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The COVID-19 pandemic reshapes the plastic pollution research – A comparative analysis of plastic pollution research before and during the pandemic

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The outbreak of the COVID-19 pandemic has exacerbated plastic pollution worldwide. So has the COVID-19 pandemic changed the research on plastic pollution? This work aims to explore the impact of the pandemic on plastic pollution research by comprehensively assessing the current status and prospects of plastic pollution research before and during the COVID-19 pandemic. A collection of publications on the topic of plastic pollution in the Web of Science database concludes that the COVID-19 pandemic has reshaped the plastic pollution research: (i) The COVID-19 pandemic has changed the trend of plastic pollution publication output. Since the COVID-19 pandemic, the number of publications on the topic of plastic pollution has shown a significant increase trend; (ii) The COVID-19 pandemic has reversed the global research landscape of research on the plastic pollution. Since the outbreak of the pandemic, more and more countries have begun to pay attention to plastic pollution. Before the pandemic, developed countries were global leaders in plastic pollution research. However, during the pandemic, developing countries began to have a significant share in the quality, quantity and international cooperation of publications; (iii) The COVID-19 pandemic has redefined the major hotspots of plastic pollution research. The focus of research has changed significantly since the pandemic. Solving plastic pollution has become a major research content. During the epidemic, in-depth research on microplastics was conducted. The results of mining the publications on plastic pollution show that there is currently no effective solution to plastic pollution caused by the COVID-19. However, given the seriousness of controlling plastic pollution, it is very necessary to continue to carry out more research.

1. Introduction

At the end of December 2019, the Corona Virus Disease 2019 (COVID-19) first appeared in Wuhan, Hubei Province, China. On January 30, 2020, the World Health Organization (WHO) recognized the outbreak constitutes a Public Health Emergency of International Concern (PHEIC). After the emergence of the virus, it spread rapidly in all countries and regions in the world. Therefore, the WHO declared COVID-19 a pandemic on March 11, 2020 (Organization, 2020). COVID-19 not only harms people’s health and the world economy, but also threatens the sustainability of the environment (Sharma et al., 2020; Wang et al., 2022b; Wang and Zhang, 2021). Among them, the sudden surge in demand for plastic products is one of the serious impacts of the epidemic on the environment.

During the COVID-19 pandemic, plastic pollution has increased. COVID-19 is a severe respiratory syndrome (Ghebreyesus, 2020), with multiple transmission mechanisms and routes, including direct transmission between people and indirect air transmission, etc. (Noorimotlagh et al., 2021a; Vosoughi et al., 2021), and it is extremely contagious. Based on these approaches, personal protective equipment (PPE) (containing large amounts of plastic) such as masks and gloves are recommended to prevent the spread of the virus (Marzoli et al., 2021), leading to a surge in plastic waste (Aalto-Korte et al., 2007; Aslan et al., 2013; Lee et al., 2019). At the same time, plastic is one of the important

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components of medical equipment and protective equipment. Due to the outbreak of the epidemic, the use of PPE such as masks and protective clothing by medical staff has increased significantly, and they are discarded after one-time use, resulting in a large amount of medical plastic waste, which seriously threatens the ecological environment (Organization, 2016; Torres and De-la-Torre, 2021; Walker, 2020). In order to control the spread of COVID-19, countries around the world have adopted various levels of containment measures to limit the movement of people (Arthi and Parman, 2021; Michie, 2020; Yip et al., 2021). Thus, consumption patterns have gradually shifted from offline to online (Hobs, 2020), and the increasing demand for plastic packaging products including medicines, online food and groceries has become the main source of plastic waste during the COVID-19 pandemic (Scaraboto et al., 2020; Singh, 2020). In addition, the plastic waste management system is also facing severe challenges (Vanapalli et al., 2021). During the COVID-19 outbreak, medical waste has grown exponentially every day. In Wuhan, China, medical waste has increased from the normal level of 40 tons/day to a peak of about 240 tons/day, exceeding the maximum incineration volume of 49 tons/day (Klemes et al., 2020). And the medical waste disposal in many cities was overloaded (Tang, 2020).

