# Microplastic Research Publications from 1991 to 2020


**Chongqing Wang, Hongru Jiang, and Yuh-Shan Ho**

**Abstract** Microplastics as emerging pollutants receive global attention and growing research interests. We report a bibliometric analysis of microplastics-related research from 1991 to 2020. 4026 documents were collected and analyzed for occurrence and types of microplastics, and research fields. We found that number of articles increased sharply from 2015, and microplastics. Environmental science is the leading subject category, followed by marine and freshwater biology, environmental engineering, materials science, toxicology water resources, multidisciplinary sciences, metallurgy and metallurgical engineering, and analytical chemistry. Marine Pollution Bulletin was the most productive journal, followed by Environmental Pollution, Science of the Total Environment, Environmental Science & Technology, and Chemosphere. The 3536 articles on microplastics were from 107 different countries, and China was the most productive country.

**Keywords** Microplastics · Environment · Bibliometric · Citations · Research trends

## 1 Introduction

Plastics have been widely used in various fields and applications due to especially their unique properties of low-cost, durability, lightness, hygiene, and corrosion resistance. The global production of plastic products exceeds $3.48 \times 10^8$ tons per

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year, resulting in a considerable amount of plastic waste (Li et al. 2020). Inevitably, plastic waste enters the aquatic environment, and it is estimated that more than $2.5 \times 10^5$ tons of plastics are floating on the global ocean surface (Eriksen et al. 2014). Large plastic debris can be easily removed from the environment, whereas plastic debris with small size is prone to be ignored and difficult to remove from environmental matrices.

Microplastics, commonly defined plastic particles less than 5 mm, receive increasing public attention and research interests all over the world (Zhang et al. 2021). Microplastics are derived from primary microplastics and secondary microplastics (Hamidian et al. 2021). The former was originally made of small-sized polymers for special purposes such as pharmaceuticals and personal care products. The latter is mainly created by fragmentation and degradation of large particles of plastics. Microplastics have been found in a wide range of ecosystems, including aquatic systems (oceans, rivers, and lakes), soils and sediments, and atmospheric air (Wang et al. 2021a). Initially, the majority of research was focused on the maritime environment. As a result of the interest in the sources and transfer channels of microplastics, more attention is being directed to additional environmental compartments.

Microplastics induce significant public attention owing to the persistence and ubiquity in water environment and the threats to ecosystems. Because of their small size, microplastics can be ingested by organisms and aquatic creatures, potentially accumulating in the food chain (Ribeiro et al. 2019). The negative consequences of microplastics involve physical injury to the gastrointestinal tract of organisms, and toxic impacts resulting from polymers and additives in the microplastics (Barboza et al. 2020). Additionally, microplastics can be carriers to concentrate and transfer pollutants. Therefore, the interaction between microplastics and pollutants and the removal of microplastics have attracted much attention (Jiang et al. 2022a, b; Bian et al. 2022). With increasing awareness of the worldwide distribution and potential risk of microplastics, more study is being conducted on identifying the origins and transfer pathways, disclosing the threats to ecosystems, attempting to regulate microplastics discharges, and removing microplastics from the environment.

Bibliometric analysis is an important method to reveal the past research evolution of microplastics, providing a better understanding of the emerging research areas. Mathematical techniques are employed to examine the published documents based on macro-perspective. The bibliometric method is related to informetrics and scien-tometrics, which provide fundamental theory and methodology for bibliometric analysis (Hood and Wilson 2001). A bibliometric analysis of the literature on a certain issue provides vital information for the topic and research progress (Ertz and Leblanc-Proulx 2018). Currently, numerous review papers (Andrady 2011; Cole et al. 2011) and bibliometric studies (Pauna et al. 2019; Palmas et al. 2021) on microplastics have been carried out.

Publication performance on microplastics and the main focuses and their development trends were studied by using the Science Citation Index Expanded (SCI-EXPANDED). This study addresses the data analysis of microplastics documents in terms of different criteria, identifying the occurrence and types of microplastics, emerging interests of the research fields, the research gap in the current state, and future perspective.

## 2 Materials and Methods

This work conducts a data-driven bibliometric study based on a literature review, aiming to explore indicators for further research on microplastics. The literature data were obtained from the SCI-EXPANDED database in Web of Science, which is one of the most important databases for scientific research. The database of the Web of Science is listed in Supporting Material (Text S1). The journal impact factor in 2020 was based on Journal Citation Reports in 2020. The published literature was collected after June 30, 2021. It was pointed out that the SCI-EXPANDED was useful to search published literature but not employed for bibliometric studies (Ho 2020a). Therefore, it is essential to have a data treatment but have data directly from the database of SCI-EXPANDED for bibliometric studies. It was reported that "front page" containing paper title, abstract, and author keywords could be used as a filter for bibliometric studies (Ho 2020b; Fu et al. 2012). *KeyWords Plus* supplied supplementary search items extracted from paper titles cited by authors and amplified author-keyword and title-word indexing (Garfield 1990). The documents searched by *KeyWords Plus* were not closely relevant to the target topic (Fu and Ho 2015). The search keywords "microplastics," "microplastic," "micro-plastics," and "micro-plastics" were searched by topic in the database. It resulted in 4972 documents from 1991 to 2020, which may be relevant to the topic. 4026 documents were used as microplastics publications for a bibliometric study because no search keywords were found on the 'front page' of 946 documents. The document records were downloaded and manually coded for analysis using Microsoft Excel 2016 (Li and Ho 2008; Ho 2021).

For one corresponding author, it was used as corresponding author (Ho 2012), while the last one of multiple corresponding authors was used as corresponding author (Ho 2019). As to single-author articles, the author was designated as the first and corresponding author (Ho 2014a). For affiliations, England, Scotland, Northern Ireland, Wales, and the Falkland Islands were assigned to the United Kingdom. Greenland was assigned to Denmark (Tchuifon Tchuifon et al. 2017). Additionally, affiliations from the USSR were assigned to Russia or Ukraine (Wambu et al. 2017). Four citation indicators were defined in this work: (1) $C_0$, (2) $C_{year}$, (3) $TC_{2020}$, and (4) $CPP_{year}$ (Ho 2013, 2014b; Wang and Ho 2011). The citation indicators were used for bibliometric analysis.

