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Scientometric study of drinking water treatments technologies: Present and future challenges

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Abstract: The knowledge of the tendencies of the drinking water treatments was changing through the previous decades and it is necessary to improve it for the benefit of the human beings. In this sense, the purpose of the study was to develop a scientometric study about the drinking water treatments in the period 2010–2020 for providing the state of art of the studies about the drinking water treatments in diverse knowledge areas and new orientations for future research. For this purpose, a search of the information was performed both in the Web of Science (WoS) and Scopus databases, and all articles and reviews related to the field of water treatment or chemistry were included. The results showed that China, the USA and the Netherlands have the majority of the most cited publications and various related multidisciplinary topics, such as infrastructure, technologies and pollution. Therefore, the study allows concluding that there is a need for research on different technologies that contribute positively to obtaining quality water for consumption and for the use of routine activities, being the combination and integration of the different treatment processes a challenge for future studies.

Subjects: Environmental Sciences; Environmental & Ecological Toxicology; Environment & Health; Environmental Change & Pollution; Environmental Chemistry; Materials Chemistry; Plant Engineering; Environmental; Novel Technologies; Water Science

Keywords: Scientometric study; drinking water treatment; drinking water purification; drinking water bibliometric study; drinking water remediation

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Carlos A. Castañeda Olivera

PUBLIC INTEREST STATEMENT

Climate change and irresponsible anthropic activities are causing a depletion of natural freshwater sources. On the other hand, population growth is causing an increased demand for drinking water, creating a great challenge to meet basic human needs. As a result, many scientific research is being developed in order to establish more adequate and feasible treatment technologies to remove the contaminants that affect water quality. These technologies for the production of quality drinking water have been evolving over the years, with greater efficiency and lower cost within the framework of sustainability. Therefore, scienciometric studies are important to identify trends in research on drinking water treatment technologies in recent years to help ensure water quality to avoid health risks to the population.

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1. Introduction

Potential research fields including technologies and contaminants were identified through previous studies in the last decade in this study. Likewise, the contributions of the countries and research centers on this issue were identified and the topics of scientometric studies about drinking water treatments were analyzed. Background of the problem, previous studies, and related theories are described below.

1.1. Background of the problem

The human right to safe drinking water implies a whole system of water resource management recognized by governments and world leaders (Grönwall & Danert, 2020). Its management comprises processes from its water balance, which allows mitigating dangerous flow events to optimize its availability (Kansoh et al., 2020).

Water is a key variable within the sustainable development goals in terms of environmental, social and economic initiatives, as highlighted by United Nations specialists in 2014 (Martins et al., 2016). Currently, climate threats and population growth are causing an increased demand for drinking water, originating a great challenge to meet human needs. In addition, unconventional water sources used as freshwater supplies in developing countries are depleting (Siraj & Rao, 2016). It is why the need for advancing research related to drinking water treatment is becoming a higher priority, as the various results of such research should be applicable in the diverse conditions of nations and should be reliable, efficient, economical, safe, and easy to implement (Sorlini et al., 2015).

Although diverse investigations are focused on traditional methods such as primary treatment, secondary treatment, and on the various methods and technologies that are used in the treatment of drinking water, there is still a lack of information on the relationships between the new technologies.

For the first 75 years of the last century, chemical clarification, granular media filtration, and chlorination were virtually the only treatment processes used in municipal water treatment; however, the last 40 years have seen a dramatic shift in the approach to potabilization, where water utilities have begun to seriously consider alternative treatment technologies to the traditional filtration/chlorination treatment approach (Issam & Rhodes, 1999). Efforts to implement efficient, economical, and technologically sustainable techniques to produce quality drinking water in developing countries have increased worldwide (Pandit & Kumar, 2015).

Normally, the treatment of drinking water seeks to eliminate the microbial load through cell lysis and the death of cyanobacteria after a chemical treatment releases toxins into the liquid medium, which has opened a range of possibilities in its treatment (Jurczak et al., 2020; Zurawell et al., 2005). Coagulation and flocculation can help form flocs for the elimination of this bacterial load; however, each treatment has advantages and disadvantages, which leads to the search for better control of the process and optimization of the applied technology (Ghernaout et al., 2010).

Even these days, research on drinking water treatment is very scattered and even scarce (Bolisetty et al., 2019). This scientometric analysis has the purpose of showing a range of possibilities and routes in the treatment of water for its purification to the scientific community and the interested public, especially to show the trends in the development of new techniques applied to solve specific or multi-parameter problems, in an organized way helping to identify topics of interest, specialized journals, main authors, and define actions in the optimization of processes or develop new routes especially when it comes to safeguarding the quality of the environment, the quality of natural resources, and the quality of the human health.

1.2. Previous studies

1.2.1. Scientometric drinking water studies

Some scientometric studies which were specifically related to the drinking water research were the following: (a) drinking water research in Africa (Wambu & Ho, 2016), (b) drinking and recreational water-related diseases (Sweileh et al., 2016b), (c) drinking water research during 1992–2011 (Fu et al., 2013), and (d) research on lead in the drinking water field from 1991 to 2007 (Hu et al., 2010).

Wambu & Ho (2016) developed a bibliometric study based on 1,917 drinking water research since 1981 until 2013 in Africa from Science Citation Index Expanded of Web of Science including: (a) publication results, (b) most used keywords, (c) most cited journals, (d) most cited publications, (e) subject areas, and (f) research by country, institutions and authors. The results showed that the publication output of related documents increased over the entire period of study, with "water", "drinking water", and "oxidative stress" being the most frequent terms in publication titles, authors' keywords and KeyWords Plus. The top three subject areas were "water resources", "environmental science", and "environmental and occupational public health". The ten most productive institutions were located in South Africa and Egypt, and the University of Pretoria was the overall most productive institution. Thus, a quarter of all of the articles published were from South Africa. It was found that articles became increasingly collaborative with greater numbers of authors, page counts and bibliographies. More than half of the internationally collaborative articles were co-authored with researchers from Europe. French and US institutions contributed to the highest number of collaborative articles.

Sweileh et al. (2016b) evaluated 2,267 publications of drinking and recreational water from Scopus database in the period 1980–2015 with a health focus for understanding the current problems about related diseases and the trends for future research about this theme. The results revealed an average of 16.82 citations per article, with an h-index of 88 for the retrieved articles. Visual mapping showed that *E. coli*, diarrhea, cryptosporidiosis, fluoride, arsenic, cancer, chlorine, trihalomethane and H. pylori were most frequently encountered in terms of title and abstract of retrieved articles. The number of articles on water microbiology was a significant ($P < 0.01$) predictor of worldwide productivity of water—related disease publications. Journal of Water and Health ranked first in number of publications with 136 (6.00 %) articles. The United States of America ranked first in productivity with a total of 623 (27.48 %) articles. Germany (15.44 %), India (16.00 %) and China (20.66 %) had the least international collaboration in water-related disease research. The Environmental Protection Agency and Centers for Disease Prevention and Control were among top ten productive institutions. In the top ten cited articles, there were three articles about arsenic, one about aluminum, one about trihalomethane, one about nitrate, one about toxoplasmosis, one about gastroenteritis, and the remaining two articles were general ones. Finally, the authors concluded that there was a linear increase in the number of publications on water-related diseases in the last decade, highlighting that arsenic in drinking water is a serious problem. In addition, they indicated that cryptosporidiosis and other infectious gastroenteritis are health risks from contaminated water, and that Asian countries did not have high international collaboration.