In response to the current crisis, scholars are increasingly turning their attention to the plastic pollution research. Research on the COVID-19 pandemic and plastic pollution has become a hot topic at present. Since the beginning of the epidemic, a large number of relevant studies have been published on the plastic pollution. In this context, whether the COVID-19 epidemic has affected the scientific research of plastic pollution is a question worthy of discussion. Therefore, this article synthesizes the existing knowledge system in this field based on published articles and research results, aiming to study the research status of plastic pollution before and during the COVID-19 pandemic, and then explore whether the COVID-19 epidemic has changed the plastic pollution research.

2. Literature review

Plastic pollution is widespread worldwide. Plastic pollution refers to the accumulation of plastic products in the environment. Plastics are widely present in terrestrial, marine and freshwater ecosystems around the world (Rochman, 2018). They are a complex pollutant that can cause a variety of sublethal and lethal effects (Paul-Pont et al., 2018; Underwood et al., 2016). The global production and use of plastic products are increasing, and plastic pollution has become a serious transboundary threat to natural ecosystems and human health (Patricio Silva et al., 2021). The outbreak of COVID-19 has exacerbated the severity of plastic pollution, and related literature has also increased significantly. Table 1 shows some relevant literature on plastic pollution.

According to Table 1, it can be seen that numerous scholars have conducted a systematic review of the relevant literature in order to grasp the characteristics and current status of plastic pollution. Bucci et al. conducted a systematic review of the plastic fragment literature based on meta-analyses and systematic reviews to determine the status of evidence regarding the effects of macroplastics and microplastics on freshwater, marine, and terrestrial organisms at all levels of biological tissues (Bucci et al., 2020). Based on the research of plastic pollution, Li et al. summarized the main characteristics of plastic pollution in the environment and proposed the research trend of future work (Akdogan and Guven, 2019; Li et al., 2020). Blettler et al. conducted a bibliometric analysis of papers on the topic of freshwater plastic pollution, and determined the knowledge gaps and research biases (Blettler et al., 2018). The status of plastic pollution in marine ecosystems and terrestrial systems has also been explored (Thushari and Senevirathna, 2020; Zhang et al., 2020a). Moreover, research on the COVID-19 epidemic and plastic pollution has aroused strong attention from scholars. For example, emphasized the impact of COVID-19 on plastic waste (Vanapalli et al., 2021). Summarized the impact of COVID-19 on large plastic pollution and its potential impact on the environment and human health.

Table 1
Research on plastic pollution.

| Ref.                     | Title                                                                 | Main research content                                                                 |
|-------------------------|----------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Vanapalli et al. (2021) | Challenges and strategies for effective plastic waste management and post COVID-19 pandemic | Present a prospective outlook on the disruption caused by COVID-19 on plastic waste management throughout the world. Provide a comprehensive overview on the effects of COVID-19 on macroplastic pollution and its potential implications on the environment and human health considering short- and long-term scenarios. Present the main challenges and discuss potential strategies to overcome them. |
| Patrício Silva et al. (2021) | Increased plastic pollution due to COVID-19 pandemic: Challenges and recommendations | Conduct a systematic review of the literature to determine the status of evidence regarding the effects of macroplastics and microplastics on freshwater, marine, and terrestrial organisms at all levels of biological tissues. Provide an overview of the characteristics of plastic pollution in the environment and suggest research trends in future work. |
| Bucci et al. (2020)      | What is known and unknown about the effects of plastic pollution: A meta-analysis and systematic review | Review the scientific literature related to microplastic research in different environmental compartments and identify the research gaps for the assessment of future research priorities. Conduct a bibliometric analysis of papers on the topic of freshwater plastic pollution, and identify knowledge gaps and research biases. |
| Li et al. (2020)         | Characteristics of Plastic Pollution in the Environment: A Review | Show the current status of plastic pollution in marine ecosystems. Discuss the main applications and consequences of plastics during the COVID-19 pandemic based on recent literature, as well as some possible solutions. |
| Akdogan and Guven (2019) | Microplastics in the environment: A critical review of current understanding and identification of future research needs | Review the scientific literature related to microplastic research in different environmental compartments and identify the research gaps for the assessment of future research priorities. |
| Thushari and Senevirathna (2020) | Plastic pollution in the marine environment | Conduct a systematic review of the effects of microplastics and macroplastics on freshwater, marine, and terrestrial organisms at all levels of biological tissues. |
| de Sousa (2021)          | Plastic and its consequences during the COVID-19 pandemic | Conduct a systematic review of the effects of microplastics and macroplastics on freshwater, marine, and terrestrial organisms at all levels of biological tissues. |
| de Sousa (2020)          | Pros and Cons of Plastic during the COVID-19 Pandemic | Conduct a systematic review of the effects of microplastics and macroplastics on freshwater, marine, and terrestrial organisms at all levels of biological tissues. |
| Sarkodie and Owusu (2021) | Impact of COVID-19 pandemic on waste management | Assess the impact of COVID-19 on plastic waste management across the globe. |
| Rhodes (2018)            | Plastic pollution and potential solutions | Conduct a systematic review of the effects of microplastics and macroplastics on freshwater, marine, and terrestrial organisms at all levels of biological tissues. |
in the short and long term (Patricio Silva et al., 2021). In view of the importance of plastics during the ongoing COVID-19 epidemic, after summarizing the main applications and consequences of plastics, potential strategies to overcome these challenges and some possible solutions have also been heatedly discussed (de Sousa, 2020, 2021; Patricio Silva et al., 2021).

