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Review

Bibliometric Analysis on the Papers Dedicated to Microplastics in Wastewater Treatments

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Abstract: The presence of microplastics (MPs) in the environment is becoming a problem for soils and seas, as well as for the food chain of animals and humans. The scientific community has been called upon to contribute to solving the problem and several papers have been published, especially in the last decade. The aim of this work is to carry out a bibliometric analysis of the scientific literature dedicated to the problem of MPs, highlighting its course over the years, and to identify the sectors to which the research could be profitably addressed. The VOSviewer software has been used to perform the analysis of the data in which specific maps were used to represent the network of the relationships among countries, journals, organizations, authors, and keywords related to the investigated topic and subtopics. The results of the survey demonstrated that during the investigated range of time, most attention has been paid to the individuation of the MPs, and to marine pollution, while a gap seems to exist in the possible advanced oxidation processes specifically addressing the degradation of MPs and their derivates.

Keywords: microplastics; bibliometric analysis; VOSviewer software; wastewater treatment; advanced oxidation processes

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1. Introduction

Nowadays the quality of water resources is seriously threatened by the discharge of various harmful pollutants that compromise its use for civil, industrial, and agricultural applications. To meet the ever-increasing demands of society, various techniques have been developed for the treatment of wastewater before it is discharged into the receiving bodies. Advanced oxidation processes, membrane filtration, electrochemical processes are often proposed to complement the standard purification processes, when their effectiveness is compromised by the presence in the wastewater of particularly bio-refractory compounds, such as the so-called persistent organic pollutants (POPs), or emerging pollutants.

A category of pollutants that is seriously endangering the health of the water in rivers and seas is represented by plastics and their derivatives. As polymers suitably designed to withstand mechanical and chemical stresses, the plastics have a very slow natural degradation process: the initial degradation involves, on the one hand, the release of possible additives, which may have their own toxicity; on the other hand, transformation of their size may occur that leads to so-called secondary microplastics, smaller than 5 mm in size.

Together with the primary MPs, deliberately produced at such a size suitable for applications in cosmetics, or in personal care products, such as soaps, creams or toothpastes, these particles are also problematic due to their high diffusivity, not only in water bodies, but also in air and in soils. The widespread presence of MPs represents a growing threat to the protection of the environment, which can compromise the civil and industrial activities of soils and seas. We can think, for example, of the coastal countries with an economy strongly linked to fishing activities: recent studies have, in fact, shown that MPs can penetrate the animal food chain and in turn, the human food chain so that, according to

various environmental sources, by 2050 the amount of plastic present in the seas could exceed the amount of fish [1,2]. Possible solutions proposed by the political institutions are focused either on forcing the consumers to reduce the use of plastic, especially single-use, or on suggesting the recovery and recycling processes from a circular economy perspective but, at the moment, the problem is far from being solved.

In this context, we understand the huge amount of work that in recent years has been dedicated to this topic by researchers who have felt called into question to remedy this situation. However, as above noted, nowadays, we are far from considering the problem solved: up to now, most of the published articles have been focused on the identification and quantification of MP pollution, and on their possible separation and collection. The research is therefore expected to continue and hopefully to be more specifically addressed towards processes that may also degrade the involved substances.

The analysis of the existing literature can be of great help in such a situation because it may allow one to take stock of the results achieved and highlight possible gaps to be fulfilled to improve the situation. In particular, bibliometric and social network analysis (SNA) may be combined to investigate specific fields of science [3,4]. SNA and maps based on network data allow the application of the systems thinking in bibliometric science, and in turn the construction of a network based on the relationships among countries, journals, organizations, authors, and keywords related to the investigated topic [5,6].

The aim of this work is to carry out a bibliometric analysis of the scientific literature dedicated to the problem of MPs, highlighting its course over the years, and to identify the sectors to which the research could be profitably addressed.

The VOSviewer software, created by the Centre for Science and Technology Studies (CWTS) of Leiden University [7,8] in the Netherlands has been used in this work to make the analysis of the data derived from the SCOPUS database. The mapping knowledge domain (MKD) methods, on which VOSviewer is also based, provide a new way to conduct such a literature survey: the knowledge of a certain topic may be presented by means of data mining, information analysis, scientific measurement and graphic plotting [4], thus providing a prompt visualization of the present research status, its possible evolution, and the emerging trends.

2. Data and Methods

In recent years, many articles and reviews have been published on MPs. Less frequently the papers examined the metadata by bibliometric analysis, which allowed one to analyze the literature data through the use of mathematical and statistical approaches. A considerable amount of academic research may be analyzed through bibliometric analysis to derive information, not only on the main investigated topic and subtopics, but also on the institutions and researchers that are leaders in the topic, and to individuate possible cooperation opportunities with them.

Data for this survey was retrieved from SCOPUS, one of the most used databases for scientific literature. The search was updated on 30 May 2021. Due to the continuous updating of records on SCOPUS, if the same search were to be performed on a different date, it would probably yield slightly different results.

The exported records included publication year, author, institution, source journal and cited references. A preliminary analysis was made to individuate the kind of documents, then attention was paid only to the articles, because the reviews, in most cases, do not represent original scientific work, but rather a state-of-the-art which may contain an overlapping of information with respect to the original papers.

The data has been represented on specific maps where nodes or labels represent the investigated items which are connected to each other by the links, and organized in clusters, depending on the interrelation between them. The maps may also be represented by the so-called *density visualization* in which the colors indicate how the nodes are distributed in the two-dimensional space: the denser the area, the more related to each other are the items included in it.

Finally, another characteristic of this software is the zooming and panning (scrolling) functionality. This is especially useful for exploring larger networks involving hundreds or thousands of nodes. When zooming in, the selection of nodes for which labels are displayed is updated and labels that previously were not shown may become visible.

In the present case, the following analyses have been performed:

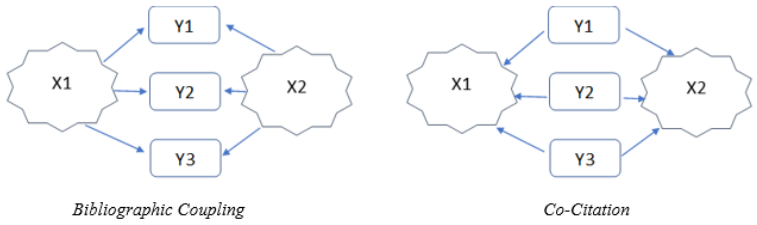
- Co-occurrence analysis—It is based on the number of times that the keywords (KWs) are repeated in the various articles. The analysis can specifically involve the KWs indicated by the authors of the articles, or the generic KWs indexed in the specific topics. The higher the KW occurrence, the larger the size of the related node in the maps. Two KWs that have been indicated together in an article, are joined by a link in the map. The thickness of the link is an indication of the total link strength (TLS), i.e., the total number of times the two words have been jointly considered as KWs in the various articles.
- Co-authorship analysis—In this case, the nodes in the map may be representative of the name of the authors of the articles, or of the country or the institution to which they belong. The relatedness of the items is determined by the number of articles co-authored by each couple of authors, or countries or institutions. A different visualization of the network in the map may also be obtained in which the size of the item is weighted with respect to the number of citations related to the linked couple of items.