Fu et al. (2013) studied the tendencies of research about global drinking water from 1992 until 2011 considering "performance of publication covering annual outputs, mainstream journals, Web of Science categories, leading countries, institutions, research tendencies and hotspots.". The results indicated that annual output of the related scientific articles increased steadily. Water Research, Environmental Science & Technology, and Journal American Water Works Association were the three most common journals in drinking water research. The USA took a leading position out of 168 countries/territories, followed by Japan and Germany. A summary of the most frequently used keywords obtained from words in paper title analysis, author keyword analysis and KeyWords Plus analysis provided the clues to discover the current research emphases. The mainstream research related to drinking water was water treatment methods and the related contaminants. Disinfection process and consequent disinfection by-products attracted much

attention. Ozonation and chlorination in disinfection, and adsorption were common techniques and are getting popular. Commonly researched drinking water contaminants concerned arsenic, nitrate, fluoride, lead, and cadmium, and pharmaceuticals emerged as the frequently studied contaminants in recent years. Disease caused by contaminants strongly promoted the development of related research.

Hu et al. (2010) developed a bibliometric study about research of drinking water based on Science Citation Index (SCI) of the Institute of Scientific Information (ISI), which now is Web of Science (WoS), in the period 1991–2007. The results from this analysis indicated that there has been an increase in the number of annual publications mainly during two periods: from 1992 to 1997 and from 2004 to 2007. United States produced 37% of all pertinent articles followed by India with 8.0% and Canada with 4.8%. Science of the Total Environment published the most articles followed by Journal American Water Works Association and Toxicology. Summary of the most frequently used keywords are also provided. "Cadmium" was the most popular author keyword in the 17 years. Furthermore, based on bibliometric results four research aspects were summarized in this paper and the historical research review was also presented.

The analysis of previous research revealed that some research does not specifically address water treatments (Sweileh et al., 2016b), focuses on one continent (Wambu & Ho, 2016) or was elaborated with data older than 10 years (Fu et al., 2013; Hu et al., 2010). Furthermore, considering the importance of drinking water at the regional and global level, there is a need for an updated study to identify new trends in water treatment research based on information provided by Scopus and WoS, two of the main multidisciplinary academic databases worldwide (Visser et al., 2021>).

The literature search based on "TITLE-ABS-KEY" has resulted in an advanced search tool that provides detailed information on each platform due to the publication of the title, abstract and keywords used by the author, which has generated a direct relationship with the article and has served to identify critical points in research on drinking water treatment and new trends in scientific research (Li et al., 2009). Fu et al. (2013) evidenced technologies concentrated mainly on the removal of arsenic, fluoride, lead, cadmium, and a nascent concern for pharmaceuticals (143 WoS articles) during the previous decade. However, nowadays, residues of bisphenol A, diethyltoluamide, perfluorobutanoic acid, carbamazepine, caffeine, and atrazine, among others, are often reported in most articles as a result of the limitations of wastewater treatment plants that are discharged to water sources and then captured for potabilization. It has guided increased interest in investigations of advanced oxidation processes for the removal of such recalcitrant compounds, including electrochemical processes (Seibert et al., 2020).

Concerns about the use of traditional disinfectants such as ozone and chlorine, formers of toxic disinfection by-products (DBPs), nitrosamines and among others (Kondo Nakada et al., 2020; Mazhar et al., 2020), has oriented new applications using polymeric nanocomposites as a promising alternative for water disinfection, with the challenge of evaluating their efficiency against DBPs (Mazhar et al., 2020). In this context, silver, TiO2 and ZnO2 nanoparticles and carbon nanotubes are the most studied (Manikandan et al., 2020).

Another aspect not considered in previous reviews is natural organic matter (NOM) in drinking water treatment, whose most applied treatment has been efficient coagulation avoiding the formation of DBP; however, with the increase of NOM fluctuation in water (concentration and composition), the efficiency of conventional coagulation was substantially reduced, so research has been oriented towards the most efficient use and its coupling with other technologies including membrane filtration, oxidation, adsorption, and other processes (Sillanpää et al., 2018).

Regarding adsorption which in this decade has shown technological advancement in the removal of arsenic As (V) and As (III), fluoride and ferrous and ferric forms of iron by applying organometallic structures (MOF) due the ultrastructural morphology of MOFs is evaluated based on

different molecular arrangements and that they outperform conventional adsorbents which are unsatisfactory for such removals, as they provide a large surface area with excellent porosity which is much higher compared to conventional adsorbents (Haldar et al., 2020). However, again the challenge is to evaluate their efficiency against their impacts to human health.

Filtration has been a widely used but constantly renewed technology to separate and purify water as it generates reduced secondary pollution (X. Li et al., 2017). However, its applicability is limited by a trade-off between membrane flux and selectivity and several studies have been aimed at fabricating novel membranes incorporating various nanomaterials such as carbon nanotubes (Yin et al., 2019), graphene oxides (Chu et al., 2017), metalorganic frameworks (Hua et al., 2019), and MXenes made from titanium carbide (Ti3C2Tx) due to this problem (Wei et al., 2019), which allows separating fluxes or a flux of particulate material, marking a challenge that should evaluate the interactions between pollutants and these membranes based on new nanomaterials (Al-Hamadani et al., 2020).

1.2.2. Other scientometric water studies

Other scientometric studies were developed about the following themes: (a) groundwater remediation research (Chen et al., 2019), (b) authorship pattern of rain water harvesting research management publications (Pu & Raja, 2019), and (c) the role of nanomaterials and nanotechnologies in wastewater treatment (Jiang et al., 2018).

Chen et al. (2019) studied groundwater research based on 2867 journal articles published from January 1950 to September 2018 from the Science Citation Index Expanded database with CiteSpace software. They used various subject terms including "groundwater restoration", "groundwater remediation" and "groundwater remediation" to retrieve publications containing these words in publication titles, keyword lists and abstracts, and excluded several categories such as (i) unrelated categories—physiology, pharmacology pharmacy, genetics heredity—(ii) document types—book chapter, data paper, proceedings abstract—and (iii) research areas—imaging science photographic technology, business economics. Among the reports in figures of the study, the following appeared: (a) Publication output performance during the period 1950–2018, (b) Distribution of co-operation among countries/territories" (c) Distribution of co-operation among research institutions, (d) Disciplines involved in the field of groundwater remediation, shown as a network of subject categories, (e) Author co-citation map/the co-operation network of productive authors, (f) The synthetic network of co-cited references, (g) Timelines of co-citation clusters and (h) The top 20 references with the strongest citation bursts. The reports in tables showed the following: (a) Distribution of 10 co-operative countries/territories and institutions, (b) Distribution of 10 "core journals" and IF in 2017 (IF is Impact Factor), (g) Journal co-citation knowledge map, (c) Major clusters of co-cited references, (d) The top 10 most-cited references, (e) Cited citations with the highest between centrality, (f) The top five references with the strongest metric of citation bursts and (g) Structurally and temporally significant references. Chen et al. (2019) concluded that existed a continued and global research interest for an urgent remediation of contaminated groundwater since 1991 and that United States of America and China contributed 56.4% of the total publications, transitioning from the pump-and-treat method to PRBs and nanoscale zero-valent iron particles. They also concluded that the research field of groundwater remediation includes the environmental sciences, ecology, engineering, and water resources and that most cited sources about this theme were the following: (a) Environmental Science and Technology, (b) Water Research, and (c) Journal of Contaminant Hydrology. Finally, as future outlook, they recommended the following: (a) Development of treatment trains, (b) Optimization of groundwater remediation design under uncertainty and (c) Development of green and sustainable remediation.