The COVID-19 epidemic has clearly exceeded people’s awareness of the threat of plastic pollution, forcing residents to increase their dependence on plastic in their lives, forming a new plastic waste plague (Vanapalli et al., 2021). According to research, in order to prevent the spread of the COVID-19 virus, some areas such as New York and Massachusetts have temporarily postponed or cancelled the ban on single-use plastic bags (Boney, 2020), which may re-inspire consumers to discard the culture that prohibits the use of plastics (Prata et al., 2020). This hinders the long-term goal of transitioning to a circular economy. Also, the COVID-19 epidemic has brought new challenges to the plastic waste management (Rcho et al., 2021). Related studies predicted that the number of plastic fragments will triple by 2030 (Patricio Silva et al., 2021). Combating the danger of plastic pollution has become an important task for global governments, commercial companies and local communities (Schuur et al., 2018), Sarkodie and Owusu assessed the impact of the COVID-19 epidemic on waste management (Sarkodie and Owusu, 2021). Vanapalli et al. provided a forward-looking outlook on the damage caused by COVID-19 to plastic waste management, and also proposed future directions and recommendations for inclusive and sustainable plastic waste management (Faezeh et al., 2021; Vanapalli et al., 2021).

In fact, in the existing research, even many scholars have reviewed the relevant literature on COVID-19 and plastic pollution. However, few studies have systematically reviewed the impact of the COVID-19 epidemic on plastic pollution research. Many recent studies have addressed some aspects of the impact of COVID-19 (Maleki et al., 2021; Noorimotlagh et al., 2021b; Wang et al., 2022a). Bibliometrics is an information analysis method widely used in academia. It can make full use of the existing knowledge base to comprehensively analyze the results of previous research and provide a more objective and reliable analysis (Rongrong et al., 2017). The use of bibliometric methods to analyze the scientific results related to recent public health emergencies can help reveal the specific contributions made by the academic community to solve the health crisis (Zhang et al., 2020b). Currently, bibliometric research is playing an increasingly important role in responding to international public health emergencies. Therefore, this article uses bibliometric analysis to systematically review the research literature on plastic pollution contained in the Web of Science (WOS) database, and innovatively compare and analyze the publication output, the global research pattern and research hotspots before and during the epidemic. The specific contributions are as follows: Firstly, analyze the output trend of publications on the plastic pollution. Secondly, through the geographical distribution of publications and cooperation networks, explore the changes in the global research pattern of plastic pollution research before the pandemic and during the pandemic. Finally, by using clustering, mine the main research content of plastic pollution research in the five years before and during the pandemic.

3. Material and methods

3.1. Research design

In order to discuss the changes in plastic pollution research before and during the COVID-19 pandemic, we mainly start from three major perspectives: the publication output pattern, the global research landscape and the research hotspot. The literature on plastic pollution in the WOS Core Collection database is systematically reviewed through bibliometric. In order to show the global plastic pollution research status before and during COVID-19, we create and compare two data sets: (a) publications on plastic pollution research from January 1, 2015 to December 31, 2019; (b) publications on plastic pollution research from January 1, 2020 to August 31, 2021. As COVID-19 broke out in December 2019, we chose January 1, 2020 as the starting point for COVID-19 to ensure the timeliness and pertinence of this article. Therefore, the publication data set from January 1, 2020 to August 31, 2021 represents publications during the COVID-19 period. The five-year data from January 1, 2015 to December 31, 2019 is used as a publication indicator before the COVID-19 pandemic to compare with the research status during the COVID-19 period. This article will follow the standard scientific drawing workflow, divided into four stages for analysis: (1) design research questions; (2) determine the database, keywords and time range; (3) collect data; (4) display and analyze the results. Fig. 1 shows the specific research framework of this study.