# 3 Results and Discussion

## *3.1 Documents Summary*

The documents used for bibliometric analysis were collected for the period 1991–2020. The total number of filtered documents relevant to microplastics is 4026. The citation indicator of CPPyear can be employed to describe the citations per publication more accurately (Ho and Ho 2015). Recently, the author number of each publication was also applied to analyze the types of documents related to specific topic (Monge-Nájera and El Ho 2017). As listed in Table 1, 14 types of documents were involved, and the type of article was the top one with an APP of 5.3, accounting for 84% of 4204 documents. Since some documents could be assigned to different document types, the total percentage was higher than 100% (Usman and Ho 2020). For example, 83 documents were assigned to proceedings papers and articles. The document type of retracted publications had the highest $CPP_{2020}$ of 124 which is due to the highly cited retracted publication with a $TC_{2020}$ of 100 or more by Lönnstedt and Eklöv (Lönnstedt and Eklöv 2016). Document type corrections had the highest APP of 6.1. In addition, each microplastics-related article had an average of 5.3 authors. The study reported by Gorsky et al. had a maximum author count of 145 (Gorsky et al. 2019). The 3546 articles were employed for bibliometric study, and this is due to the complete structure of article-type research.

**Table 1** Citations and authors according to document type

| Document type | TP | TP* | % | AU | APP | $TC_{2020}$ | $CPP_{2020}$ |
|---|---|---|---|---|---|---|---|
| Article | 3546 | 3544 | 84 | 18,750 | 5.3 | 113,771 | 32 |
| Review | 411 | 411 | 10 | 2008 | 4.9 | 24,725 | 60 |
| Proceedings paper | 83 | 83 | 2.0 | 338 | 4.1 | 2122 | 26 |
| Editorial material | 82 | 76 | 2.0 | 205 | 2.7 | 2288 | 28 |
| Meeting abstract | 72 | 72 | 1.7 | 261 | 3.6 | 16 | 0.22 |
| News item | 40 | 17 | 1.0 | 17 | 1.0 | 7 | 0.18 |
| Letter | 27 | 27 | 0.64 | 77 | 2.9 | 914 | 34 |
| Correction | 25 | 25 | 0.59 | 152 | 6.1 | 17 | 0.68 |
| Book chapter | 4 | 4 | 0.10 | 17 | 4.3 | 169 | 42 |
| Book review | 1 | 1 | 0.024 | 1 | 1.0 | 0 | 0 |
| Data paper | 1 | 1 | 0.024 | 2 | 2.0 | 4 | 4.0 |
| Note | 1 | 1 | 0.024 | 2 | 2.0 | 8 | 8.0 |
| Retracted publication | 1 | 1 | 0.024 | 2 | 2.0 | 124 | 124 |
| Retraction | 1 | 1 | 0.024 | 3 | 3.0 | 2 | 2.0 |

*TP* number of publications, *AU* number of authors, *APP* number of authors per publication; $TC_{2020}$: the total number of citations from Web of Science Core Collection since publication year to the end of 2020; $CPP_{2020}$: number of citations ($TC_{2020}$) per publication (*TP*)

### 3.2 Language of Publications

Many bibliometric studies regard publication languages as one basic content (Wang and Ho 2011). There were nine languages in use, and English accounted for 99% of the 3546 articles. Some other languages were as follows: Russian (11 articles), German (9 articles), Japanese (6), Chinese (5), French (5), Ukrainian (4), Korean (1), and Spanish (1). The $CPP_{2020}$ of articles in English was 32, remarkably higher than that of non-English articles (2.5). Moreover, the *APP* of articles written in English was 5.3, higher than that of non-English articles (3.0). It should be noted that most of the journals in the Clarivate Analytics database are published in English.

### 3.3 The Variation of Publications

Figure 1 presents the variation of *TP* and $CPP_{2020}$. A significant increase in the number of articles was observed from 109 in 2015 to 1372 in 2020, indicating that microplastics receive increasing attention in the research field. The increase in the number of articles can be attributed to researchers' finding a new topic or developing research interests in microplastics. In 2014, with 70 articles, we had the highest $CPP_{2020}$ of 190. Three of the top ten cited articles were published in 2014, including articles by Eriksen et al. (2014), Cozar et al. (2014), and Van Cauwenberghe and Janssen (2014), which ranked third, fourth, and tenth, respectively. A total of 1650 microplastics articles (47% of 3546 articles) were not cited by published studies in the publication year ($C_0 = 0$) (Ho and Kahn 2014).

### 3.4 The Subject Category of Web of Science

A total of 9531 journals were indexed Journal Citation Reports in 2020, and 178 subject categories were involved. The relationship between article number in a specific subject category and publication year provides some information about research trends and the interactions (Ho et al. 2010). Table 2 shows the top ten subject categories. In 2020, the environmental sciences category was the most productive category with 2449 articles (69% of 3546 articles), followed distantly by other categories. This implies that microplastics become emerging pollutants and gain great attention due to potential environmental threats. Compared to the top ten categories, microplastics articles in the multidisciplinary sciences category had the highest $CPP_{2020}$ (55), and it was followed by the environmental engineering category ($CPP_{2020}$ of 50). The *APP* in the environmental engineering