Analysis of the Knowledge

A very common way to examine the importance or the visibility of a paper is to take account for the number of citations that a paper has received in time. However, other aspects can be highlighted also considering the lists of the References in the articles which are usable to make the so-called citation analysis. In particular, citation being a two-way process, it may be referred to as:

(1) the cited analysis which accounts for the authors that cite the papers selected in the specific survey (who cites them?): this represents the knowledge output, connected to the importance of a paper for other authors.
(2) the citing analysis which describes the citing behavior of the authors of the selected papers (who is cited by them?): this may indicate the knowledge input, because it gives an indication of the possible information used by the authors to make their work.

Among others, **Bibliographic coupling** and **Co-citation** analysis are two possible functions available on VOSviewer software allowing these two kinds of analyses to be performed. The following Scheme 1 represents the main difference between them.



Scheme 1. Bibliographic coupling and co-citation methods.

In particular, ***Bibliographic coupling***, couples two articles (X1, X2) which refer to other common articles (Y_i) in their bibliographies: attention is paid to possible similarities between X1 and X2 because they refer to the same papers.

Co-citation analysis—the co-citation analysis is related to the list of the references of a publication. Attention is paid to the papers X1 and X2 which may be considered as possible sources of information in support of research presented in papers Y_i. In this case a co-citation relationship exists between the articles X1, X2 as well as between the authors

of the articles, or between their related countries [9]. The more two publications are cited together, the more similarities between their contents can be assumed [10], and the higher is the weight of the link between the items (co-citation link strength).

Finally, regardless of the KWs that have been indicated in the article, or indexed by the database, the software also allows for the text analysis, the so-called **term analysis**. In this case the document is analyzed by evaluating the co-occurrence of the single words contained in a text. In the case of scientific articles, either the abstract, or the title, or both can be subjected to this analysis.

In the different kinds of analysis, the color of the items in a map can be related either to the cluster to which the item has been associated, or to the average publication year (APY) of all the articles which contain a specific KW or which have been made by a given author.

3. Data Analysis

The initial query Q1 was performed against the fields keyword, title and abstract, using the SCOPUS function "TITLE-ABS-KEY".

Query Q1: TITLE-ABS-KEY (microplastic * OR nanoplastic *) AND PUBYEAR > 2010

This search yielded 6551 documents. Among them 5163 articles, 274 conference proceedings, 124 book chapters, and 697 reviews have been identified. Their trends in time show that the interest to this topic started to be relevant from 2015: at that time MP problems were also discussed at scientific conferences and also became relevant topics in books (see Figure 1).

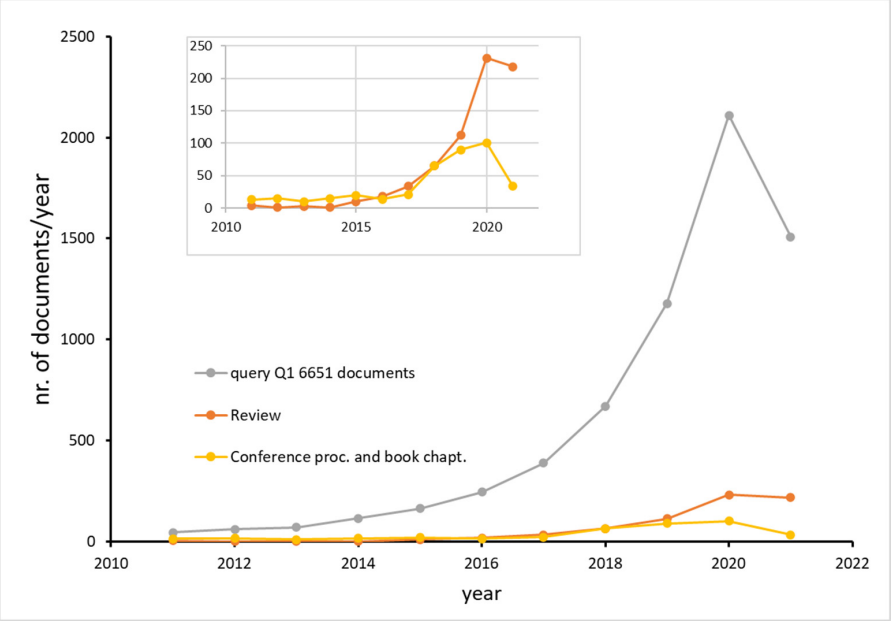
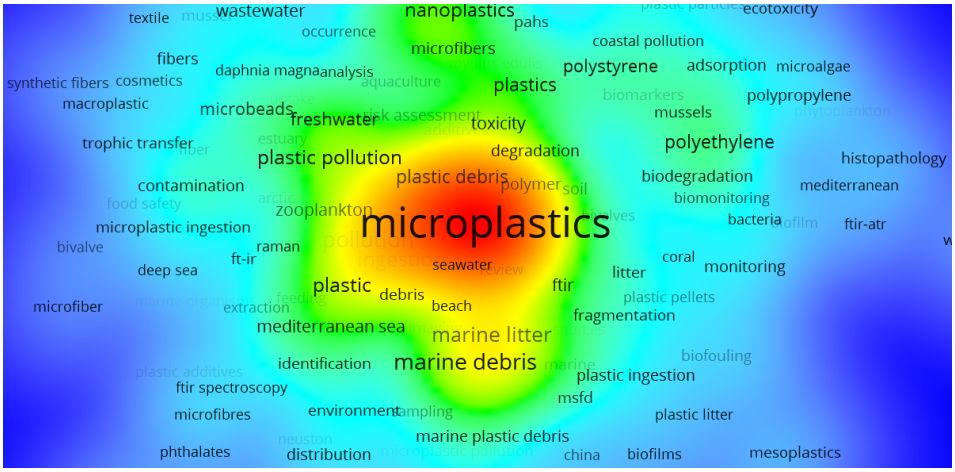


Figure 1. Trend of the number of total documents, reviews or conference proceedings and book chapters published from the year 2010.

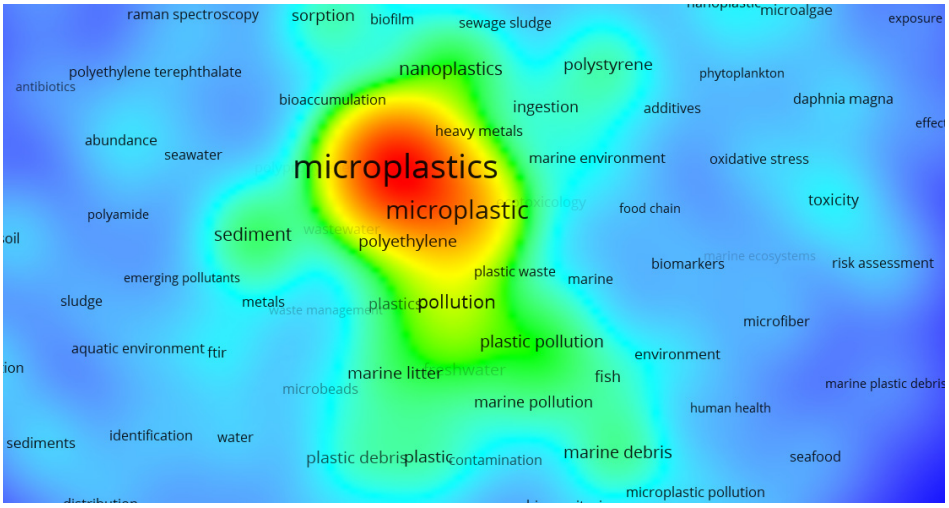
A first screening of these articles was carried out through the co-occurrence analysis of the KWs indicated by the authors. The huge amount of data was divided into four subsets extended over the different years of investigation, so that each subset included a comparable number of documents.