3.2. Methodology

3.2.1. Bibliometrics

Bibliometrics is an advanced technology used to summarize, analyze and visualize various disciplines (Lio et al., 2018). It is an effective comprehensive knowledge evaluation system that combines mathematics, statistics and linguistics. Bibliometrics can help researchers grasp the basic structure, development hotspots, development trends and other information of the research field by analyzing a large amount of historical document data. In addition, the bibliometric analysis method focuses on the overall research of the literature, organically combines qualitative analysis and quantitative analysis, breaking the limitations of traditional information analysis methods that cannot be quantified and repeatable. Bibliometrics is an important tool to analyze large-scale research literature and determine the development status and research results of a field. It has been widely used to reveal the research status of various research fields. Therefore, in this research, we use bibliometric methods to objectively describe and summarize the research status of plastic pollution.

3.2.2. Visual analysis

Network vision analysis visualizes the analysis results by mapping the knowledge domain. Visual analysis can draw a complex knowledge domain into a visual knowledge graph through data mining, information processing and knowledge measurement, reveal the dynamic development of the knowledge domain, and help users quickly obtain applicable scientific intelligence information. In addition, by visualizing research results, work efficiency can be improved, and errors caused by manual analysis can be reduced or avoided, which greatly improves the accuracy and reliability of the results. Many software tools can be used to support bibliometric analysis, such as VOSviewer, CiteSpace, BibExcel, R, CitNetExplorer, SciMAT, VantagePoint and Gephi. This article mainly uses VOSviewer and CiteSpace visualization software to visualize the retrieved data. CiteSpace and VOSviewer are information visualization software developed using Java language (Chen and C., 2004). They can combine data mining algorithms, bibliometrics and information visualization (Kou et al., 2021), and can be used to make maps to visualize bibliographic network data. CiteSpace and VOSviewer software take into account the dual characteristics of “graph” and “spectrum”, which are both a visualized knowledge graph and a serialized knowledge pedigree. They can centrally display the evolution of knowledge in a certain field on a map, presenting many potentially complex relationships between knowledge and information, such as networks, structures, intersections, or derivations. Furthermore, CiteSpace and VOSviewer can also be used to construct and visualize the co-occurrence network of important terms extracted from publications, so as to accurately capture scientific frontiers, hotspots and trends in specific fields. They have become popular knowledge graph drawing tools and are widely used. It is applied to many fields of bibliographic analysis. Therefore, we use VOSviewer to conduct national co-occurrence analysis to determine the international cooperation networks for plastic pollution research before and during the pandemic, and use CiteSpace to draw the hotspot cluster.
views of plastic pollution research before and during the pandemic.

3.2.3. Text cluster analysis

In order to better analyze the difference between the research topics of plastic pollution before and during the pandemic, and fully grasp the hot spots in the field of plastic pollution research, we need to use the text clustering method to perform cluster co-occurrence analysis on keywords. Co-word clustering analysis adopts the clustering calculation method to perform correlation calculations according to the co-occurrence frequency of keywords (Zhong et al., 2008), and classifies closely related words to obtain the topic network to observe the evolution trajectory of subject knowledge (Ca Llon et al., 1991; Law and Whittaker, 1992). Keyword is usually the core and essence of an article, it is a high-level generalization and refinement of the topic of the article. Therefore, keyword analysis allows people to determine the current research focus by summarizing the content of commonly used keywords. Keyword cluster analysis is the basis for distinguishing the frontiers of research in this field. It can reveal the turning points of research fields and themes, and clarify the links between fields (Qin et al., 2014). Author keywords can reflect the issues involved in the article and the author’s preference, so the author keywords are more suitable for describing the research focus and characteristics of the article (Wang et al., 2012, 2017). Consequently, we analyze the author keywords in this study through keyword clustering and network analysis.