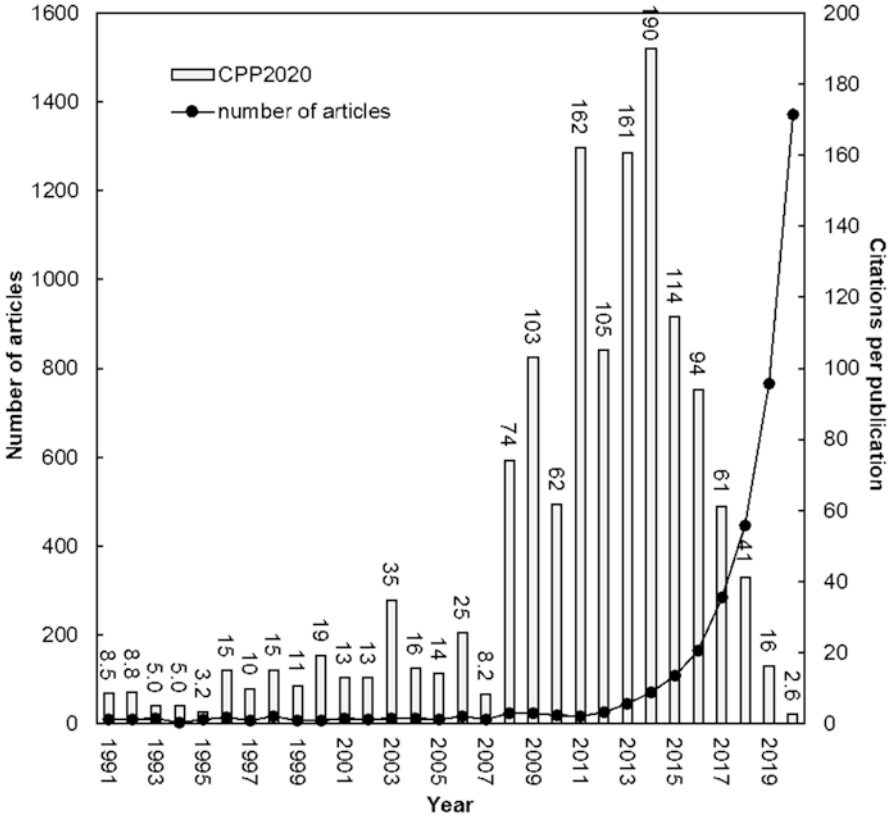


**Fig. 1** The number of articles and citations per publication by year. $CPP_{2020}$: number of citations ($TC_{2020}$) per publication

category was 5.7, and the metallurgy and metallurgical engineering category had an *APP* of 3.8. Figure 2 shows the variation trend of the top five subject categories. Microplastics-related studies were reported chiefly in the category of environmental sciences. The category of environmental sciences has been the most popular since 2011. The first microplastics article in the category of environmental sciences was published in 2006 by Ng and Obbard in *Marine Pollution Bulletin* (Ng and Obbard 2006). Furthermore, the category of multidisciplinary chemistry become popular in recent years, ranking tenth in 2020. The of multidisciplinary materials science category published 217 microplastics-related articles and ranked fourth, but ranked 11th in 2020 since only 27 articles were reported. Journals could be assigned to different subject categories, and hence the total percentage was larger than 100%. For example, *Water Research* journal was assigned to the environmental engineering category, the environmental sciences category, and the water resources category.

**Table 2** The top ten productive Web of Science category

| Web of Science category | *TP* (%) | $TC_{2020}$ | $CPP_{2020}$ | AU | APP |
|---|---|---|---|---|---|
| Environmental sciences | 2449 (69) | 88,547 | 36 | 13,642 | 5.6 |
| Marine and freshwater biology | 756 (21) | 28,503 | 38 | 4095 | 5.4 |
| Environmental engineering | 406 (11) | 20,485 | 50 | 2315 | 5.7 |
| Multidisciplinary materials science | 217 (6.1) | 2948 | 14 | 885 | 4.1 |
| Toxicology | 215 (6.1) | 7419 | 35 | 1123 | 5.2 |
| Water resources | 178 (5.0) | 4218 | 24 | 964 | 5.4 |
| Multidisciplinary sciences | 155 (4.4) | 8524 | 55 | 857 | 5.5 |
| Metallurgy and metallurgical engineering | 131 (3.7) | 1721 | 13 | 503 | 3.8 |
| Analytical chemistry | 106 (3.0) | 3015 | 28 | 522 | 4.9 |
| Multidisciplinary chemistry | 80 (2.3) | 1186 | 15 | 395 | 4.9 |

*TP* number of publications, % percentage of 3546 articles, $TC_{2020}$ the total number of citations from Web of Science Core Collection since publication year to the end of 2020, $CPP_{2020}$ number of citations ($TC_{2020}$) per publication (*TP*), *AU* the total number of authors, *APP* number of authors per publication

## *3.5 Analysis Based on Journals*

A total of 3546 articles related to microplastic researches were reported in 566 journals. These journals covered 112 subject categories of Web of Science. The top five journals publishing more than 100 microplastics-related articles included: *Marine Pollution Bulletin* ($IF_{2020}$ = 5.553) with 573 articles (16% of 3546 articles), *Environmental Pollution* ($IF_{2020}$ = 8.071) with 426 articles (12%), *Science of the Total Environment* ($IF_{2020}$ = 7.963) with 361 articles (10%), *Environmental Science & Technology* ($IF_{2020}$ = 9.028) with 172 articles (4.9%), and *Chemosphere* ($IF_{2020}$ = 7.086) with 135 articles (3.8%). All above journals were related to the field of environment, suggesting microplastics gained great growing attention and research interests due to environmental problems. *Science* with three articles, places first with the highest $IF_{2020}$ of 47.728, followed by *Nature Nanotechnology* with one article ($IF_{2020}$ = 39.213), and *Advanced Materials* with one article ($IF_{2020}$ = 30.849). Microplastics-related studies were preferred by top journals, such as *Science* and *Nature Nanotechnology*, indicating the importance and popularity of the microplastics topic.

## *3.6 Analysis Based on Countries*

The articles (0.28% of 3546 articles) without affiliation information were excluded from the analysis. The 3536 articles related to microplastic studies were from 107 countries. Among them, a total of 2539 single-country articles were from 55 countries, while 997 articles with international collaborations were from 101 countries.