Pu & Raja (2019) identified the authorship pattern of the publications related to water harvesting management since 2008 until 2017, with bibliographic data from Web of Science database, using the following search terms: "Rainwater Harvesting" and "Rainwater Harvesting Management" and obtaining 1070 records about 3994 authors who contributed to this theme. Among the reports in

tables in the study, the following appeared: (a) Year-wise output, (b) Cited references, (c) Authorship pattern, (d) Degree of collaboration, (e) Authorship Pattern of Literature, (f) Author Productivity, (g) Top Prolific Author, and (h) Co-Authorship Index. Finally, Pu & Raja (2019) concluded that three authors' collaboration was dominant during the period of study, that the author productivity was higher from 2008 to 2010, that the degree of collaboration was identified as the value 0.935, and that the study shows the increase of the trend towards the collaborative research.

Jiang et al. (2018) presented the following figures: (a) The annual publication number of top six productive countries during 1997–2016, (b) The cooperation network of the top 30 productive countries/territories, (c) The cooperation network of the top 30 productive institutions, and (d) Timeline view of a network related to co-occurring keywords. Jiang et al. (2018) also presented the following tables: (a) Top 20 productive countries/territories during 1997–2016, (b) The top 20 productive institutes during 1997–2016, (c) The 15 most productive subjects during 1997–2016, (d) The 20 most productive journals during 1997–2016, (e) listed the top 20 keywords with the strongest bursts, (f) Most highly cited articles during 1997–2015.

1.3. Related theories

About scientometrics, Chellappandi and Vijayakumar (2018) explained: Scientometrics analyses the quantitative aspects of the production, dissemination and use of scientific information with the aim of achieving a better understanding of the mechanisms of scientific research as a social activity. Additionally, Sengupta (1992) indicated: The terms bibliometrics, informetrics, scientometrics and librametrics are derived out of fusion of the terms metrics with bibliography, information, science and library respectively and that these terms are analogous, or rather synonymus, in nature and their major scope and application involves different facets of library and information science.

Data were obtained from the Web of Science (WoS) and Scopus databases, and the VOSviewer tool was used. WoS is an integrated digital scientific citation indexing service published by Thomson Reuters that provides access to multiple databases from academic and scientific disciplines, especially in natural sciences, engineering, and biomedical research (Mongeon & Paul-Hus, 2016). Scopus is the largest scientific electronic database, which allows to retrieve related articles and present the results as bibliometric tables and maps (Sweileh et al., 2016a). The VOSviewer tool was developed at the Center for Science and Technology Studies for the visualization of bibliometric networks (Van Eck & Waltman, 2010).

VOSViewer is a freely available software that is designed primarily for use in the analysis of bibliometric networks, and allows the creation of maps of publications, authors or journals based on a co-citation network, or the creation of maps of keywords based on a co-occurrence network. In addition, it offers a viewer that allows to examine them in detail, offering a diverse visualization emphasized in some aspect (Moral-Muñoz et al., 2020). According to Van Eck & Waltman (2010), in the visual map of VOSViewer each circle represents a term and the size of the circle and the fonts represent the activity of the term; furthermore, if the circle and the font are bigger then the term in the field and vice versa will be more active. The distance between any two terms in the diagram represents the degree of association between the two terms and if the distance of the circle between the two terms is lower, then the correlation between the two terms and vice versa will be stronger (Van Eck & Waltman, 2010).

2. Materials and methods

2.1. Type of study

It is a cross sectional study which research methodology adopts a quantitative approach by direct observation of scientific literature published in Web of Science (WoS) and Scopus databases, limiting it to the period since January 2010 until August 2020. This study is based on the scientific productions in drinking water treatments.

Research and literature review articles were counted in the study. Among the research articles were taken into account those that provided their own results, which have been evaluated by scientific peers and which present the typical structure of introduction, materials and methods, results, discussion, and references were considered (Kerans et al., 2020). In addition, the review articles mainly focus on synthesizing existing knowledge were considered (Kerans et al., 2020; Prester et al., 2021).

2.2. Database search strategy and selection criteria

In both WoS and Scopus databases, the search was performed with four phrases related to drinking water treatment: drinking water and treatment plant or potabilization or purification ("drinking water" AND (treatment AND plant OR potabilization OR purification) AND NOT "supply" AND NOT "accessing" AND NOT "access") in the title, abstract, and keywords, thus increasing precision and minimizing false positive results due to that "water" is present in many non-engineering articles.

The search included document types such as articles and reviews from January 2010 until August 2020. In the WoS database, the categories included were: (a) Environmental Sciences, (b) Water Resources, (c) Engineering Environmental, (d) Engineering Chemical, (e) Chemistry Multidisciplinary, (f) Chemistry Analytical, (g) Engineering Civil, (h) Public Environmental Occupational Health, (i) Chemistry Organic, (j) Microbiology, (k) Environmental Studies, (l) Biotechnology Applied Microbiology, (m) Materials Science Multidisciplinary, (n) Multidisciplinary Sciences, (o) Electrochemistry, (p) Computer Science Artificial Intelligence, (q) Green Sustainable Science Technology, (r) Biochemical Research Methods, (s) Computer Science Information Systems, (t) Chemistry Applied, (u) Biochemistry Molecular Biology, (v) Nanoscience Nanotechnology, (w) Polymer Science, (x) Ecology, (y) Marine Freshwater Biology and (z) Engineering Multidisciplinary. Meanwhile, the subject areas included in the Scopus database were: (a) Environmental Science, (b) Chemistry, (c) Biochemistry, Genetics and Molecular Biology, (d) Engineering, (e) Agricultural and Biological Sciences, (f) Chemical Engineering, (g) Pharmacology, Toxicology and Pharmaceutics, (h) Immunology and Microbiology, (i) Materials Science, (j) Earth and Planetary Sciences, (k) Energy, (l) Multidisciplinary and (m) Computer Science.

All subject areas that did not belong to the field of water technology or chemistry, such as veterinary medicine, psychology, art, etc., were excluded. The word "wastewater" was also excluded.

To ensure the accuracy of the documents selected according to the query string, the authors manually and randomly reviewed a sample of 100 documents both selected and excluded for each database. The information was extracted from WoS in txt format and from Scopus in csv format.