3.3. Data collection

High-quality shared data is the key to understanding, managing and mitigating the impact of the epidemic. The data collected in this paper comes from the WOS Core Collection database (Gong et al., 2019). The WOS Core Collection is a high-quality digital database that covers a wide range of publications from different fields and is a comprehensive citation database with wide coverage (Archambault et al., 2006; Mongeon et al., 2016). Databases such as WOS and Scopus are the main data sources for bibliometric analysis. Many studies have compared these mainstream databases and found that WOS and Scopus produce similar results in bibliometric analysis and have good consistency (Archambault et al., 2009; Falagas et al., 2008; Norris and Oppenheim, 2007). Of course, there are differences between the WOS and Scopus databases. Scopus contains a wider coverage of publications and more related bibliometric data than WOS (Meho and Rogers, 2008; Wang et al., 2021a). On the other hand, according to related studies, WOS can provide higher quality data, including a complete record of each article and detailed citation analysis, which makes data processing more efficient (Lopes and de Carvalho, 2018; Martín-Martín et al., 2018; Odriozola-Fernández et al., 2019). And in terms of social sciences and humanities, WOS is recommended because of its high proportion of exclusive journals (Mongeon and Paul-Hus, 2016; Norris and Oppenheim, 2007). The WOS Core Collection has always maintained strict journal selection standards and evaluation process, and its journal evaluation standards have been recognized by the international academic community. At present, a large number of articles use WOS as a data source for bibliometric analysis, and reliable conclusions can be obtained (Gao et al., 2020a, 2020b; Zhang and Liang, 2020). Therefore, we select the relevant documents to be retrieved from the WOS Core Collection database and collect the data to carry out the corresponding research. The search field used in this study is TS, which contains title, abstract, and keywords. Keywords retrieved include “plastic pollution” and “plastic waste” and so on. The time range is 2015–2021, and the search time is August 31, 2021. According to the search criteria, a total of 3729 articles were obtained through strict and systematic search. Subsequently, the screening work was carried out. This study selects documents based on the following criteria: (1) delete non-English articles and only use English articles; (2) select articles whose document types are “Article” and “Review”; (3) delete articles that are not related to plastic pollution, and select articles that are closely related to the scope of this article. A total of 56 articles were deleted. Eventually, 3673 articles published on the WOS database were obtained, of which 1550 articles were published from 2015 to 2019, and 2123 articles were published from 2020 to 2021. All data are exported as complete records for result analysis. Fig. 2 shows the research data collection process.

4. Results and analysis

4.1. Trend of global plastic pollution publications output

The amount of scientific literature in a field is an important indicator to evaluate the research ability of the group in this field, and it is also extremely important for evaluating the current development of the field. According to statistics, the annual change trend of the total number of publications and the daily average number of publications is shown in Fig. 3. Between 2015 and 2021, 3,673 papers on the plastic pollution are included in the WOS database. Since 2015, the total number of scientific publications on the subject of plastic pollution has been increasing, especially the number of publications in 2020 is as high as 1,088, with an average annual increase of 470. The daily average number of publications on the plastic pollution research also shows an upward trend. What is more obvious is that from 2019 to 2021, the daily average number of publications has increased rapidly. In 2019, the average daily number of publications is 1.693. But in 2021, it reaches 4.295. This may be related to the occurrence of the COVID-19 pandemic at the end of 2019. After the WHO declared that COVID-19 became a PHEIC on January 30, 2020, government agencies and research institutes around the world have launched a large number of relevant studies to alleviate the challenges posed by COVID-19. We also observe that the total number of publications from 2020 to 2021 (2,123 publications) is much
higher than that in the five years of 2015–2019 (1,550 publications). Also, the daily average number of publications from 2020 to 2021 is 1.712 times that of 2015–2019. This shows that after the outbreak of the COVID-19 epidemic, global attention to plastic pollution has increased, and many scholars have conducted a large number of continuous studies to respond to the challenges posed by the epidemic to plastic pollution management.

4.2. Comparative analysis of global research landscape before and during COVID-19

In this section, we conduct a comparative analysis of the global research landscape before and during COVID-19 to discuss the changes in plastic pollution research.