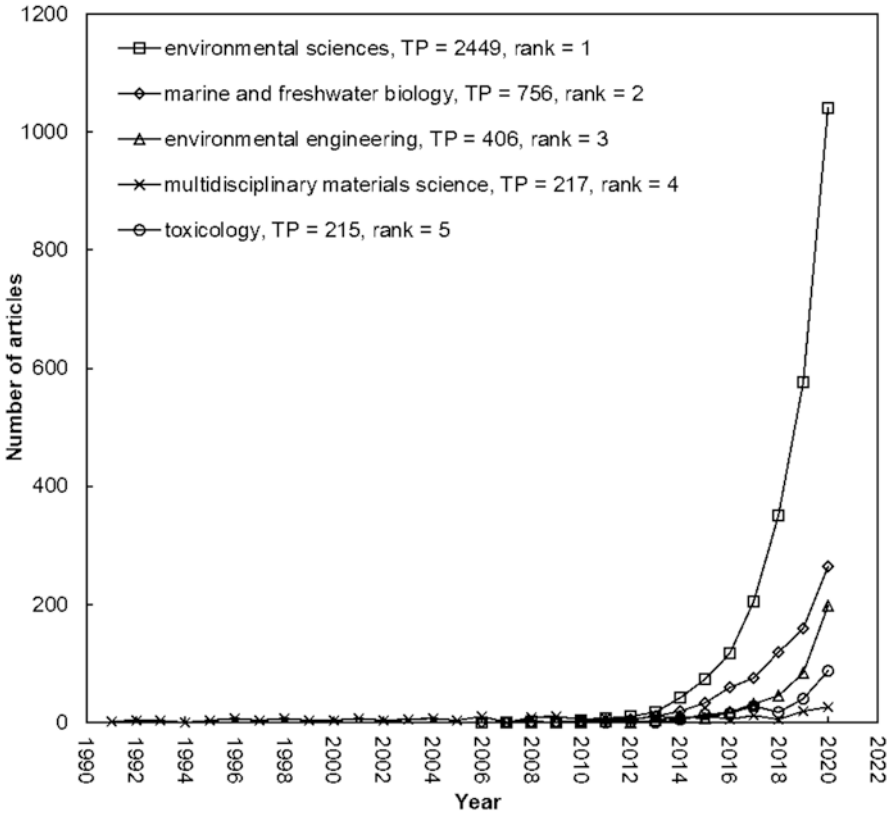


**Fig. 2** Microplastic articles in the Web of Science categories

The top 13 productive countries, publishing over 100 articles, are displayed in Table 3. These countries included seven European countries (Germany, UK, Italy, France, Spain, Netherlands, and Portugal), three American countries (USA, Canada, and Brazil), two Asiatic countries (China and Russia), and one Oceanian country (Australia). Additionally, South Africa published 52 articles, ranking first in Africa. The indicators, including *TP*, *IP*, *CP*, *FP*, *RP*, and *SP* were applied to compare publication performance (Hsu and Ho 2014). China had the highest publication indicators, with a *TP* of 25%, an *IP* of 6%, a *FP* of 23%, and a *RP* of 23%. USA was the most collaborative country, with 230 collaborative articles and a *CP* of 23%. Russia was poor in collaborative studies due to the most single-author articles with *SP* of 22%. The variation of published articles for the top five countries is shown in Fig. 3. The annual number of microplastics-related publications was no more than 10 before 2014, primarily reported by Russia. A sharp increase was found in China after 2017. China, the USA, Germany, the UK, and Italy were also the top five countries on the total number of articles in 2020.

**Table 3** Top 13 productive countries with *TP* > 100

| Country | TP | *TPR* (%) | *IPR* (%) | *CPR* (%) | *FPR* (%) | *RPR* (%) | *SPR* (%) |
|---|---|---|---|---|---|---|---|
| China | 869 | 1 (25) | 1 (16) | 2 (20) | 1 (23) | 1 (23) | 7 (3.4) |
| USA | 460 | 2 (13) | 3 (5.5) | 1 (23) | 2 (8.7) | 2 (8.9) | 2 (13) |
| Germany | 403 | 3 (11) | 2 (5.5) | 3 (17) | 3 (8.5) | 3 (8.5) | 4 (7.9) |
| UK | 320 | 4 (9.0) | 4 (3.6) | 4 (17) | 4 (6.1) | 4 (6.2) | 3 (11) |
| Italy | 250 | 5 (7.1) | 5 (2.9) | 5 (13) | 5 (5.3) | 5 (5.4) | 10 (2.2) |
| France | 199 | 6 (5.6) | 8 (1.8) | 6 (12) | 8 (3.3) | 8 (3.4) | 7 (3.4) |
| Spain | 198 | 7 (5.6) | 7 (2.1) | 7 (11) | 6 (3.5) | 6 (3.5) | N/A |
| Australia | 149 | 8 (4.2) | 15 (1.1) | 8 (10) | 10 (2.4) | 10 (2.4) | 15 (1.1) |
| Netherlands | 144 | 9 (4.1) | 16 (1.0) | 8 (10) | 11 (2.2) | 11 (2.3) | 10 (2.2) |
| Canada | 133 | 10 (3.8) | 11 (1.3) | 11 (7.8) | 12 (2.2) | 13 (2.2) | 5 (6.7) |
| Russia | 129 | 11 (3.6) | 6 (2.3) | 18 (3.2) | 7 (3.5) | 7 (3.5) | 1 (22) |
| Portugal | 109 | 12 (3.1) | 14 (1.2) | 12 (6.0) | 14 (2.1) | 14 (2.1) | 15 (1.1) |
| Brazil | 101 | 13 (2.9) | 12 (1.3) | 15 (4.7) | 12 (2.2) | 12 (2.2) | N/A |

*TP* total number of articles, *TPR* (%) rank of total number of articles and percentage, *IPR* (%) rank of single country articles and percentage in all single country articles, *CPR* (%): rank of internationally collaborative articles and percentage in all internationally collaborative articles, *FPR* (%) rank of first-author articles and percentage in all first-author articles, *RPR* (%) rank of corresponding-author articles and percentage in all corresponding-author articles, *SPR* (%) rank of single-author articles and percentage in all single-author articles, N/A not available

## *3.7 Analysis Based on Institutions*

Table 4 demonstrates the top ten institutions as characterized by six indicators (Hsu and Ho 2014). Single-institution articles accounted for 33% of 3536 articles, while inter-institutionally collaborative articles accounted for 67%, suggesting that many researchers conducted collaborative studies on microplastics. It is worthwhile that the Chinese Academy of Sciences in China, the Russian Academy of Sciences in Russia, the National Research Council (CNR) in Italy, and the French Research Institute for Exploitation of the Sea (IFREMER) in France are national government institutions, rather than universities. The Chinese Academy of Sciences was ranked first and had the highest publication indicators, with a *TP* of 4.1%, a *CP* of 5.9%, a *FP* of 2.7%, and a *RP* of 2.5%. University of Chinese Academy of Sciences in China took the second position with *TP* of 2.4% and *CP* of 3.6%. Russian Academy of Sciences had the maximum publication indicators with *IP* of 3.1% and *SP* of 11%. All these 86 articles collaborated with the Chinese Academy of Sciences in China. However, the university had no institution-specific articles or single-author articles, respectively, and three first-author articles and corresponding-author articles. Chinese Academy of Sciences and the Russian Academy of Sciences was the most productive institutions, probably because they have a number of departments or branches (Li et al. 2009).