Due to the trend of publications over the years, the first subset included the documents published from 2011 to 2018; those related to 2019 were included in the second set, while those of 2020 were divided between the third and the fourth sets; the latter also included the articles published in the fraction of the year 2021 (up to the day of the extraction of the data from SCOPUS). The data is then represented in the maps of Figure 2 in density visualization

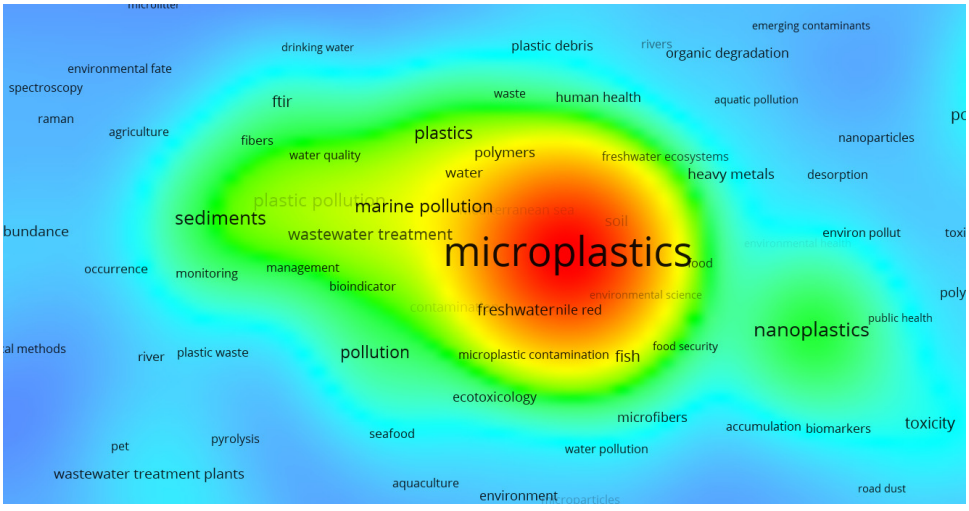
mode, and for each subset the KWs repeated at least five times were represented. In particular, the maps have been zoomed around the main KW "microplastics" to highlight the terms which have been mostly associated with it over the years.



Subset 1: 2011–2018

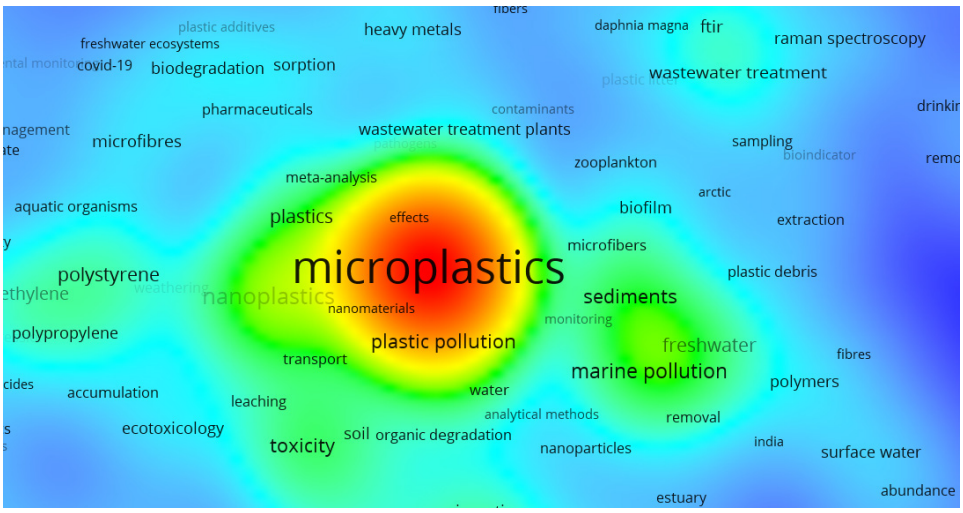


Subset 2: 2019



Subset 3: 2020 (fraction1)

Figure 2. *Cont.*



Subset 4: 2020 (fraction2)–2021

Figure 2. Density visualization of the co-occurrence map of the KWs used in the articles derived from query Q1, with a minimum occurrence of 5. The results have been divided in 4 groups, depending on the publication year of the related articles.

The quantification of the same information is shown in Figure 3, which compares the occurrence of the main KWs and the variation of the related values over the four ranges of time investigated in the maps of Figure 1.

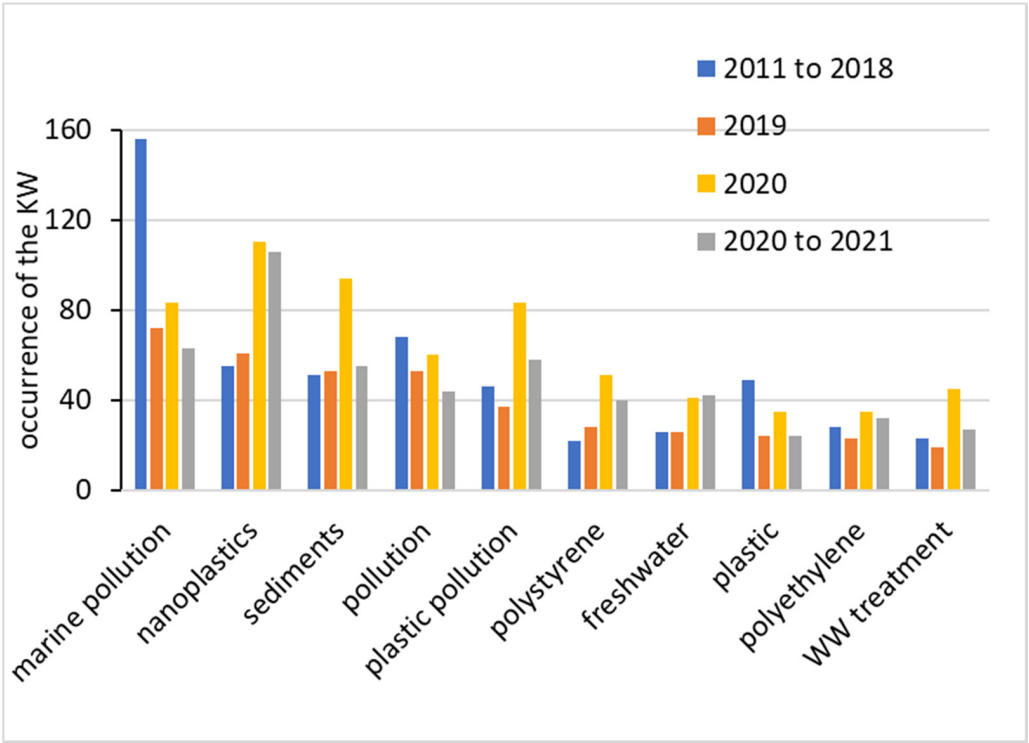


Figure 3. Trend of the occurrence of the main KWs that, other than microplastics, were repeated more than 5 times.

From this first survey it could already be seen that the main attention has always been paid to the presence of MPs in the sea. Lower numbers were related to the *wastewater treatment* (WWT) term, as it was also visible from the density visualization map, in which this term became more evident in the third subset of data related to 2020.