2.3. Data analysis

A scientometric analysis was applied to observe the evolution of the scientific literature and identify specific characteristics of the related knowledge domain. The scientometric method permitted to analyze a large amount of information and determine the evolution of such important field of research as the treatment of water for human consumption (Sun & Cao, 2020). The data were organized and analyzed as described in previous studies (Hu et al., 2010; Wang et al., 2010; Wambu & Ho, 2016; Fu et al., 2013; Sweileh et al., 2016b). Microsoft Excel software was used to organize the papers by year and subject area, as well as to determine the top 10 journals, top 10 papers, technologies used, main pollutants, and pollutants removed in 2010 and 2019. Density visualization maps and group analysis were carried out using the VOSviewer tool (Tapia-Pacheco et al., 2020).

With the support of VOSviewer, a descriptive analysis of the study was carried out, identifying the areas, topics, sources, countries, journals and institutions that publish the most on drinking water treatment. Subsequently, the networks developed with the main thematic axes associated

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with the key words of the publications were analyzed. Likewise, the most cited publications were identified and citations to date were estimated. Special emphasis was placed on the evolution of contaminants and drinking water treatment technologies due to the importance of the topic (Siraj & Rao, 2016; Sorlini et al., 2015).

Finally, trends in the study of pollutants and the evolution of treatment technologies in the last decade were analyzed. In addition, a programming routine was developed to purge information from both WoS and Scopus databases to avoid duplicity of articles because many of them are indexed in both academic databases.

3. Results and discussion

This section includes the diverse analysis which were realized and the comparison with previous studies. This section contains: scientific documents in WoS and Scopus, thematic areas, main sources of research on drinking water purification, author keyword trend analysis, active countries in potabilization research, productivity of water treatment articles by institution, authors' production, most cited articles, trends in research related to drinking water purification, and trends in the study of contaminants.

3.1. Scientific documents in WoS and Scopus

The quantities of scientific documents (original articles and reviews) of the WoS and Scopus databases are presented in Figure 1. The Scopus database contains the largest number of scientific documents on the subject of water purification. The strong overlap between both databases was reported by Visser et al. (2021>). The total number of scientific documents analyzed in the period 2010–2020 was 6038 between the two databases. The scientific documents published only in WoS

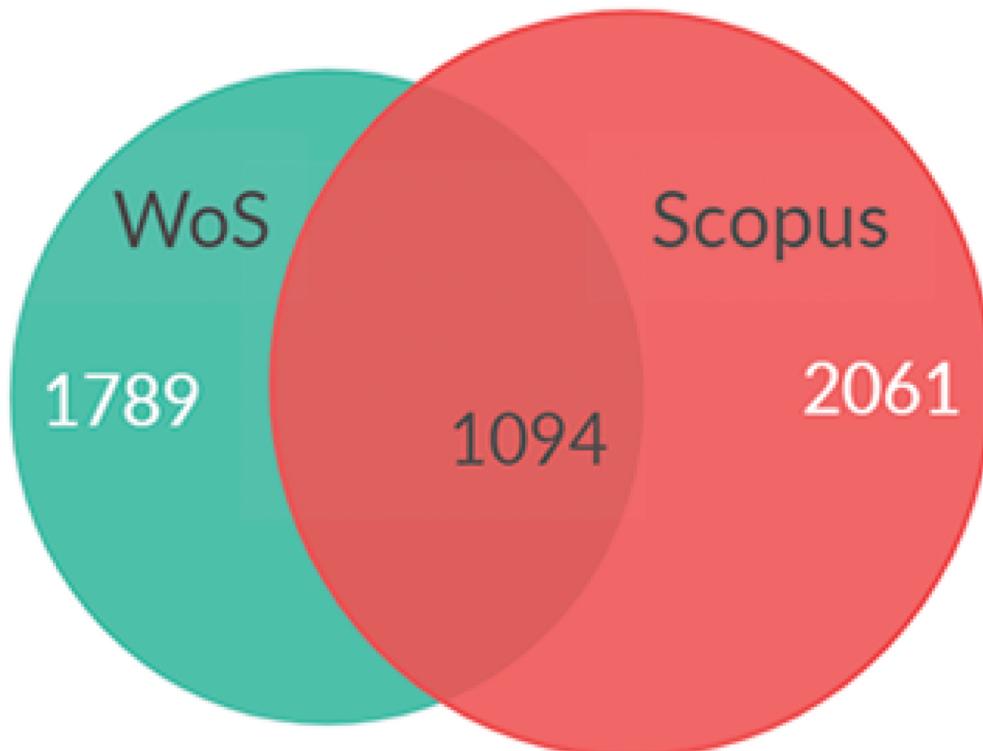**Figure 1. Quantities of original articles and reviews which were published in WoS and Scopus databases.**

Table 1. Main types of published documents: a) WoS and b) Scopus					
WoS			**SCOPUS**		
Document type	**Documents**	**Percentage (%)**	**Document type**	**Documents**	**Percentage (%)**
Article	2703	90.7%	Article	2999	86.8%
Review	180	6%	Review	156	4.5%
Book Chapter	2	0.1%	Book chapter	70	2.0%
Proceedings Paper	74	2.5%	Conference paper	218	6.3%
Data Paper	1	0.03%	Conference review	13	0.4%
Early Access	20	0.67%			
	2980	**100.0%**		**3456**	**100.00%**

were 1789 (36.18%), in both databases were 1094 (22.12%), and the scientific documents that were published only in Scopus were 2061 (41.68%); that is, 4944 articles were published.

The scientific documents related to water purification are presented in Table 1. The Web of Science database presents 2,703 documents (90.7%) in the "article" category, 180 documents (6%) in the "review" category, and 74 documents (2.5%) in the category "Proceedings Papers". The latter correspond to articles that were first presented at a conference and that were later adapted to be published in one of the journals in the database. On the other hand, the "Data Paper" category is aimed at a series of previously published and peer-reviewed academic metadata. The "Early Access" category corresponds to articles of electronic publication preliminary to their allocation of volume and turn number in the publication (Clarivate Analytics, 2020). The Book Chapter, Data Paper and Early Access categories represent 0.8% of publications on WoS.

Regarding the Scopus database, the "research articles" were 2999 articles (86.8%), reviews were 156 (4.5%), book chapters were 70 (2.0%), conference articles were 218 (6.3%), and Conference Review were 13 (0.4%). In this study, articles and reviews were analyzed due to the fact that they represent more than 90% of the scientific documents in both databases.

In respect to scientific productivity, the number of documents published per year was first evaluated, considering the period from January 2010 to August 2020, in order to study the frequency of publication on the subject of drinking water, as well as the general trend diachronic. The number of works in Scopus obtained was 3155 and in WoS was 2883.

WoS has maintained original articles in close percentages (90.7%) to what was previously reported by Fu et al. (2013) in the previous decade (88%); however, in that period they did not report review articles, which represented 6% in the period 2010–2020 and were slightly higher than what was accounted for Scopus (4.5%). This information has provided insight into the current status, trends and factors involved with drinking water quality that have included several systematic reviews on a scientific basis, aimed at contributing to sustainable development (T. Wang et al., 2020). In addition, researchers have found a much faster way to publish their research through conference articles with higher impact in the Scopus database (6.3%) making them more available to the reading public.