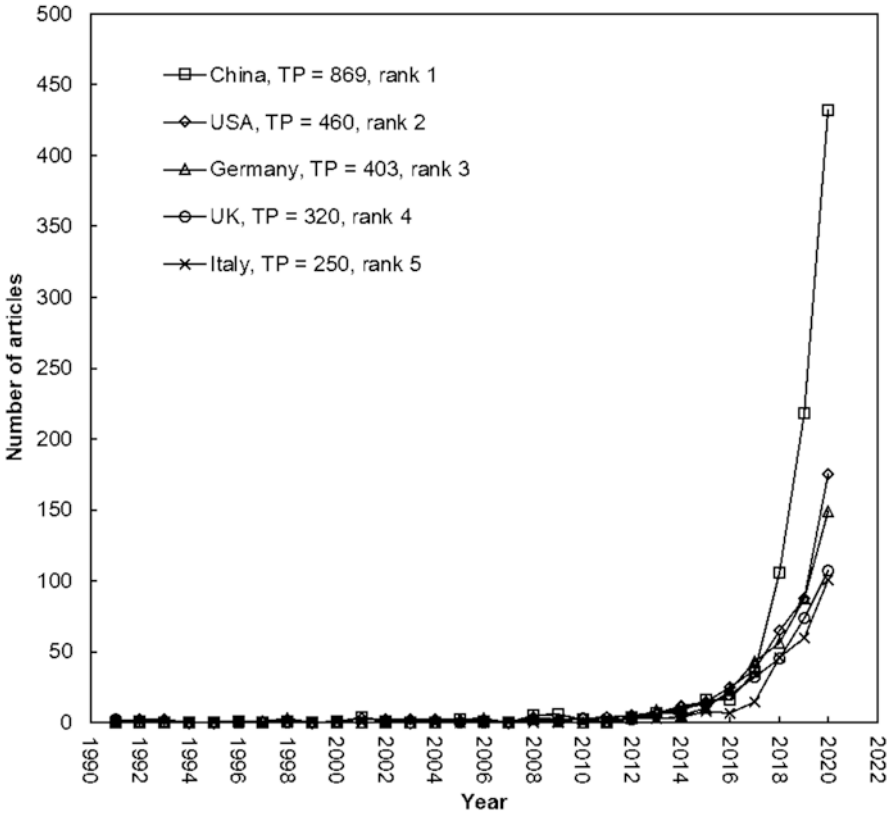


**Fig. 3** Comparison of development trends among the top five productive countries

## *3.8 The Important Articles in 2020*

The publication indicator, $C_{2020}$, could offer supplementary insights into understanding the influence of highly cited articles (Ho 2012). The ranking of 3546 microplastics-related articles differed significantly for sorting by $TC_{2020}$ or sorting by $C_{2020}$. Among these publications, 22% articles exhibited $C_{2020} = 0$ and 17% articles had $TC_{2020} = 0$. In addition, 73% of the top 100 $C_{2020}$ publications were among the top 100 $TC_{2020}$ papers. A total of 2508 articles (71% of 3546 articles) contained microplastics-related keywords in the Title. 3296 articles (94% of 3507 articles with abstracts) had search keywords in the Abstract. 2106 articles (74% of 2854 articles with author keywords) had microplastics-related keywords in author keywords. Seven of the top 20 articles on $TC_{2020}$ had microplastics-related keywords in all Title, Abstract, and author keywords. For example, publications reported by Eriksen et al. (. 2013), Van Cauwenberghe and Janssen (2014), Claessens et al. (2011), Woodall et al. (2014), Van Cauwenberghe et al. (2013), Farrell and Nelson (2013), and Fendall and Sewell (2009) ranked ninth with $TC_{2020}$ of 589, tenth with $TC_{2020}$ of

**Table 4** Top ten productive institutions

| Institute (country) | TP | *TPR* (%) | *IPR* (%) | *CPR* (%) | *FPR* (%) | *RPR* (%) | *SPR* (%) |
|---|---|---|---|---|---|---|---|
| Chinese Academy of Sciences (China) | 145 | 1 (4.1) | 34 (0.43) | 1 (5.9) | 1 (2.7) | 1 (2.5) | 10 (1.1) |
| University of Chinese Academy of Sciences (China) | 86 | 2 (2.4) | N/A | 2 (3.6) | 230 (0.085) | 228 (0.085) | N/A |
| East China Normal University (China) | 83 | 3 (2.3) | 4 (1.1) | 3 (3.0) | 3 (1.7) | 3 (1.6) | N/A |
| Russian Academy of Sciences (Russia) | 70 | 4 (2.0) | 1 (3.1) | 10 (1.4) | 2 (1.8) | 2 (1.8) | 1 (11) |
| University of Plymouth (UK) | 53 | 5 (1.5) | 3 (1.2) | 5 (1.6) | 5 (0.74) | 5 (0.68) | N/A |
| University of Exeter (UK) | 50 | 6 (1.4) | 34 (0.43) | 4 (1.9) | 26 (0.40) | 21 (0.42) | N/A |
| National Research Council (CNR) (Italy) | 41 | 7 (1.2) | 34 (0.43) | 6 (1.5) | 15 (0.51) | 11 (0.51) | 10 (1.1) |
| French Research Institute for Exploitation of the Sea (IFREMER) (France) | 38 | 8 (1.1) | 70 (0.26) | 7 (1.5) | 98 (0.17) | 65 (0.23) | N/A |
| Nanjing University (China) | 37 | 9 (1.0) | 9 (0.69) | 15 (1.2) | 4 (0.85) | 4 (0.82) | N/A |
| University of Toronto (Canada) | 37 | 9 (1.0) | 45 (0.34) | 11 (1.4) | 15 (0.51) | 16 (0.45) | 3 (2.2) |

*TP* total number of articles, *TPR* (%) rank of total number of articles and percentage, *IPR* (%) rank of single institute articles and percentage in all single institute articles, *CPR* (%) rank of inter-institutionally collaborative articles and percentage in all inter-institutionally collaborative articles, *FPR* (%) rank of first-author articles and percentage in all first-author articles, *RPR* (%) rank of corresponding-author articles and percentage in all corresponding-author articles, *SPR* (%) rank of single-author articles and percentage in all single-author articles, N/A not available

583, 13rd with $TC_{2020}$ of 537, 15th with $TC_{2020}$ of 532, 16th with $TC_{2020}$ of 512, 17th with $TC_{2020}$ of 511, and 19th with $TC_{2020}$ of 465, respectively.