3.1. Analysis of the Data Related to the WWT and MPs

Among other things, the analysis presented in the previous section highlighted that terms such as "*polystyrene*, *polyethylene* and *terephthalate*" also appeared significantly in the maps. This is probably because these polymers are among the most frequently assumed as representatives of the behavior of MPs, many authors may have used such terms as KWs, rather than "*microplastics*".

Therefore, in order to better identify the articles dedicated to the treatment of wastewaters containing MPs, we used the query (Q2), in which the term *wastewater* was combined with the possible alternatives: "*polystyrene*, OR *terephthalate*, OR *MP*".

Query Q2: (TITLE-ABS-KEY (wastewater) AND TITLE-ABS-KEY (microplastic * OR nanoplastic * OR polystyrene * OR terephthalate)) AND PUBYEAR>2010

The inclusion of these terms in the query almost doubled the number of resulting documents: in fact, if the aforementioned terms were excluded, only 579 documents resulted from the search, while their presence in Q2 led to 1121 documents, of which 931 were articles. The following analysis in this work was based on these 931 articles.

3.2. Term Co-Occurrence Analysis

The **term analysis** was carried out by identifying, among the 22,000 total terms, those which were repeated at least 10 times in the title and abstract of the 931 articles. For each term a relevant score was calculated by the software. Based on this score, the 60% most relevant terms were plotted in the following map (Figure 4). The resulting 317 terms were summarized into three well-defined clusters, two of which, the red and the green ones, stand out in terms of the number of involved words, consisting of about 152, and 150 items. In the red cluster the terms seemed to identify the analysis techniques used in the various studies on water treatment, while the green cluster focused on the details of the treatment plants and on the type of plastics studied.

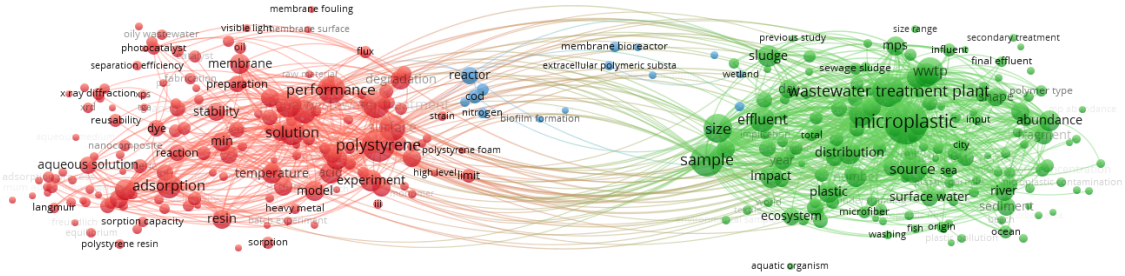


Figure 4. Term-occurrence analysis of data derived from the query Q2. An interactive visualization of the map is available at https://bit.ly/3xVikiF (The installation of Java 1.8.0 is needed before copying the link on the browser (the same is required for all the other links). Accessed date: 30 May 2021.

3.3. Co-Occurrence Analysis

This analysis was dedicated to the co-occurrence of the KWs indicated by the authors. In particular, the 82 KWs repeated at least five times have been considered, which are aggregated into eight clusters in the map in Figure 5.

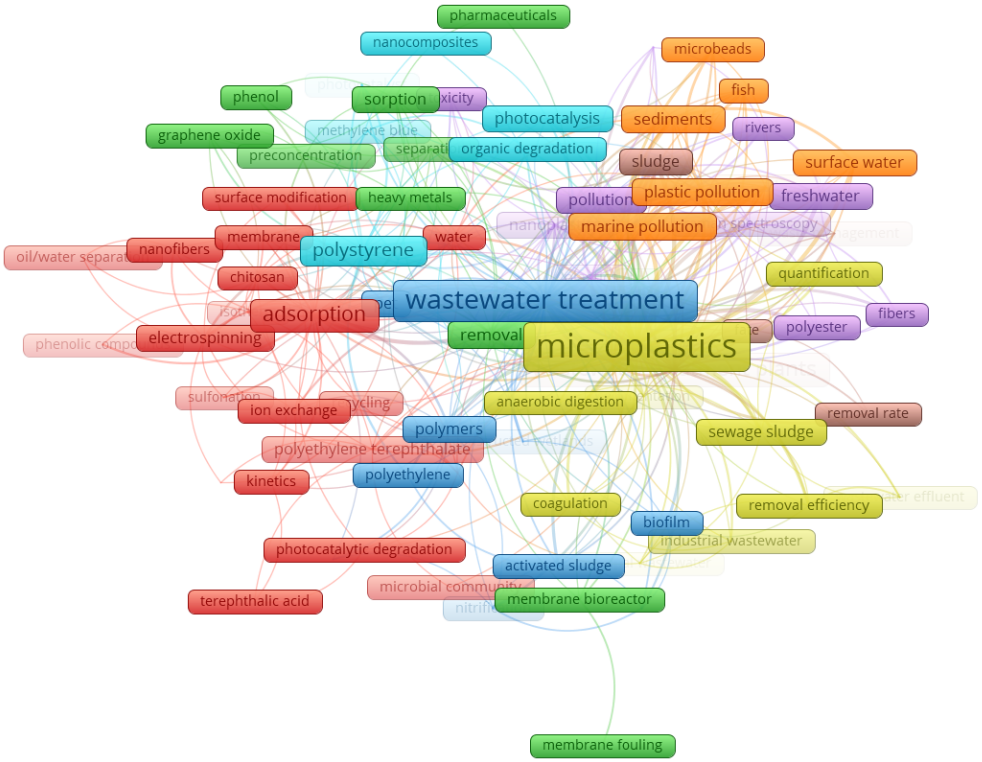


Figure 5. Co-occurrence map of the KWs with minimum occurrence of 5 in the articles derived from the query Q2. The size of the frames is correlated to the occurrence of the related KWs; colors refer to the different clusters with which each item is associated. An interactive visualization of the map is available at https://bit.ly/3y00xaa, (in which the label_*frames* can be selected). Accessed date: 30 May 2021.

As pointed out above, in such a representation, regardless of the size of each item, which is related to the occurrence of the KW, the proximity of the items indicates the relationship between them. Therefore, by analyzing the combinations of the various items, we could get an idea of the subtopics investigated.

The most crowded cluster (20 items were involved in it) was the red one which could be the result of the fairly generic works on water treatment: the term *adsorption* presented the highest TLS of this cluster. The lowest number of items (five) was instead involved in the brown cluster in which such terms as *removal rate*, *sludge*, *waste management* appeared along with the term *WWTP* where 32 links with a TLS of 109 were associated.

The other clusters were of about the same size (8–10 items each). The main KW *microplastics* was part of the yellow cluster: fifty-seven links started from its related item with a TLS of 378. It was interesting to note that along with *microplastics*, the KWs "*industrial wastewater*, *municipal wastewater*, and *wastewater effluent* were associated in this cluster with terms such as *sewage sludge*, *anaerobic digestion*, which could indicate the sectors correlated to the treatment of sludges, which represent the final destination of MPs in WWTP.

The KW *wastewater treatment* appeared in the blue cluster with 60 links and a TLS of 210. In the light green cluster we note the presence of many terms linked to *microfibers* which represent a large contribution to the presence of MPs in water bodies, probably due to the washing of textiles.

In this regard, a verification of this contribution was made through an additional search (Q3) in which the term "*textile*" was inserted.