Figure 2 shows the temporal trend of the number of publications. An increasing trend of publications per year is observed in both academic bases. Regarding the WoS database, publications related to research on water purification have increased since 2010 reaching 400 articles in

Figure 2. Documents by year in Scopus and WoS.
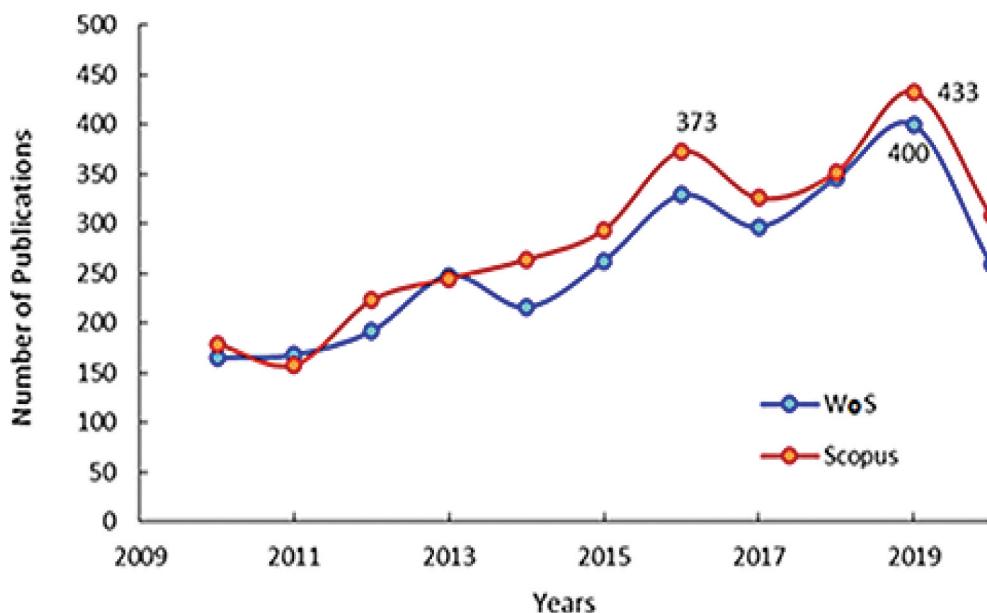
2019. In relation to Scopus, scientific production in 2011 was lower than in 2010, but in the year 2019, a production of 433 documents published between articles and reviews was observed.

A growing interest of the scientific community in evaluating the application of new technologies in water treatment, purification and/or potabilization is evident, because the assurance of drinking water quality is of utmost importance in human health (Tsitsifli & Kanakoudis, 2018) and environmental sustainability (Teodosiu et al., 2018).

3.2. Thematic areas

An analysis of the main research areas covered in the last 10 years is shown in Figure 3. For WoS (Figure 3a), the area of environmental science has covered most publications (39.34%), followed by Water Resources (22.32%), Environmental Engineering (20.24%), Chemical Engineering (10.70%), Chemistry Multidisciplinary (4.3%), and others (3.10%). Scopus shows more studies in the thematic area of Environmental science (38.95%), Chemistry (10.84%), Engineering (6.47%), Biochemistry, Genetics and Molecular Biology (6.46%), and Medicine (5.73%). The subject areas of Agricultural and Biological Sciences, Pharmacology, Toxicology and Pharmaceutics, Immunology and Microbiology, and Materials Science also stand out with 25.17% (Figure 3b).

The differences in the subject areas of both databases are evident. WoS maintains its own area for water resources (22.32%) and Scopus does not have a specific thematic area for water, which shows that the topics are diversified in several thematic areas of engineering, chemistry, etc. Likewise, a multidisciplinary and diverse audience of scientists is observed, contributing to the improvement of drinking water quality conditions. Besides, it indicates the strong relationship that exists between chemical science as the basis of the fundamental properties of matter and its conversion, which to a great extent sustains the environmental sciences in search of friendly solutions to make water drinkable. In addition, environmental sciences and environmental and chemical engineering lead the production of scientific papers in both academic databases; however, the Scopus database includes a greater number of thematic areas, indicating a greater multidisciplinary in this subject.

Figure 3. Documents by subject area: (a) WoS and (b) Scopus.
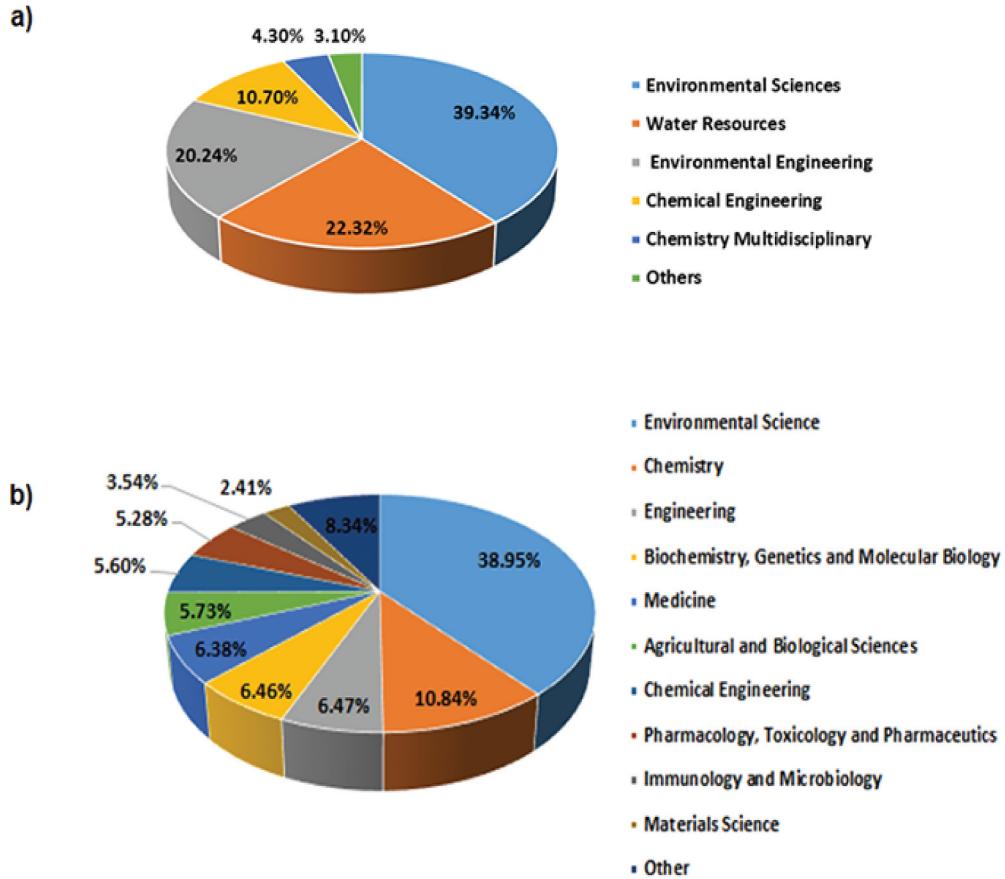
### 3.3. Main sources of research on drinking water purification

For the identification of the main sources, journals with ten or more papers published in this field of research during the study period were chosen. In the case of WoS, 567 sources were identified of which 61 met this requirement (10.76%) (Figure 4a), while for Scopus of 808 sources counted, only 50 met the above requirements (6.19%) (Figure 4b).