Figure 4 manifested the citation variation of the top ten highly cited articles with microplastics-related keywords in the Title or author keywords. A study conducted by Barnes et al. (2009) ranked first on annual citations between 2012 and 2020 in the field of microplastics. An article by Browne et al. (Browne et al. 2011) had a similar trend of increasing citations. Table 5 shows the top ten highly cited papers with microplastics-related keywords in the Title or author keywords. The top 10 publications were reported by 20 institutes derived from 11 countries. The UK reported five of the top ten highly cited publications, followed by the USA (3 articles), Finland (2), and one each by Australia, Belgium, Canada, France, Germany, Ireland, Norway, and Switzerland. It can be deduced that microplastics receive great attention in most developed countries, and this can be ascribed to the massive production and consumption of plastic products and increasing environmental awareness. The University of Plymouth in the UK reported four articles among the top ten highly cited papers, and it was followed by the Algalita Marine Research Foundation

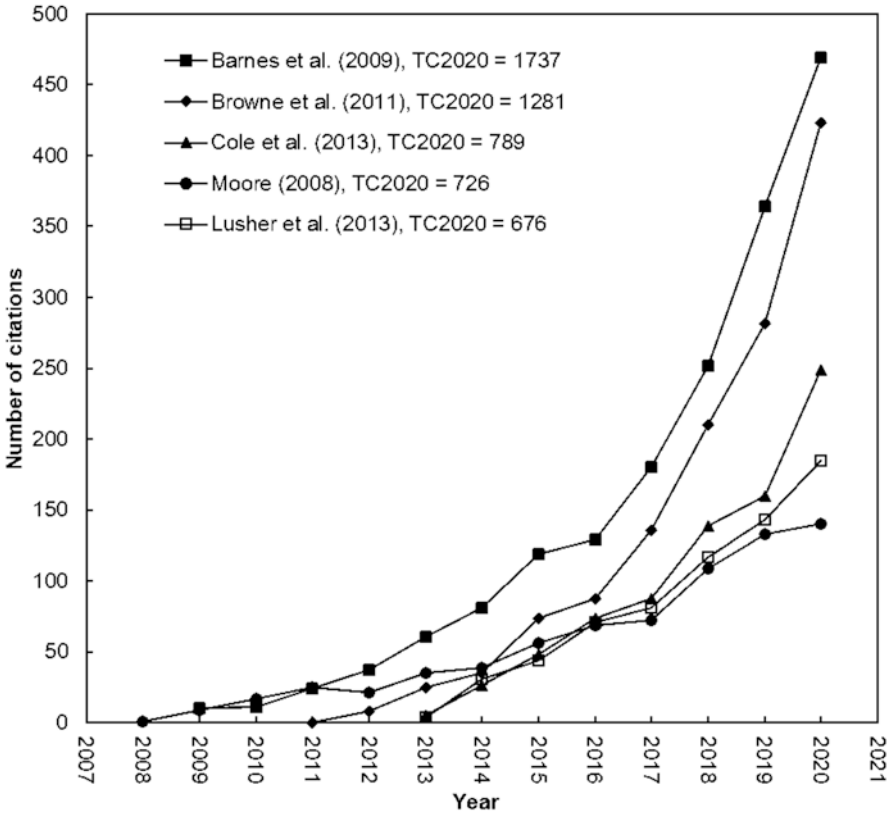


**Fig. 4** Citations of the top five most frequently cited articles with search keywords in their title or author keywords

in the USA and the University of Exeter in the UK, which published two of the top ten articles, respectively.

Among 3546 microplastics-related articles, four articles ranked in the top ten $TC_{2020}$ and $C_{2020}$, indicating the most frequently cited and most impactful articles. The four important articles in 2020, considering high citations and impacts, were discussed as below:

1. Accumulation and fragmentation of plastic debris in global environments (Barnes et al. 2009)

$$TC_{2020} = 1737, \text{ rank first and } C_{2020} = 469, \text{ rank first.}$$

In this work, the global plastics production and the accumulation of plastic waste were briefly surveyed. The presence of plastic debris in global environments was discussed in detail, as was the accumulation trend. It was found that the particle size of plastics in the environment decreased and the abundance and worldwide distribution of microplastics increased in the past decades. Many studies on

**Table 5** The top ten most frequently cited articles with search keywords in their title or author keywords

| *R* ($TC_{2020}$) | *R* ($C_{2020}$) | Title | Country | References |
|---|---|---|---|---|
| 1 (1737) | 1 (469) | Accumulation and fragmentation of plastic debris in global environments | UK, France, USA | Barnes et al. (2009) |
| 2 (1281) | 2 (423) | Accumulation of microplastic on shorelines woldwide: Sources and sinks | Ireland, Australia, UK, Canada | Browne et al. (2011) |
| 6 (789) | 5 (249) | Microplastic ingestion by zooplankton | UK, Norway | Cole et al. (2013) |
| 7 (726) | 30 (140) | Synthetic polymers in the marine environment: A rapidly increasing, long-term threat | USA | Moore (2008) |
| 8 (676) | 8 (185) | Occurrence of microplastics in the gastrointestinal tract of pelagic and demersal fish from the English Channel | UK | Lusher et al. (2013) |
| 9 (589) | 11 (178) | Microplastic pollution in the surface waters of the Laurentian Great Lakes | USA | Eriksen et al. (2013) |
| 10 (583) | 14 (174) | Microplastics in bivalves cultured for human consumption | Belgium | Van Cauwenberghe and Janssen (2014) |
| 11 (578) | 7 (200) | The impact of debris on marine life | UK | Gall and Thompson (2015) |
| 12 (544) | 12 (177) | Uptake and effects of microplastics on cells and tissue of the blue mussel *Mytilus edulis* L. after an experimental exposure | Switzerland, Germany | Von Moos et al. (2012) |
| 13 (537) | 13 (176) | Ingestion and transfer of microplastics in the planktonic food web | Finland | Setälä et al. (2014) |

$TC_{2020}$ the total number of citations from Web of Science Core Collection since publication year to the end of 2020, $C_{2020}$ the number of citations of an article in 2020 only, *R* ranking in 3546 microplastics articles

microplastics reported the occurrence and abundance of microplastics in different regions, providing better knowledge of the sources, quantities, and distribution. More valuable and comparable data were still required due to the variation in sampling methodology. In addition, it was pointed out that the environmental consequences of microplastics were still poorly understood.