Query Q3: ((TITLE-ABS-KEY (wastewater) AND TITLE-ABS-KEY (microplastic * OR nanoplastic * OR polystyrene * OR terephthalate)) AND PUBYEAR>2010) AND TITLE-ABS-KEY (textile) AND (LIMIT-TO (DOCTYPE, "ar"))

The search resulted in 64 documents which represent 30% of the total.

We also noted the presence of KWs *biodegradation* and *photocatalytic degradation* in the red cluster, while no terms appeared to be related to treatments specifically dedicated to the degradation of MPs. Although it is known that the result of bibliographic search is closely related to the combination of the keywords that are chosen to carry out the search, such a result may be indicative of the existence of a big gap in the studies in this sector. To verify this fact, we changed the combination of the KWs, using the Q4 and Q5 queries in which the term *degradation* has been inserted, constraining it by a maximum of two words from the term *microplastic* or *nanoplastic*: in this case the research led to 7 articles (Table 1). The search was even less effective when we entered the terms *advanced oxidation processes*, which in fact reduced the results to just three articles.

Table 1. List of the articles derived from the queries Q4 and Q5.

Title		Source	Query
- The role of the reactive species involved in the photocatalytic degradation of hdpe microplastics using C,N-TiO_2 powders [11]	2021	Polymers	Q4
- Visible light photocatalytic degradation of polypropylene microplastics in a continuous water flow system [12]	2021	J. of Hazardous Materials	Q4
- Degradation of polyvinyl chloride microplastics via an electro-Fenton-like system with a TiO2/graphite cathode [13]	2020	J. of Hazardous Materials	Q4
- Ultraviolet-C and vacuum ultraviolet inducing surface degradation of microplastics [14]	2020	Water Research	Q4
- Simultaneous separation of multiphase emulsion mixture and catalytic degradation of BPA via microalgae residue membranes [15]	2020	Chemical Engineering J.	Q4
- Degradation of cosmetic microplastics via functionalized carbon nanosprings [16]	2019	Matter	Q4
- Mass flows and removal of eight bisphenol analogs, bisphenol -A diglycidyl ether and its derivatives in two wastewater treatment plants in New York State, USA [17]	2019	Science of the Total	Q4
- Oxidation of microplastics by O3 and O3/H2O2: surface modification and adsorption capacity [18]	2021	J. of Water Process Engineering	Q5
- Microplastics in the environment: occurrence, perils, and eradication [19]	2021	Chemical Engineering Journal	Q5
- Fate of COVID-19 occurrences in wastewater systems: emerging detection and treatment technologies—a review [20]	2020	Water	Q5

Query Q4: ((TITLE-ABS-KEY (wastewater) AND TITLE-ABS-KEY (degradation PRE/2 microplastic * OR nanoplastic *)) AND PUBYEAR>2010) AND (LIMIT-TO (DOCTYPE,"ar"))

Query Q5: ((TITLE-ABS-KEY (wastewater) AND TITLE-ABS-KEY (microplastic * OR nanoplastic *)) AND PUBYEAR>2010) AND TITLE-ABS-KEY (advanced oxidation processes) AND (LIMIT-TO (DOCTYPE,"ar")).

The data of Figure 5 has also been reported as a function of the APY: Figure 6 gives an indication of the fact that the original studies started from the works involving the adsorption processes for the treatment of WW, while the MP treatment is related to more recent studies.

3.4. Co-Authorship Analysis

As anticipated above, this type of analysis allows one to derive information on the possible collaborations between the research groups and authors from the different countries.

The papers collected were co-authored by researchers from 85 countries. Among them, those countries with at least three publications were included in the analysis: the 53 countries that exceeded the threshold are represented on the map in the Figure 7 and are grouped into seven clusters. China and the USA are the two most productive countries in terms of the number of papers published on this topic (293 and 104 articles, are by Chinese and American authors, respectively). The following countries in the top-five list are Germany (63) Spain (53) and the UK (47).

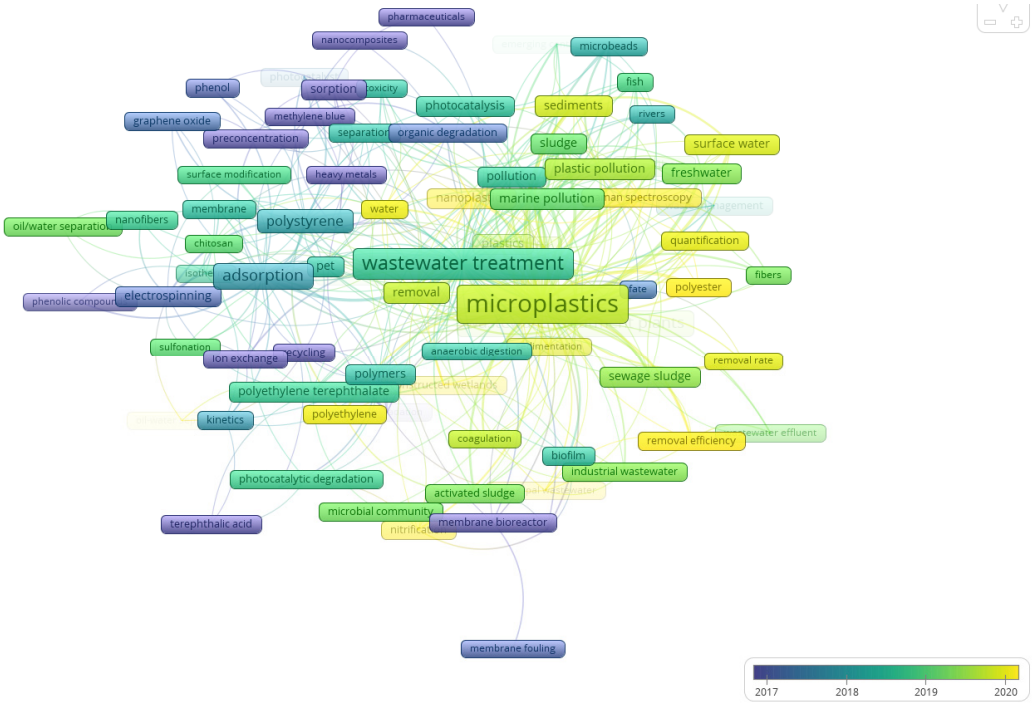


Figure 6. Co-occurrence map of the KWs with minimum occurrence of 5 in the articles derived from the query Q2. The color of item is associated to the average publication year (APY) of all the articles in which the related KW has been used. An interactive visualization of the map is available at https://bit.ly/2UAdKrt (in which the label_*frames* can be selected). Accessed date: 30 May 2021.