The 2883 WoS articles were published in 567 journals, of which ten journals covered (40.16%) of these publications (see Table 2). Among these journals, Water Research with 260 publications (9.02%), Science of the Total Environment with 176 publications (6.10%), and Desalination and Water Treatment with 147 publications (5.10%) stand out.

The 3155 Scopus articles were published in 808 journals, and ten journals published 33.66% of them (see Table 3). The top journals that published at least 10 articles on potabilization are Water Research with 296 publications (9.41%), Chemosphere with 157 publications (4.99%), and Science of the Total Environment with 132 publications (4.19%).

The journal Water Research had the highest number of citations (9875), followed by Science of the Total Environment (4719) and Chemosphere (3375). Of this ranking, six have an H index greater than 198. In addition, six journals are in Scopus quartile 1, two journals in quartile 2, and two in quartile 3. It is important to note that of the 10 most productive journals, three were published in the United Kingdom, four in the Netherlands, two in the United States, and one in

Figure 4. Sources of studies: (a) WoS and (b) Scopus.
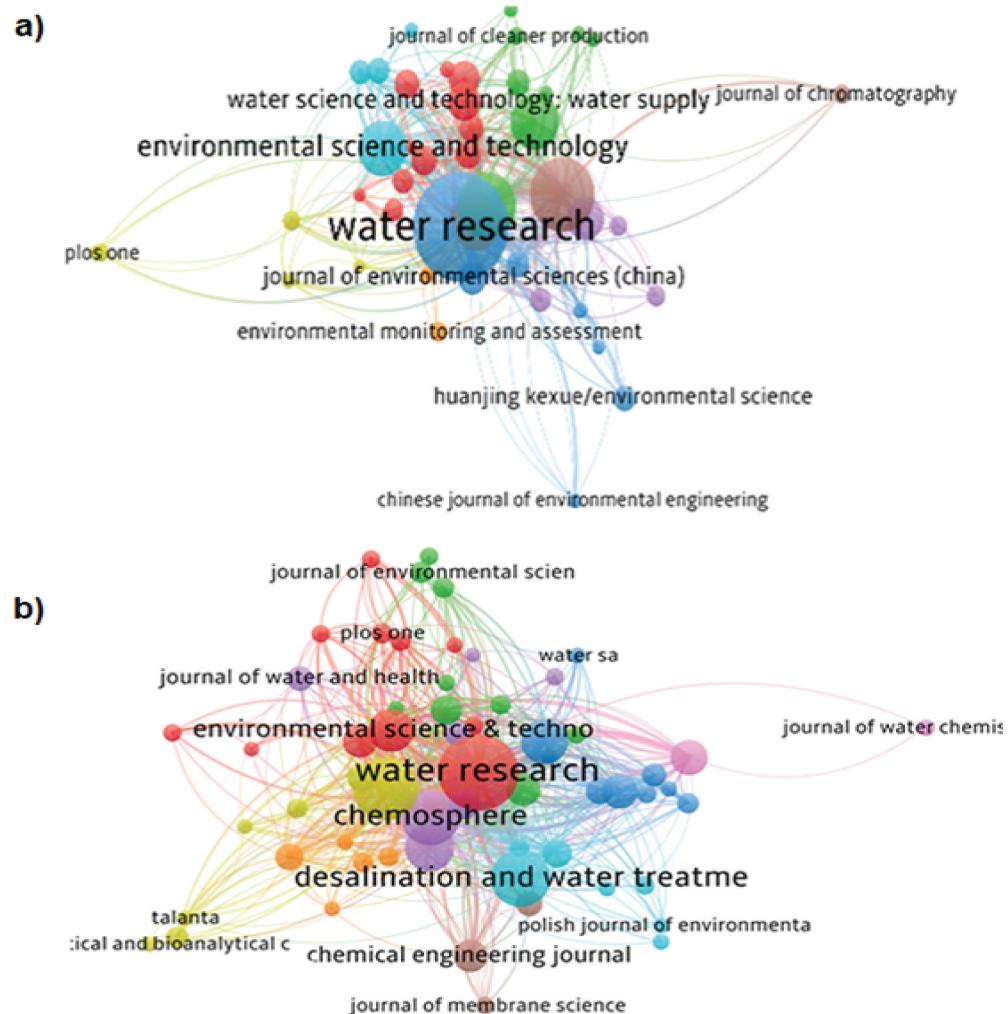
Germany. The subject areas related to water treatment studies are: Environmental Science, Engineering, Chemistry, and Chemistry Engineering.

Of the top 10 journals, only one journal combines water and health, indicating interdisciplinary characteristics of the study of water treatment. The high impact factor of the journal Water Research (9,130) reflects its status as a leading academic journal in the field of water treatment. Similarly, the journal Water Research had the highest citations (8332), followed by the journal Environmental Science and Technology (3669), and then Chemosphere with 3218 citations. Six of the 10 journals are in Scopus quartile 1, three journals in quartile 2, and one in quartile 3. It is important to note that four of the ten most productive journals were published in the Netherlands and three in the United Kingdom. The thematic areas related to water treatment studies are: Environmental Science, Engineering, and Chemistry.

As presented in Tables 2 and 3, 8 of the 10 journals with the highest scientific production and impact are indexed in both academic databases, a similar result was reported by Martín-Martín et al. (2018). Moreover, all journals can be classified in the area of technology and engineering. Additionally, the wide and diversified number of sources indicates a great interest of the editors in this topic.

TP: Total Production., Q: Quartil, H-Index: Hirsh index

Table 2. Top 10 WoS journals

N°	Source	TP	Cites	% publications	H	Q	Country	Topic
1	Water research	260	9875	9.02	285	Q1	Netherlands	Engineering
2	Science of the total environment	176	4719	6.1	224	Q1	Netherlands	Chemistry
3	Desalination and water treatment	147	588	5.1	51	Q2	United States	Engineering
4	Chemosphere	143	3375	4.96	228	Q1	United Kingdom	Chemistry
5	Environmental science and pollution research	98	1386	3.4	98	Q2	Germany	Environmental Science
6	Water Science and Technology: Water Supply	91	322	3.16	37	Q3	United Kingdom	Environmental Science
7	Environmental Science and Technology	84	2931	2.91	373	Q1	United States	Chemistry
8	Journal of Hazardous Materials	57	2353	1.98	260	Q1	Netherlands	Environmental Science
9	Journal of water supply research and technology-aqua	53	280	1.84	48	Q3	United Kingdom	Environmental Science
10	Chemical engineering journal	49	1160	1.7	198	Q1	Netherlands	Chemical Engineering

Table 3. Top 10 Scopus journals

N°	Source	TP	Cites	% publications	H	Q	Country	Topic
1	Water Research	296	8332	9.41	285	Q1	Netherlands	Engineering
2	Chemosphere	157	3218	4.99	228	Q1	United Kingdom	Chemistry
3	Science of the Total Environment	132	3105	4.2	224	Q1	Netherlands	Environmental Science
4	Environmental Science and Technology	95	3669	3.02	373	Q1	United States	Chemistry
5	Environmental Science and Pollution Research	94	1207	2.99	98	Q2	Germany	Environmental Science
6	Desalination and Water Treatment	89	390	2.83	51	Q2	United States	Engineering
7	Journal of Hazardous Materials	62	2864	1.97	260	Q1	Netherlands	Environmental Science
8	Water Science and Technology: Water Supply	53	151	1.69	37	Q3	United Kingdom	Environmental Science
9	Journal of Water And Health	45	298	1.43	56	Q2	United Kingdom	Environmental Science
10	Journal of Environmental Sciences (China)	39	673	1.24	90	Q1	Netherlands	Environmental Science

TP: Total Production,, Q: Quartil, H-Index: Hirsh index

Fu et al. (2013) conducted a study covering the period 1992–2011 and noted that the journals Water Research, Environmental Science & Technology, and Journal of American Water Works Association were the three most common journals in drinking water research. For this last decade Water Research was in first place; in addition, there has been a growth in scientific publications in journals such as Chemosphere and Science of the Total Environment.