4.2.1. Geographical distribution of publications

The global geographic distribution of related research work can show the different research capabilities of countries/regions. In order to show the state of scientific production in various countries, the information that authors record in publications is used to track their countries and then to calculate the total number of publications in those countries. Tables 2 and 3 show the performance of publications in the top ten productive countries before and during the COVID-19 pandemic, respectively. Figs. 4 and 5 respectively show the global distribution of publications in these two time periods. In the map, different colors are used to distinguish the country/region’s active participation in plastic pollution research.

According to statistics, 105 countries participated in research related to plastic pollution during 2015–2019. Most of these countries are located in Asia, Europe and America, and Oceania is also an important part. At the national level, the color of the United States on the map is closest to red, indicating that the United States ranks first in the number of publications, with a total of 191 articles, ahead of other countries.
Followed by China (187 publications) and the United Kingdom (142 publications). India (137 publications) and Australia (117 publications) are ranked fourth and fifth respectively, followed by Spain, Germany, France, and Canada. Moreover, in terms of total citations, the United States ranks first in the world with 14,855 total citations, followed by the United Kingdom (8,311 citations) and Australia (8,116 citations). China and India have low total citations and rank relatively low. It can be observed that during this period, developed countries play a dominant role in plastic pollution research, and there is a gap between developing and developed countries in terms of the number of publications and the total citations.

From 2020 to 2021, 111 countries participated in plastic pollution research, which shows that since the epidemic, more and more countries have begun to pay attention to the development of plastic pollution. Regarding scientific production in various countries, the most relevant country is China, which has 318 publications. The ten most productive countries are shown in Table 3: China (318 publications), the United States (275 publications), the United Kingdom (187 publications), India (177 publications), Italy (136 publications), Spain (135 publications), Germany (130 publications), Australia (126 publications), Canada (97 publications) and France (92 publications). Although the countries with higher productivity have not changed, the number of publications in these countries has increased significantly compared with before the epidemic, especially China. Secondly, from the perspective of the total citations, the country with the most citations is no longer the United States but China, with 1,976 citations, and India’s citations and rankings have also risen. Therefore, it can be found again that COVID-19 has prompted all countries in the world to increase their research on plastic pollution, especially in developing countries such as China and India, which have made great progress in the quantity and quality of publications.

4.2.2. Global cooperation

Fig. 6 shows the country co-authoring network before and during the
pandemic. In the network map, nodes (circles) represent different countries, and the size of each node represents the number of publications. The degree of cooperation is explained by the line between the nodes, with a thicker line between two nodes representing a higher degree of cooperation between the two countries, and a thinner line representing a lower degree of cooperation between the countries.

It can be seen from Fig. 6 that during the COVID-19 pandemic, the number of connections between countries in the network map increase, indicating that more countries have carried out international cooperation. The ties between most countries have been significantly strengthened. Before the pandemic, cooperation among countries in this field is mainly concentrated in developed countries and many cooperative groups are formed, while the cooperation from developing countries is less. However, during the pandemic, a large number of cooperative researches are conducted between developing countries and developed countries.

According to the analysis in this section, we can draw conclusions that the epidemic has changed the global landscape of plastic pollution research. The outbreak of COVID-19 has prompted various countries in the world to strengthen research on plastic pollution.

4.3. Comparative analysis of research hotspots before and during COVID-19

In this section, we conduct a comparative analysis of the research hotspots of plastic pollution before and during COVID-19 to explore the changes in plastic pollution research. Knowledge cluster analysis and evolutionary research are the basis for distinguishing the frontiers of research in this field, which can reveal the turning points of research fields and research topics, and clarify the connections between fields. The cluster view can show the distribution of research fields from different angles. It is a visual classification of existing research results, which is convenient for researchers to sort out the complicated data information efficiently. Therefore, the cluster graph generated by CiteSpace information visualization software is used to track the research hotspots in the research process. Fig. 7 shows the changes in research hotspots during 2015-2019 and 2020-2021. Each # in the figure represents a cluster. There are six clusters in the plastic pollution research during 2015 to 2019, and the cluster labels are #0 plastic pollution, #1 pyrolysis, #2 biodegradation, #3 concrete, #4 nanoplastic and #5 reuse. The cluster labels for plastic pollution research in 2020-2021 are #0 pyrolysis, #1 microplastics, #2 circular economy, #3 microplastics, #4 marine debris, and #5 biodegradation. These cluster labels characterize the main research themes of plastic pollution research before and during the pandemic.