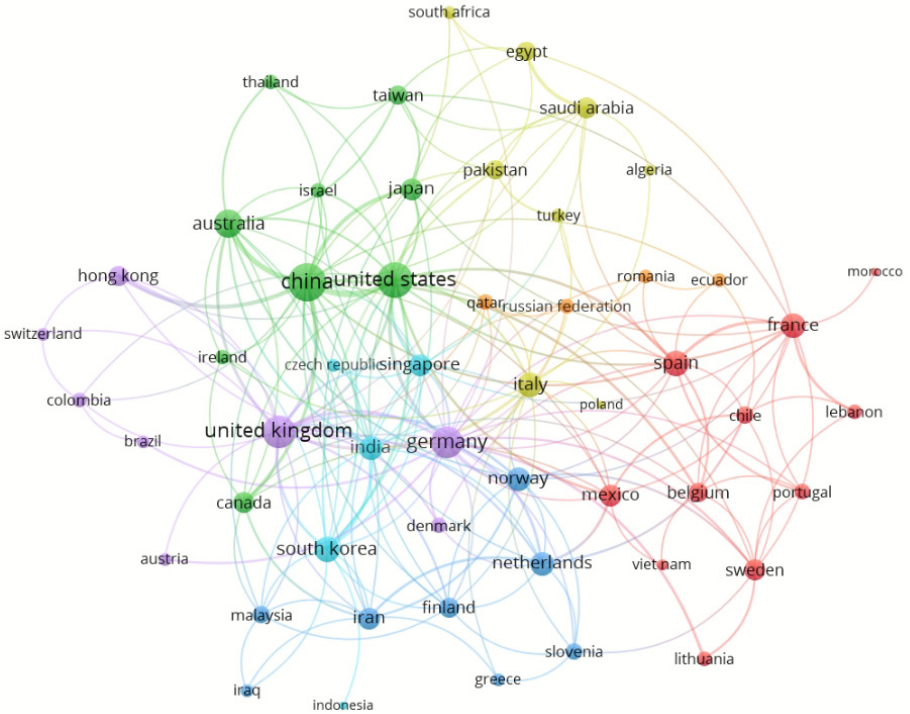


Figure 7. Co-authorship map. In this visualization the size of the item is related to the TLS of all the authors of the indicated country.

The number of links which start from one node gave an indication of the possible collaborations that the country associated with that node activated with other countries.

The greater the number of works co-authored by the two countries, the higher the strength of the link. Therefore, the total link strength (TLS) of a node indicated the total number of times that a specific country has been co-involved in conjunction with any other country, within the 53 countries individuated in the whole analysis.

Figure 7 shows the map related to this analysis in which the nodes were weighted according to the TLS.

Based on this parameter, China and USA remained at the top of the top-five list (TLS = 70, 56), but this time were followed by the UK, Germany and Australia which entered the list with TLS values, respectively, 45, 44, and 31.

It could be observed that the collaboration between the various countries was quite good, probably because the problem of MP is felt worldwide. The total number of links was 198 with a global TLS equal to 320: about half of the involved countries had a specific TLS greater than 10.

3.5. Co-Citation Analysis

This analysis gave an indication of those papers that might represent the basic knowledge on which the research on a given topic had been based. In the present case the analysis was extended to papers and authors. Due to the huge numbers involved (more than 59,300 authors, and more than 39,000 references), we decided to focus on the most relevant articles and authors. Based on this data, the adopted software made it possible, from the one hand, to calculate the total strength of the links connected to each reference, thus identifying the top-10 list of the articles with the highest TLS (Table 2); from the other hand, to derive the co-cited map of the authors (Figure 8) with a minimum number of citations equal to 50, with 414 authors falling into this range. The data was also in this case weighted with respect to the TLS value.

Table 2. The top-10 most cited articles in the References of the 931 papers derived from the query Q2; TLS represents the total number of times that the article appears in the Reference Lists together with any other article of the whole class of examined papers.

Authors	Title	Citations	TLS
F. Murphy, C. Ewins, F. Carbonnier, and B. Quinn	Wastewater treatment works (WwTW) as a source of microplastics in the aquatic environment [18]	112	6623
S. A.Carr, J. Liu, A. G.Tesoro	Transport and fate of microplastic particles in wastewater treatment plants [19]	99	6221
S. A.Mason, D. Garneau, R. Sutton, Y. Chu, K. Ehmann, J. Barnes, P. Fink, D. Papazissimos, D. L. Rogers	Microplastic pollution is widely detected in US municipal wastewater treatment plant effluent [20]	62	3746
M. Lares, M. Chaker Ncibi, M. Sillanpää, M. Sillanpää	Occurrence, identification and removal of microplastic particles and fibers in conventional activated sludge process and advanced MBR technology [21]	56	3446
S. L. Wright, R. C. Thompson, T. S. Galloway	The physical impacts of microplastics on marine organisms: a review [22]	49	3218
A. L. Andrady	Microplastics in the marine environment [23]	50	3136
D. Eerkes-Medrano, R. C. Thompson, D. C. Aldridge	Microplastics in freshwater systems: a review of the emerging threats, identification of knowledge gaps and prioritization of research needs [24]	49	3078
V. Hidalgo-Ruz, L. Gutow, R. C. Thompson, M. Thiel	Microplastics in the marine environment: a review of the methods used for identification and quantification [25]	47	2753
S. M. Mintenig, I. Int-Veen, M. G. J. Löder, S. Primpke, G. Gerdts	Identification of microplastic in effluents of waste water treatment plants using focal plane array-based micro-Fourier-transform infrared imaging [26]	44	2734
S. Ziajahromi, P. A. Neale, L. Rintoul, F. D.L. Leusch	Wastewater treatment plants as a pathway for microplastics: Development of a new approach to sample wastewater-based microplastics [27]	42	2697