3.4. Author keyword trend analysis

In a scientific article, keywords express the main idea and thematic concept. Keywords can summarize the general characteristics of the research content, permitting the establishment of the relationship between research contents and the definition of the general direction of scientific research (Zhu et al., 2019).

In the WoS database, the frequency of keywords in the 2883 articles was examined and 6851 keywords were found. For a better analysis, those keywords with a minimum of 20 occurrences were determined, and 59 keywords met this requirement, while the frequency of keywords in the 3155 articles in the Scopus database was examined and 7313 keywords were found. Likewise, 52 keywords with a minimum of 20 occurrences were identified (see Figure 5b).

Figure 5a shows that in the WoS database, the most frequent descriptor is drinking water, with 443 occurrences (5.43%), followed by water treatment with 200 occurrences (2.45%), adsorption with 134 (1.64%), drinking water treatment with 129 (1.58%), and water purification with 102 occurrences (1.25%). The same figure shows the co-occurrence of the keywords in the 2883

Figure 5. Map of co-occurrence of keywords: (a) WoS and (b) Scopus. Source: VOS Viewer.
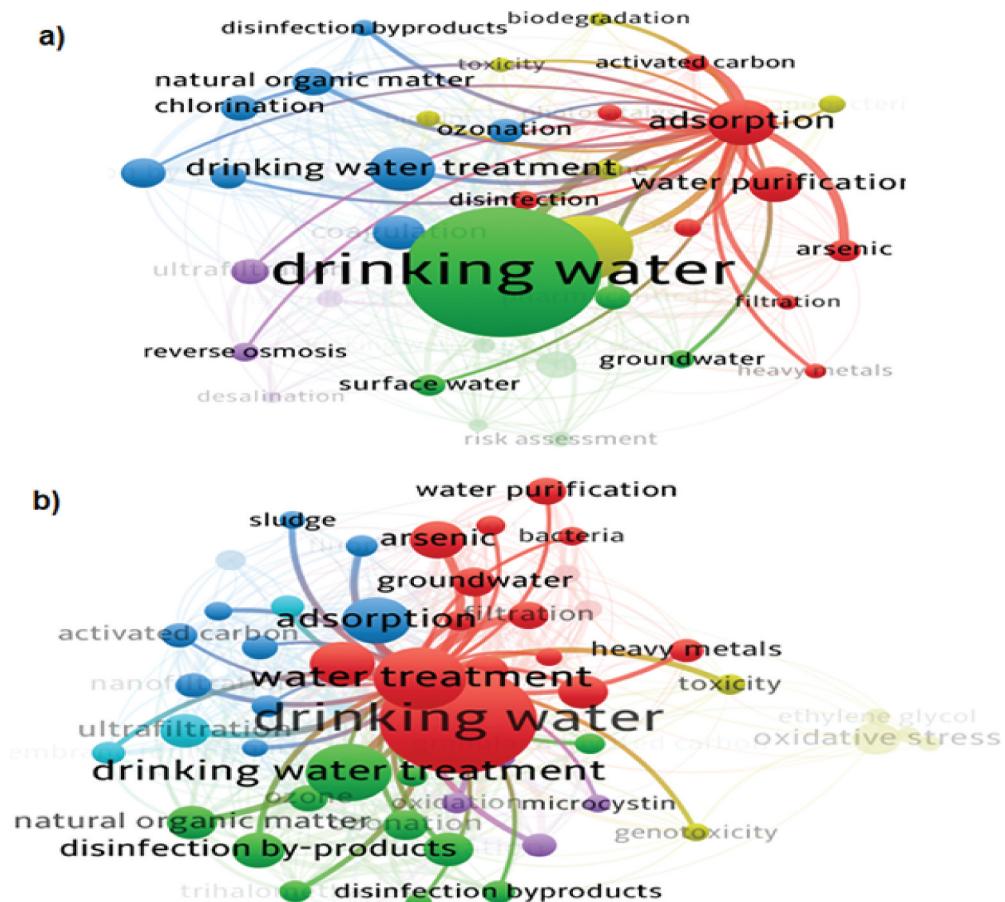
documents analyzed from the WoS database, which refers to the underlying relationships between the terms (due to their tendency to appear together) and allows to group them into categories. Six major groups or clusters can be distinguished.

The three main clusters are: (a) the first cluster revolves around the word "water" and relates terms such as: drinking water, drinking water treatment, water quality, groundwater, surface water (green color), among others; (b) the second cluster relates more to the field of disinfection by-products and includes terms such as chlorination, disinfection by-products, natural organic matter, trihalomethanes, ozonation, coagulation (light blue color), among others; and (c) the third cluster (red color) adds terms related to unconventional technologies, such as: adsorption, activated carbon, arsenic, filtration, heavy metals, photocatalysis, among others. All the word clusters concur among them, so they present a close conceptual linkage.

Figure 5b shows that in the Scopus database, the most frequent descriptor is drinking water, with 463 occurrences (6.33%), followed by water treatment with 187 occurrences (2.55%), drinking water treatment with 164 (2.24%), adsorption with 113 (1.54%), and coagulation with 103 (1.40%) occurrences. This figure shows the co-occurrence of the keywords in the 3155 documents analyzed from the Scopus database, which refers to the underlying relationships between the terms (due to their tendency to appear together) and allows us to group them into categories. Six major groups or clusters can be distinguished, but this study is focused on the most relevant ones.

The first cluster revolves around treatments and relates terms such as: drinking water, water treatment, coagulation, filtration, disinfection, water purification, arsenic, among others. The arsenic is one of the pollutants that are repeated in the different studies due to its extreme toxicity in addition to fluorine, and iron (Fu et al., 2013; Hu et al., 2010), the new removal techniques include the application of Metal Organic Framework (MOF), with a challenge to explore new synthesis routes and morphology that keep them stable under different reaction conditions; furthermore, the use of mixed matrix membranes applied in MOFs such as carbon nanotubes could optimize removal processes and future investigations should address adsorption mechanisms to achieve profitable synthesis routes and large-scale production (Haldar et al., 2020).