2. Accumulation of microplastic on shorelines worldwide: sources and sinks (Browne et al. 2011)

$$TC_{2020} = 1281, \text{ rank second and } C_{2020} = 423, \text{ rank second.}$$

Browne et al. (2011) reported a worldwide study on the sources and transfer pathways of microplastics. It was found that fibers from washing clothes were an important source of microplastics. A large amount of microplastic fibers were identified in marine environments, and most of them originated from sewage

effluent because of the washing of clothes. This study offered novel insights into the sources, abundance, sinks, and pathways of microplastic into the environment. Subsequently, more research interests are paid on microplastics in the freshwater environment.

3. Microplastic ingestion by zooplankton (Cole et al. 2013)

$$TC_{2020} = 789, \text{ rank sixth and } C_{2020} = 249, \text{ rank fifth.}$$

Intake of microplastics by various marine biota has been widely reported by researchers, such as mussels, fish, and seabirds. Cole et al. conducted research on microplastic ingestion by zooplankton due to their important ecological role in marine food webs (Cole et al. 2013). Bioimaging techniques were employed to examine the microplastics in zooplankton in different stages, such as ingestion, egestion, and adherence. Ingestion of microplastics by zooplankton in the ocean was verified, and negative impacts included reduced function and health, transferring pollutants to predators, and the ingesting of fecal pellets. This study not only provides insights into the knowledge of microplastic contamination in aquatic environments but also induces significant attention to the problems of microplastic pollution.

4. Occurrence of microplastics in the gastrointestinal tract of pelagic and demersal fish from the English Channel (Lusher et al. 2013)

$$TC_{2020} = 676, \text{ rank eighth and } C_{2020} = 185, \text{ rank eighth.}$$

In this work, the abundance of microplastics in natural environments was investigated through the fish samples from the English Channel. It was reported that the studied pelagic species and demersal species had ingested microplastics. Polyamide (36%) and rayon (58%) were the most common types of ingested plastics. The potential consequences of ingesting microplastics were not studied. The widespread occurrence of microplastics and their ingestion by fish suggest that revealing the potential risks of microplastics in the marine environment is imperative.

## *3.9 Research Focuses and Their Trends*

To better understand the research topic, the keywords in microplastics-related publications were examined. A total of 3257 articles (92% of 3546 articles from 1991 to 2020) published in the active period from 2013 to 2020 were further analyzed for research focuses and their trends. The words in article Title, Abstracts, author keywords, and *KeyWords Plus* were explored, and microplastics-related articles were ranked based on the study period, which was exhibited in Supplementary Material A, B, and C. The top 20 author keywords commonly mentioned in articles were listed in Table 6. Besides the keywords, including microplastic, microplastics, micro-plastic, and micro-plastics, plastic pollution

**Table 6** Top 20 author keywords in publications related to microplastics

| Author keywords | TP | 2013–2020 Rank (%) | 2013–2014 Rank (%) | 2015–2016 Rank (%) | 2017–2018 Rank (%) | 2019–2020 Rank (%) |
|---|---|---|---|---|---|---|
| Microplastics | 1234 | 1 (45) | 1 (27) | 1 (44) | 1 (46) | 1 (46) |
| Microplastic | 511 | 2 (19) | 2 (15) | 2 (19) | 2 (21) | 2 (18) |
| Plastic pollution | 139 | 3 (5.1) | 7 (3.8) | 7 (4.3) | 4 (4.7) | 3 (5.4) |
| Pollution | 129 | 4 (4.8) | 5 (5.1) | 5 (5.3) | 3 (5.9) | 5 (4.3) |
| Marine debris | 110 | 5 (4.1) | 3 (13) | 3 (10) | 7 (4.0) | 8 (3.1) |
| Sediment | 109 | 6 (4.0) | 7 (3.8) | 54 (1.0) | 9 (3.5) | 4 (4.5) |
| Marine litter | 90 | 7 (3.3) | 7 (3.8) | 4 (6.2) | 6 (4.5) | 13 (2.6) |
| Plastic | 87 | 8 (3.2) | 4 (11) | 8 (3.3) | 7 (4.0) | 13 (2.6) |
| Ingestion | 79 | 9 (2.9) | 7 (3.8) | 6 (4.8) | 4 (4.7) | 17 (2.1) |
| Polystyrene | 79 | 9 (2.9) | 40 (1.3) | 11 (2.4) | 14 (2.5) | 6 (3.2) |
| Polyethylene | 74 | 11 (2.7) | N/A | 8 (3.3) | 10 (3.2) | 11 (2.6) |
| Nanoplastics | 73 | 12 (2.7) | N/A | 17 (1.9) | 17 (1.8) | 6 (3.2) |
| Freshwater | 70 | 13 (2.6) | N/A | 17 (1.9) | 11 (2.7) | 10 (2.7) |
| Adsorption | 67 | 14 (2.5) | 40 (1.3) | 122 (0.48) | 22 (1.5) | 8 (3.1) |
| Fish | 61 | 15 (2.2) | 12 (2.5) | 27 (1.4) | 15 (2.3) | 15 (2.3) |
| Oxidative stress | 53 | 16 (2.0) | N/A | N/A | 60 (0.84) | 11 (2.6) |
| Sorption | 52 | 17 (1.9) | 40 (1.3) | 17 (1.9) | 19 (1.7) | 18 (2.0) |
| Marine pollution | 51 | 18 (1.9) | 12 (2.5) | 11 (2.4) | 11 (2.7) | 22 (1.5) |
| Plastic debris | 48 | 19 (1.8) | 40 (1.3) | 11 (2.4) | 11 (2.7) | 25 (1.4) |
| Surface water | 47 | 20 (1.7) | N/A | 122 (0.48) | 40 (1.0) | 16 (2.2) |