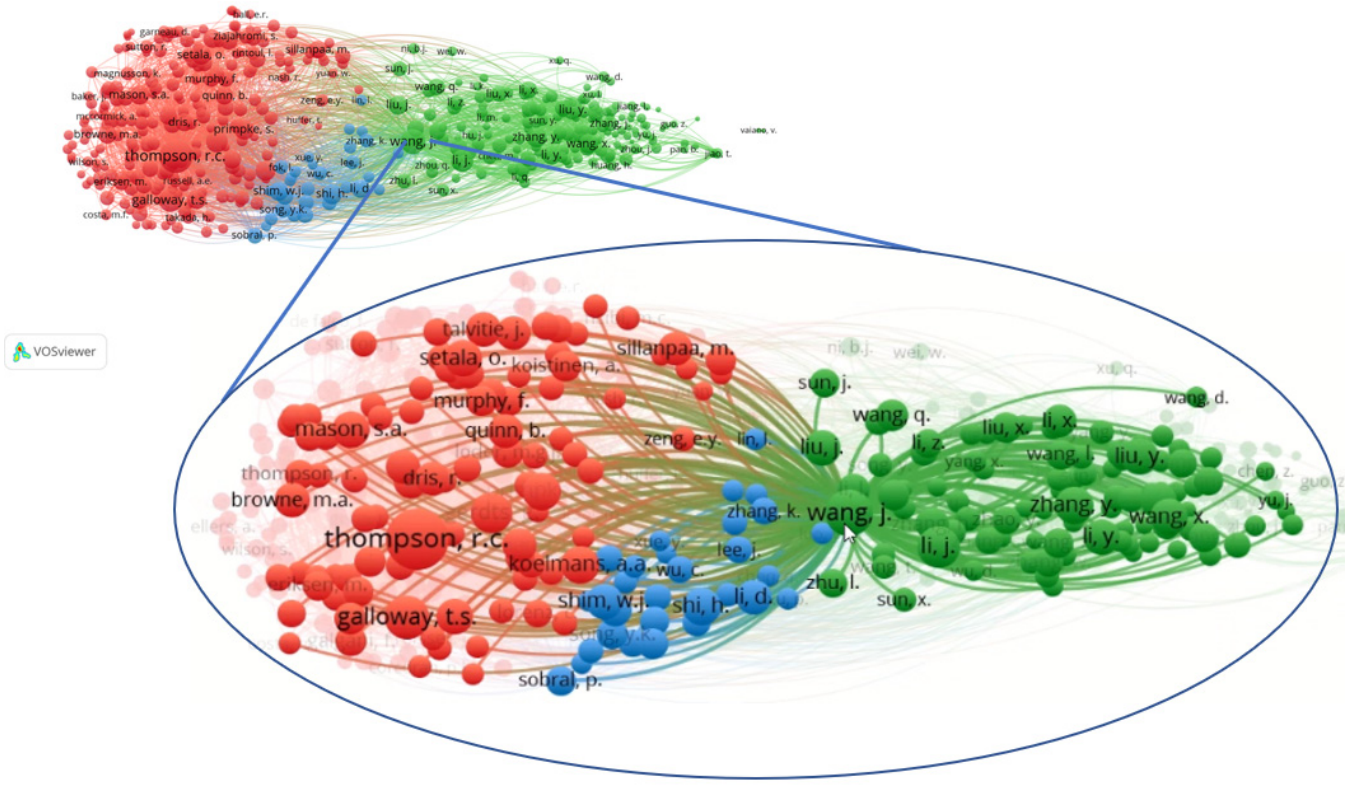


Figure 8. Co-citation map resulting from the citing analysis of the authors which have been cited more than 50 times. The size of a dot is related to the TLS, i.e., the number of times that the related author appears, along with any other author- in the list of the references of the examined papers. *Inset*—zoom visualization of the authors linked to Wang J. An interactive visualization of the map is available at https://bit.ly/2UqMBHH. Accessed date: 30 May 2021.

If the data in Table 2 is considered, two papers of 2016 stood out among the others, which deal with the presence of MPs in WWTPs. These two papers with a TLS greater than 6000, were followed by five other papers with TLS of the order of 3000 and the last three with about 2700. Three reviews were also included in the list that focused on the presence of MPs in the marine environment: among others, Thompson, R.C. also appeared as a co-author of these reviews. As it is shown in the following co-citation analysis, he resulted in being the author with the highest TLS value.

Three clusters were identified in the map in Figure 8 related to the author co-citation analysis: the two largest clusters seemed to revolve around the two main authors Thomson, R.C. (h-index 73) and Wang, J. (h-index 34). These two authors, one from the UK, the second from China, were first and second on the list of the authors with the highest value of TLS, thus representing the most cited authors in conjunction with other authors of the group. As specified above, the TLS value is a measure of the number of times that an author has been co-cited together with other authors, in the list of references of the articles examined. Therefore, considering that not all the authors deal with the same subtopics, the high TLS value of a given author indicates his relevance in the whole investigated sector.

Analyzing in greater detail the records on SCOPUS, relating to these two authors, we note that among the 201 publications by Thompson, 47 are classified in the specific sectors of *Microplastics*, *marine debris*, and *litter*: his most cited paper is from 2009 (*Accumulation and fragmentation of plastic debris in global environments* [28]), while his most recent research addresses the situation of the different areas of the environment such as the Arctic Sea [29], the Everest Mountains [30], the Ganges River [31].

As for Wang j., among his 146 documents, 15 are classified in the sectors *Microplastics*, *marine debris*, and *litter*, most of which were on specific China-related case-studies. His most cited paper is "*Microplastics pollution in inland freshwaters of China: A case study in urban*

surface waters of Wuhan, China" [32] from 2017. Perhaps, it was precisely for this reason that, despite being one of the major authors cited, none of his papers appeared in the list of the 10 most cited references.

It is also of note that, while the red cluster in Figure 8 involved authors from a mix of different nationalities, the green cluster grouped mostly Chinese authors. This may indicate that in most cases the papers done by Chinese authors tend to quote authors of their own nationality. However, in this case the author Wang seems to represent a *trait d'union* between the two clusters. In fact, clicking on the related item clearly appears (inset of Figure 8) that the links starting from Wang J. are about half divided between authors of cluster 1 and cluster 2.

4. Conclusions

Based on the data extracted from SCOPUS, in this work we have presented a bibliometric analysis of the articles published in the last decade on the problem connected to the presence of MPs in WW. The analysis was carried out using the VOSviewer software from which a prompt visualization of the data has been obtained: the specific maps allowed the immediate display of information on both the articles and the authors, as well as an indication of the scientific input on which the studies were based.

The co-occurrence of the most relevant KWs, specifically indicated by the authors of the related papers, allowed the identification of the various subtopics of the scientific research on MPs and WWT. The visualization of the data, weighted by the APY of the related articles, allowed the evaluation of the temporal evolution of the research and to identify the topics originally investigated, and those of recent investigation.

China and USA are the most involved countries in these studies, in terms of both the number of published papers, and the TLS of the pairs of authors cited by the various articles. Approximately 43% of the total papers of this survey were in fact published by Chinese or American authors. The trend of the TLS values indicated a good collaboration between the various countries, probably because the problem of MPs is felt worldwide. Among the whole items involved in the co-authorship map, 198 links have been identified with a global TLS equal to 320: about half of the involved countries had a specific TLS greater than 10.

The analysis highlighted the ever-growing interest of the scientific community in the MP problem, especially when the marine environment is involved. The initial studies appeared to be mostly devoted to the MP detection and the related separation technologies. More recently, attention has also been paid to municipal WWTP and sewage sludge, as possible pathways for MPs entering the aquatic environment. A large gap seems to still exist on the possible degradation techniques for MPs and their derivates.

As a final consideration, we would like to specify that some implicit limitations exist in doing a bibliometric analysis. As we specified above, the result of a bibliographic search is closely related to the combination of keywords that are chosen to carry out the search; thus, depending on their combination, some details could be missed in the analysis. Some problems could also arise from possible ambiguities in the author's name, or in the synonyms and abbreviated terms which are used as keywords. These problems are generally solved by the software which performs a sort of parsing of the cited references in order to identify their constituent elements, such as author names, publication years, source titles, and so on. A thesaurus file can be used to solve the second problem, to merge synonyms and abbreviated terms, and correct spelling differences.

Moreover, especially in such sectors where the number of publications is currently growing exponentially, the results of the analysis could significantly change over the course of months or even weeks.

For all these reasons, rather than definitive conclusions or absolute numbers, the results of this survey should be considered as general trends or suggestions to be used as an indication of the possible ways in which the next studies should be addressed.