Comparing the keyword cluster tags for the two time periods, it may reasonably conclude that the focus of research has changed significantly. With the challenges brought by the COVID-19 epidemic to the plastic pollution management, how to solve plastic pollution has become a hot topic, especially these cluster labels: pyrolysis, circular economy and
biodegradation. So as to understand the main content of plastic pollution research, the clustering results for 2020–2021 are further analyzed.

(a) Pyrolysis

Pyrolysis has always been a hot spot in the research of plastic pollution and related topics. It has been studied extensively both before and during COVID-19, especially during COVID-19. Although incineration is a common way to dispose of plastic waste (Geyer et al., 2017), it has many negative effects on the environment (Moharir and Kumar, 2019). Pyrolysis provides an environmentally friendly alternative to incineration and inefficient landfilling. Pyrolysis is the degradation of organic materials under heat and anaerobic conditions (Qureshi et al., 2020), which converts plastic waste into fuel, such as pyrolyzing relevant wastes (gloves, masks, etc.) generated during COVID-19 and converting them into liquid oil and other products (Al-Salem et al., 2017; Jung et al., 2021; Qin et al., 2018; Suresha et al., 2020). Pyrolysis provides an effective means of recovering energy and chemicals through carbon rearrangement. This alternative technology that converts plastic waste into value-added products can help turn the current COVID-19 crisis into an opportunity and reduce the negative impact of plastic waste on the environment and human health.

(b) Microplastics

Notably, microplastics occupy two major clusters in plastic pollution research during the epidemic, becoming one of the strongest keywords in this area. Microplastics refer to plastic fragments and particles less than 5 mm in diameter. They are considered to be emerging persistent pollutants and have become an issue of increasing concern around the world. Microplastics originate from the fragmentation of large plastic garbage or direct environmental discharge (de Souza Machado et al., 2018), and there are multiple sources of microplastics, as shown in Fig. 8. Human activities (such as inefficient waste management practices and littering), physical properties of plastic particles (such as shape, size, and density), climatic conditions (such as rainfall intensity and wind speed), and topography can affect the deposition and retention of microplastics in the soil environment (Karbalaei et al., 2018; Lei et al., 2018; Oliviero et al., 2019). In addition, other sources of microplastics in the terrestrial environment include household waste, personal care products, poorly managed solid waste landfills, etc. (B et al., 2017; Rillig et al., 2017; Zs et al., 2016; Zubris and Richards, 2005). Equally important, microplastics derived from medical applications, pharmaceuticals, and personal care cosmetics have received a lot of attention due to the outbreak of new coronary pneumonia. During the ongoing global COVID-19 pandemic, the handling of microplastics generated by PPE is considered a new current environmental challenge (de Sousa, 2020; Fadare and Okoffo, 2020). In particular, disposable masks used to slow down the spread of COVID-19 from person to person have become a key source of microplastic pollution due to improper disposal.

(c) Circular economy

Circular economy is an economic development model characterized by resource conservation and recycling, and in harmony with the environment. Its characteristic is that all materials and energy can be used reasonably and lastingly in this continuous economic cycle, thereby reducing the impact of economic activities on the natural environment to the smallest possible extent. The circular economy allows the used resources to be retained in the socio-economic system for a long time, and enables the waste in the disposal stage can be reused as a secondary raw material to ensure that natural resources are used as little as possible (Korhonen et al., 2018; Li et al., 2021; Rossi et al., 2020). At present, studies have been conducted to highlight the need for circular economy strategies such as reduction and recycling for the COVID-19 epidemic to minimize waste generation throughout the product life cycle (Kochańska et al., 2021; Parashar and Hait, 2020; Wang et al., 2022c). Therefore, in order to solve the environmental problem of plastic pollution, many countries are adopting different strategic systems to effectively use plastic waste and promote the use of technology that plastic waste replaces recycled materials of limited resources (Rajmohan et al., 2019). It aims to protect the environment from plastic pollution through the overall changes in the design, production, use and recycling of plastic products (Shin et al., 2020). For example: recycling masks used during

Fig. 8. Generation and dispersion of microplastics in terrestrial environments. Source: ([Kumar et al., 2020]).
the COVID-19 pandemic (Crespo et al., 2021; Dang et al., 2021; Jir-awattanasomkul et al., 2021; Torres and De-la-Torre, 2021). Thus, the establishment of a resource efficiency policy based on the concept of circular economy is essential for effective plastic waste management.

