265

Carbery M, O'Connor W, Palanisami T (2018) Trophic transfer of microplastics and mixed contaminants in the marine food web and implications for human health. Environ Int 115:400–409

Catrouillet C, Davranche M, Khatib I, Fauny C, Wahl A, Gigault J (2021) Metals in microplastics: determining which are additive, adsorbed, and bioavailable. J Environ Sci Processes Impacts 23:553–558

Cherniak SL, Almuhtaram H, McKie MJ, Hermabessiere L, Yuan C, Rochman CM, Andrews RC (2022) Conventional and biological treatment for the removal of microplastics from drinking water. J Chemosphere 288:132587

Çobanoğlu H, Belivermiş M, Sıkdokur E, Kılıç Ö, Çayır A (2021) Genotoxic and cytotoxic effects of polyethylene microplastics on human peripheral blood lymphocytes. Chemosphere 272:129805

Cole M, Lindeque P, Halsband C, Galloway TS (2011) Microplastics as contaminants in the marine environment: a review. Mar Pollut Bull 62:2588–2597

Dong C-D, Chen C-W, Chen Y-C, Chen H-H, Lee J-S, Lin C-H (2020) Polystyrene microplastic particles: in vitro pulmonary toxicity assessment. J Hazard Mater 385:121575

Du J, Zhou Q, Li H, Xu S, Wang C, Fu L, Tang J (2021) Environmental distribution, transport and ecotoxicity of microplastics: a review. J Appl Toxicol 41:52–64

Fadare OO, Wan B, Guo L-H, Zhao L (2020) Microplastics from consumer plastic food containers: are we consuming it? Chemosphere 253:126787

Gao F, Li J, Sun C, Zhang L, Jiang F, Cao W, Zheng L (2019) Study on the capability and characteristics of heavy metals enriched on microplastics in marine environment. Mar Pollut Bull 144:61–67

Goodman KE, Hare JT, Khamis ZI, Hua T, Sang Q-X (2021) Exposure of human lung cells to polystyrene microplastics significantly retards cell proliferation and triggers morphological changes. J Chem Res Toxicol 34:1069–1081

Guzzetti E, Sureda A, Tejada S, Faggio C (2018) Microplastic in marine organism: environmental and toxicological effects. Environ Toxicol Pharmacol 64:164–171

Huang Z, Weng Y, Shen Q, Zhao Y, Jin Y (2021) Microplastic: a potential threat to human and animal health by interfering with the intestinal barrier function and changing the intestinal microenvironment. J Sci Total Environ 785:147365

Lattin GL, Moore CJ, Zellers AF, Moore SL, Weisberg SB (2004) A comparison of neustonic plastic and zooplankton at different depths near the southern California shore. Mar Pollut Bull 49:291–294

Li Z, Hu X, Qin L, Yin D (2020) Evaluating the effect of different modified microplastics on the availability of polycyclic aromatic hydrocarbons. Water Res 170:115290

Makhdoumi P, Amin AA, Karimi H, Pirsaheb M, Kim H, Hossini H (2021) Occurrence of microplastic particles in the most popular Iranian bottled mineral water brands and an assessment of human exposure. J Water Process Eng 39:101708

Mohamed Nor NH, Kooi M, Diepens NJ, Koelmans AA (2021) Lifetime accumulation of microplastic in children and adults. Environ Sci Technol 55:5084–5096

Nuelle MT, Dekiff JH, Remy D, Fries E (2014) A new analytical approach for monitoring microplastics in marine sediments. Environ Pollut 184:161–169

Peydayesh M, Suta T, Usuelli M, Handschin S, Canelli G, Bagnani M, Mezzenga R (2021) Sustainable removal of microplastics and natural organic matter from water by coagulation–flocculation with protein amyloid fibrils. J Environ Sci Technol 55:8848–8858

Polis GA, Anderson WB, Holt RD (1997) Toward an integration of landscape and food web ecology: the dynamics of spatially subsidized food webs. Annu Rev Ecol Syst 28:289–316

Praveena SM, Shaifuddin SNM, Akizuki S (2018) Exploration of microplastics from personal care and cosmetic products and its estimated emissions to marine environment: an evidence from Malaysia. Mar Pollut Bull 136:135–140

Rios LM, Moore C, Jones PR (2007) Persistent organic pollutants carried by synthetic polymers in the ocean environment. Mar Pollut Bull 54:1230–1237

Schirinzi GF, Pérez-Pomeda I, Sanchís J, Rossini C, Farré M, Barceló D (2017) Cytotoxic effects of commonly used nanomaterials and microplastics on cerebral and epithelial human cells. Environ Res 159:579–587

Schwabl P, Köppel S, Königshofer P, Bucsics T, Trauner M, Reiberger T, Liebmann B (2019) Detection of various microplastics in human stool: a prospective case series. Ann Intern Med 171:453–457

Schymanski D, Goldbeck C, Humpf H-U, Fürst P (2018) Analysis of microplastics in water by micro-Raman spectroscopy: release of plastic particles from different packaging into mineral water. Water Res 129:154–162

Shen M, Zhang Y, Almatrafi E, Hu T, Zhou C, Song B, Zeng Z, Zeng G (2022) Efficient removal of microplastics from wastewater by an electrocoagulation process. J Chem Eng J 428:131161

Shi X, Zhang X, Gao W, Zhang Y, He D (2022) Removal of microplastics from water by magnetic nano-Fe3O4. J Sci Total Environ 802:149838

Teuten EL, Saquing JM, Knappe DR, Barlaz MA, Jonsson S, Björn A, Rowland SJ, Thompson RC, Galloway TS, Yamashita R (2009) Transport and release of chemicals from plastics to the environment and to wildlife. Philosophical Transactions of the Royal Society b: Biological Sciences 364:2027–2045

Thompson RC, Moore CJ, Vom Saal FS, Swan SH (2009) Plastics, the environment and human health: current consensus and future trends. Philosophical Transactions of the Royal Society b: Biological Sciences 364:2153–2166

Ustabasi GS, Baysal A (2019) Occurrence and risk assessment of microplastics from various toothpastes. Environ Monit Assess 191:1–8

Wagner M, Scherer C, Alvarez-Muñoz D, Brennholt N, Bourrain X, Buchinger S, Fries E, Grosbois C, Klasmeier J, Marti T (2014) Microplastics in freshwater ecosystems: what we know and what we need to know. Environ Sci Eur 26:1–9

Woodall LC, Gwinnett C, Packer M, Thompson RC, Robinson LF, Paterson GL (2015) Using a forensic science approach to minimize environmental contamination and to identify microfibres in marine sediments. Mar Pollut Bull 95:40–46