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References

1. More Plastic than Fish in the Sea by 2050, Says Ellen MacArthur | Davos 2016 | The Guardian. Available online: https://www.theguardian.com/business/2016/jan/19/more-plastic-than-fish-in-the-sea-by-2050-warns-ellen-macarthur (accessed on 2 July 2021).
2. Do the Oceans Have More Plastic Than Fish Because of Pollution? Available online: https://www.businessinsider.com/plastic-in-ocean-outweighs-fish-evidence-report-2017-1?r=US&IR=T (accessed on 2 July 2021).
3. Thomson, W.; Kelvin, L. *White Paper Using Bibliometrics in Evaluating Research*; Thomson Reuters: Philadelphia, PA, USA, 2008.
4. Zou, X.; Yue, W.L.; Vu, H. Le Visualization and analysis of mapping knowledge domain of road safety studies. *Accid. Anal. Prev.* **2018**, *118*, 131–145. [CrossRef]
5. Pauna, V.H.; Buonocore, E.; Renzi, M.; Russo, G.F.; Franzese, P.P. The issue of microplastics in marine ecosystems: A bibliometric network analysis. *Mar. Pollut. Bull.* **2019**, *149*, 110612. [CrossRef]
6. Chen, D.; Liu, Z.; Luo, Z.; Webber, M.; Chen, J. Bibliometric and visualized analysis of emergy research. *Ecol. Eng.* **2016**, *90*, 285–293. [CrossRef]
7. Van Eck, N.J.; Waltman, L. Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics* **2010**, *84*, 523–538. [CrossRef]
8. Van Eck, N.J.; Waltman, L. Visualizing Bibliometric Networks. In *Measuring Scholarly Impact*; Springer International Publishing: Cham, Switzerland, 2014; pp. 285–320.
9. Palmas, S.; Mais, L.; Mascia, M.; Vacca, A. Trend in using TiO_2 nanotubes as photoelectrodes in PEC processes for wastewater treatment. *Curr. Opin. Electrochem.* **2021**, *28*, 100699. [CrossRef]
10. Li, J.; Hale, A. Identification of, and knowledge communication among core safety science journals. *Saf. Sci.* **2015**, *74*, 70–78. [CrossRef]
11. Vital-Grappin, A.D.; Ariza-Tarazona, M.C.; Luna-Hernández, V.M.; Villarreal-Chiu, J.F.; Hernández-López, J.M.; Siligardi, C.; Cedillo-González, E.I. The role of the reactive species involved in the photocatalytic degradation of hdpe microplastics using c,n-tio2 powders. *Polymers* **2021**, *13*, 999. [CrossRef]
12. Uheida, A.; Mejía, H.G.; Abdel-Rehim, M.; Hamd, W.; Dutta, J. Visible light photocatalytic degradation of polypropylene microplastics in a continuous water flow system. *J. Hazard. Mater.* **2021**, *406*, 124299. [CrossRef]
13. Miao, F.; Liu, Y.; Gao, M.; Yu, X.; Xiao, P.; Wang, M.; Wang, S.; Wang, X. Degradation of polyvinyl chloride microplastics via an electro-Fenton-like system with a TiO_2/graphite cathode. *J. Hazard. Mater.* **2020**, *399*, 123023. [CrossRef] [PubMed]
14. Lin, J.; Yan, D.; Fu, J.; Chen, Y.; Ou, H. Ultraviolet-C and vacuum ultraviolet inducing surface degradation of microplastics. *Water Res.* **2020**, *186*, 116360. [CrossRef]
15. Cao, G.; Li, Q.; Wang, R.; Wang, C.; Duan, X.; Ho, S.H. Simultaneous separation of multiphase emulsion mixture and catalytic degradation of BPA via microalgae residue membranes. *Chem. Eng. J.* **2020**, *393*, 124750. [CrossRef]
16. Kang, J.; Zhou, L.; Duan, X.; Sun, H.; Ao, Z.; Wang, S. Degradation of Cosmetic Microplastics via Functionalized Carbon Nanosprings. *Matter* **2019**, *1*, 745–758. [CrossRef]
17. Xue, J.; Kannan, K. Mass flows and removal of eight bisphenol analogs, bisphenol A diglycidyl ether and its derivatives in two wastewater treatment plants in New York State, USA. *Sci. Total Environ.* **2019**, *648*, 442–449. [CrossRef] [PubMed]
18. Murphy, F.; Ewins, C.; Carbonnier, F.; Quinn, B. Wastewater Treatment Works (WwTW) as a Source of Microplastics in the Aquatic Environment. *Environ. Sci. Technol.* **2016**, *50*, 5800–5808. [CrossRef]
19. Carr, S.A.; Liu, J.; Tesoro, A.G. Transport and fate of microplastic particles in wastewater treatment plants. *Water Res.* **2016**, *91*, 174–182. [CrossRef]
20. Mason, S.A.; Garneau, D.; Sutton, R.; Chu, Y.; Ehmann, K.; Barnes, J.; Fink, P.; Papazissimos, D.; Rogers, D.L. Microplastic pollution is widely detected in US municipal wastewater treatment plant effluent. *Environ. Pollut.* **2016**, *218*, 1045–1054. [CrossRef] [PubMed]
21. Lares, M.; Ncibi, M.C.; Sillanpää, M.; Sillanpää, M. Occurrence, identification and removal of microplastic particles and fibers in conventional activated sludge process and advanced MBR technology. *Water Res.* **2018**, *133*, 236–246. [CrossRef] [PubMed]

22. Wright, S.L.; Thompson, R.C.; Galloway, T.S. The physical impacts of microplastics on marine organisms: A review. *Environ. Pollut. (Barking Essex 1987)* **2013**, *178*, 483–492. [CrossRef]
23. Andrady, A.L. Microplastics in the marine environment. *Mar. Pollut. Bull.* **2011**, *62*, 1596–1605. [CrossRef]
24. Eerkes-Medrano, D.; Thompson, R.C.; Aldridge, D.C. Microplastics in freshwater systems: A review of the emerging threats, identification of knowledge gaps and prioritisation of research needs. *Water Res.* **2015**, *75*, 63–82. [CrossRef]
25. Hidalgo-Ruz, V.; Gutow, L.; Thompson, R.C.; Thiel, M. Microplastics in the marine environment: A review of the methods used for identification and quantification. *Environ. Sci. Technol.* **2012**, *46*, 3060–3075. [CrossRef]
26. Mintenig, S.M.; Int-Veen, I.; Löder, M.G.J.; Primpke, S.; Gerdts, G. Identification of microplastic in effluents of waste water treatment plants using focal plane array-based micro-Fourier-transform infrared imaging. *Water Res.* **2017**, *108*, 365–372. [CrossRef] [PubMed]
27. Ziajahromi, S.; Neale, P.A.; Rintoul, L.; Leusch, F.D.L. Wastewater treatment plants as a pathway for microplastics: Development of a new approach to sample wastewater-based microplastics. *Water Res.* **2017**, *112*, 93–99. [CrossRef]
28. Barnes, D.K.A.; Galgani, F.; Thompson, R.C.; Barlaz, M. Accumulation and fragmentation of plastic debris in global environments. *Philos. Trans. R. Soc. B Biol. Sci.* **2009**, *364*, 1985–1998. [CrossRef] [PubMed]
29. Kanhai, L.D.K.; Gardfeldt, K.; Krumpen, T.; Thompson, R.C.; O'Connor, I. Microplastics in sea ice and seawater beneath ice floes from the Arctic Ocean. *Sci. Rep.* **2020**, *10*, 1–11. [CrossRef]
30. Napper, I.E.; Davies, B.F.R.; Clifford, H.; Elvin, S.; Koldewey, H.J.; Mayewski, P.A.; Miner, K.R.; Potocki, M.; Elmore, A.C.; Gajurel, A.P.; et al. Reaching New Heights in Plastic Pollution—Preliminary Findings of Microplastics on Mount Everest. *One Earth* **2020**, *3*, 621–630. [CrossRef]
31. Napper, I.E.; Baroth, A.; Barrett, A.C.; Bhola, S.; Chowdhury, G.W.; Davies, B.F.R.; Duncan, E.M.; Kumar, S.; Nelms, S.E.; Hasan Niloy, M.N.; et al. The abundance and characteristics of microplastics in surface water in the transboundary Ganges River. *Environ. Pollut.* **2021**, *274*, 116348. [CrossRef] [PubMed]
32. Wang, W.; Ndungu, A.W.; Li, Z.; Wang, J. Microplastics pollution in inland freshwaters of China: A case study in urban surface waters of Wuhan, China. *Sci. Total Environ.* **2017**, *575*, 1369–1374. [CrossRef] [PubMed]