*TP* total number of articles, N/A not available

was the most commonly employed author keyword in 2013–2020 (in 139 articles; 5.1%), followed by pollution (129; 4.8%), marine debris (110; 4.1%), and sediment (109; 4.0%). Based on the results of keywords, it can be deduced that microplastics gain great attention due to environmental problems. The potential pollution from microplastics becomes the key concern. Reports on microplastics date back to the 1970s, and less attention was received until the beginning of the twenty-first century (Shim et al. 2018). Motivated by the report of Thompson et al. (2004), renewed interest over the last decade has made microplastics an emerging research area with an emphasis on environmental pollution. Numerous studies have been reported on microplastics in marine environment, and this is in agreement with the keywords of marine debris. Three keywords "marine debris", "marine litter", and "marine pollution" suggest that great attention is paid to microplastics in the marine environment and the potential environmental pollution. The sources, fate, and potential impacts of microplastics are extensively investigated in marine environments (Auta et al. 2017). Subsequently, researchers expanded the focus to freshwater and terrestrial environments since an estimated 80% of microplastics in the marine environment derive from land (Rochman

2018). This meets the top keywords of "sediment," "freshwater," and "surface water." "Freshwater" and "surface water" are used as author keywords since the period of 2015–2016, and the rank of them has increased constantly, especially for "surface water", implying that microplastics in freshwater environment gain increasing attention in the past several years.

With the increasing occurrence and abundance of microplastics, the potential threats to marine life gain more interest. Microplastics are of special concern due to their accessibility to many organisms and their potential for physical and toxicological injury (Habibi et al. 2022). Microplastics are of special concern due to the accessible size to many organisms with potential physical and toxicological injury (Habibi et al. 2022). The keywords "ingestion," "fish," and "oxidative stress" reveal great interest in the consequences of microplastics on aquatic organisms and animals. The emerging keyword "oxidative stress" since 2017 and its elevated rank suggest in-depth research on the potential threat of microplastics. "Nanoplastics" as an emerging keyword since 2015, and nanoplastics receive special interests owing to the nano-specific features, such as larger surface area, more accessible size for organisms, and difficulty in detection (Koelmans et al. 2015). "Adsorption" and "sorption" refer to the interaction of toxic chemicals with microplastics (Wang et al. 2018), and this is a hot topic relating to the toxicity of microplastics in environments.

The keywords "polyethylene" and "polystyrene" are related to the types of microplastics. The existence of different microplastics has been reported in various environments. The major polymer types of microplastics involve (1) polyethylene, (2) polystyrene, (3) polypropylene, (4) polyethylene terephthalate, (5) polyester, (6) polyvinyl chloride, and (7) polyamide. Fig. S1 shows the development of research trends of the eight polymers and microplastics. Polyethylene is the most-frequently-mentioned microplastics followed by polystyrene and polypropylene, and this agrees well with the composition of microplastics in real environment. The number of articles mentioning polyethylene, polystyrene, and polypropylene increased sharply after 2016.

Microplastics in the marine environment are mainly derived from the transport of terrestrial microplastics in the waterbody. Wastewater treat plant is a vital source of microplastics in the waterbody, and atmosphere is also a migration pathway for microplastics (Jiang et al. 2022c). The previous research on the microplastics abundance focused on the natural environments, including marine, freshwater, soil, and atmosphere environments. However, with the microplastics transportation in the food chain, current research about the abundance of microplastics in human blood, feces, and fetuses attracts more attention. The relationship between health and microplastics has been emphasized. The threat of microplastics could be divided into the direct and indirect hazards to ecosystems. In addition to the adsorption of heavy metals, metalloids, and organic pollutants on microplastics surfaces (Wang et al. 2021b), researchers are more interested in the combined toxicity of microplastics and pollutants and the migration of microplastics into organisms. Besides, the focus of research has gradually shifted from microplastic toxicity to aquatic organisms and mice to the effects of microplastics on human health (Prata et al. 2020).

Research on microplastics includes several topics: (1) the occurrence and distribution of microplastics in the marine environment and global regions; (2) the ingestion and potential threat of microplastics to marine life and the ecological environment; (3) the sources and transfer of microplastics from human habits; (4) the interactions between microplastics and other toxic substances for identifying the potential threat of microplastics; and (5) the occurrence and abundance of microplastics in soil, sediments, and the atmosphere. It should be pointed out that the identification of microplastics is highly dependent on the sampling methodology. Research data in the initial stage may be misleading due to inappropriate sampling. With significant advances in sampling technologies, more valuable and comparable data can be reported (Barnes et al. 2009). With better knowledge and an in-depth understanding of the wide existence and penitential threats of microplastics, the control of microplastics discharge and the removal of microplastics from the environment are becoming imperative (Wang et al. 2022; Jiang et al. 2022d).

## 4 Conclusion

1. A total of 4026 documents of microplastics-related studies were collected; 14 document types were involved, and articles accounting for 84% were used for bibliometric analysis. English was the most widely used language among nine languages.
2. The number of articles increased sharply since 2015, indicating that microplastics received increasing attention in the research field. This can be ascribed to finding a new topic or research interests about microplastics. Web of Science category of environmental sciences was the leading category (69% of 3546 articles). This implies that microplastics become emerging pollutants and gain great attention due to potential environmental threats. Microplastics-related research was published in 566 journals, and the top three most productive journals included *Marine Pollution Bulletin*, *Environmental Pollution*, and *Science of the Total Environment*.
3. Of the 3536 articles on microplastics from 107 different countries, articles from single country accounted for 72%, while the percentage of articles with international collaborations was 28%. China was the most productive country, followed by USA, Germany, UK, and Italy. In additional, single-institution and inter-institutionally collaborative articles were 33% and 67% of these microplastics-related papers. The top 3 institutes were from China, including Chinese Academy of Sciences, University of Chinese Academy of Sciences, and East China Normal University.
4. The most impactful articles in 2020 were discussed. With the increasing occurrence and abundance of microplastics, the potential threats to marine life gain more interest. The major polymer types of microplastics involve polyethylene, polystyrene, polypropylene, polyethylene terephthalate, polyester, polyvinyl chloride, and polyamide. The research focus and perspectives were briefly summarized. This work provides insights into a better understanding of microplastics-related research.

**Conflicts of Interest** The authors declare no conflict of interest.

**Data Availability Statement** Data available on request from the authors.

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