(d) Marine debris

A large amount of plastic waste generated globally enters the aquatic environment and has harmful effects on the aquatic system (Uhrin et al., 2021). For example, plastic fragments deposit in sediments and entangle marine animals. This problem has become more serious during the COVID-19 pandemic. Many scholars have tried to find different waste management methods to curb the exacerbation of the problem (Payne et al., 2019; Wang et al., 2021b).

(e) Biodegradation

Biodegradation has received a lot of attention from scholars before and during the pandemic. Plastic waste is the most difficult waste to solve because it is hard to biodegrade (Payne et al., 2019). In addition, the waste plastics accumulated in the environment can be further degraded into small pieces such as microplastics and nanoplastics through weathering, which are more harmful to the environment and humans than large plastics. The increase in global demand for plastics during COVID-19 has led to serious plastic waste pollution. In order to alleviate this phenomenon, a variety of plastic degradation modes have been studied and tried, including physical, thermal and chemical degradation methods (Mahadevan, 2021). Microbial-based plastic waste degradation strategies offer a feasible method to mitigate the environmental pressure caused by the accumulation of plastic waste (Qin et al., 2021; Sánchez, 2020).

5. Conclusion

This work systematically reviewed the publications related to plastic pollution in the WOS database before COVID-19 pandemic (2015–2019) and during COVID-19 pandemic (2020–2021). It aims to explore whether the COVID-19 epidemic has changed plastic pollution research. The main conclusions drawn in this article are as follows:

(i) The COVID-19 pandemic has changed the trend of publication output for plastic pollution research. Since 2015, the total number and the daily average number of publications have both shown an increasing trend, especially after the outbreak of the COVID-19 pandemic. The total number of publications in less than two years during the COVID-19 pandemic has been much higher than in the five years prior to the pandemic, indicating that the COVID-19 pandemic has prompted increasing attention to research on plastic pollution worldwide.

(ii) The COVID-19 pandemic has changed the global research landscape on the plastic pollution research. During the COVID-19 pandemic, the number of countries conducting plastic pollution research and the number of publications in a single country has increased pronouncedly compared to before the pandemic. Before the COVID-19 pandemic, developed countries played a leading role in plastic pollution related research and there was a certain gap between developing and developed countries in terms of both the number of publications and total citations. However, the quantity and quality of publications in developing countries such as China and India have been rapidly improved, and they have become an important part of the plastic pollution research during the COVID-19 pandemic. In addition, developing countries have obviously strengthened their cooperation with many developed countries.

(iii) The COVID-19 pandemic has changed the main hotspots of plastic pollution research. By mining the keyword clustering results before and during the COVID-19 pandemic, it is observed that the research content has changed significantly since the pandemic. How to solve plastic pollution has become a major focus. In addition, microplastics have been intensively studied during the pandemic, and improper handling of PPE is considered to be a key source of microplastics pollution.

In summary, the COVID-19 epidemic has reshaped the plastic pollution research. The output of plastic pollution publications, the global research landscape, and research topics have all changed. The impact of the COVID-19 epidemic on plastic pollution is profound and dynamic. Also, the surge in plastic pollution caused by the COVID-19 pandemic has not been resolved, which has seriously affected the global environmental situation and environmental supervision. Accordingly, in order to build a green, environmentally sustainable world, it is necessary to continue to increase the research results related to COVID-19 and plastic pollution to meet the challenge of the COVID-19 epidemic. Furthermore, it is recommend that future research further investigate the changes in plastic pollution research during the COVID-19 pandemic and enrich the selected databases for more comprehensive research.

Author contribution statement

Qiang Wang: Conceptualization, Methodology, Software, Data curation, Writing- Original draft preparation, Supervision, Writing- Reviewing and Editing. Min Zhang: Methodology, Software, Data curation, Investigation Writing- Original draft, Writing- Reviewing and Editing. Rongrong Li: Methodology, Data curation, Investigation Writing- Original draft, Writing- Reviewing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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