In addition, the second cluster is more related to the field of disinfection by-products and includes terms such as chlorine, disinfection by-products, natural organic matter, trihalomethanes, ozone, drinking water treatment, among others. Finally, the third cluster adds terms related to non-conventional technologies, such as: adsorption, activated carbon, ultrafiltration, nanofiltration, reverse osmosis, ion exchange, among others, due to the interaction with the natural organic material of the water; therefore, the investigations are oriented in knowing the possible dangers and adverse effects to the human health by routes of cutaneous exposure or by inhalation of such by-products (Mazhar et al., 2020). Another relevant one is the investigation in the application of chlorine to inactivate enteric viruses in concentrations and contact time that are adequate and in the evaluation of factors that influence the treatment of drinking water, such as the type of virus, pH, temperature, and water matrix (Rachmadi et al., 2020).

All groups of words co-occur with each other and therefore present a close conceptual linkage. In addition, four of the five most frequent keywords are located in both databases, which confirms the overlapping of articles and reviews that was previously reported.

3.5. Active countries in potabilization research

Although potabilization is a global concern, the intensity of research in this field may vary in different countries. Therefore, it is important to perform an analysis of articles published globally, which can serve as an indicator to determine the demand for this topic.

Figure 6 shows the network between countries of international co-authorship. Countries are indicated by a label and a circle. If a country is more important, then the label and the circle are

Figure 6. Network visualization of major countries in water treatment research: (a) WoS and (b) Scopus.
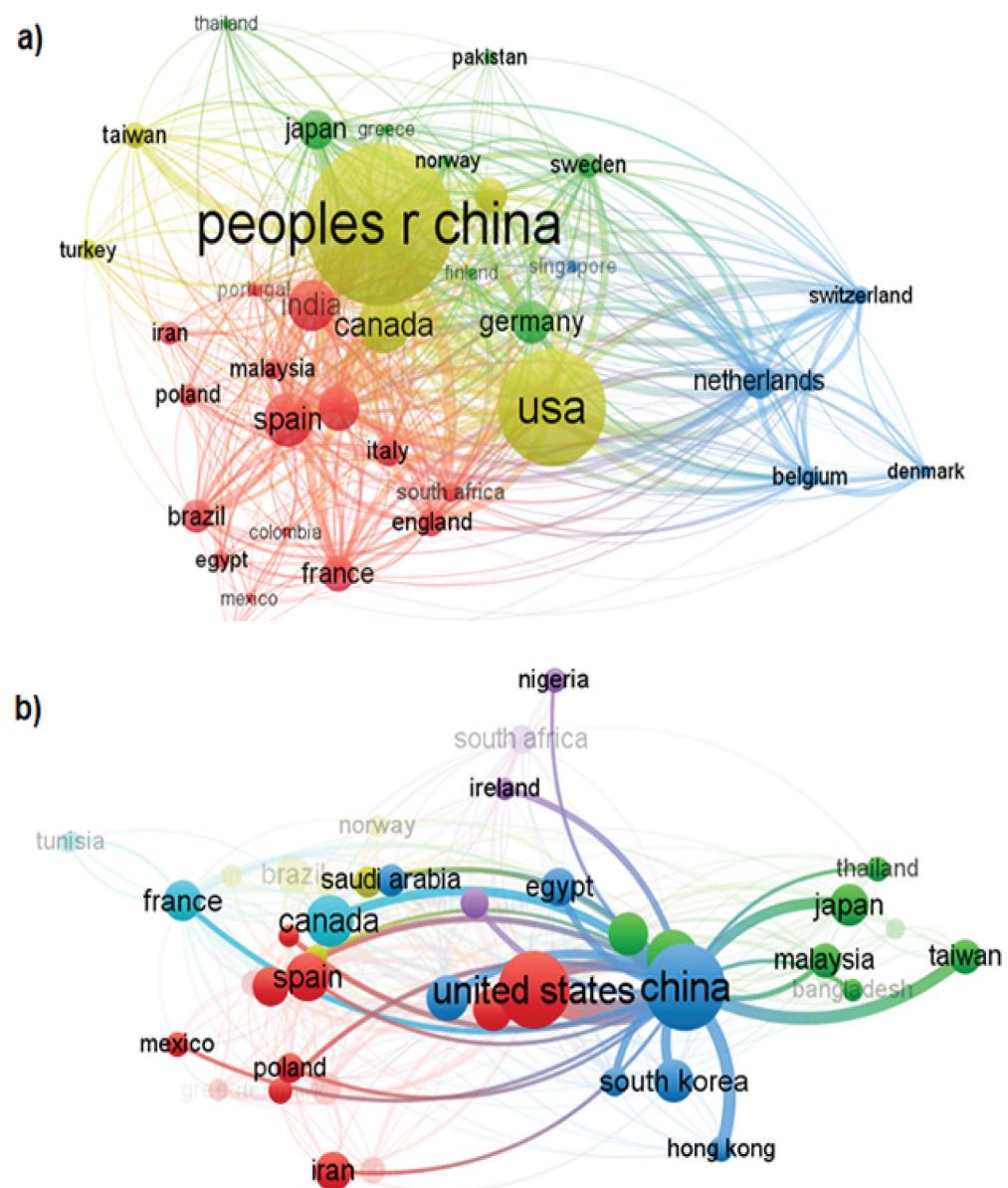
bigger. The size of each circle shows the number of articles written by authors from the country. Each link between two circles from different countries indicates that there is co-authorship between organizations in those countries.

In Figure 6a, with respect to WoS, six large groups or clusters can be distinguished, corresponding to the countries that produce the most articles. In the first cluster are China, the United States of America, Canada, South Korea, among others. The second cluster is more related to European countries such as Spain, Italy, England, Poland, France, Portugal, as well as Latin countries such as Brazil, Colombia, Mexico, among others. Finally, the third cluster involves another group of countries mainly from Central Europe such as: Belgium, Denmark, Holland, Switzerland, as well as Asian countries such as Saudi Arabia and Singapore, among others.

In addition, it can be observed that according to the WoS database, China is the most active country in the production of studies related to water treatment during the last decade. Researchers from China contributed 717 articles, which represents 31.41%. In addition, researchers from the United States contributed 479 articles, representing 16.62%. Researchers from Canada contributed 198 articles, representing 6.87%. There is quite a difference between China and the USA. Among the countries of the European region the most outstanding are the following: Spain, Germany, and the Netherlands with 183, 137, and 108 articles, respectively.

Similarly, in Figure 6b according to the Scopus database, China has been the most active in the production of studies related to water purification during the last decade. Researchers from China contributed 709 articles (22.54%). It is understandable due to the significant efforts of the Chinese government dedicated to resolving water supply-demand conflicts (Zhu et al., 2019). Meanwhile, researchers from the United States of America contributed 514 articles in the last decade, accounting for 16.34%. Researchers from India have contributed 216 articles (6.87%). There is quite a difference between China, the United States of America, and India. Besides, the European countries that have contributed the most in this field of research were Spain and Germany with 153 and 133 articles, respectively. Based on the interconnections between different countries, it is evident that cooperation prevails in Europe when conducting research.

Figure 6b shows the co-authorship relationships of countries according to the Scopus database, due to their tendency to appear together and which allows them to be grouped into categories. Six large groups or clusters can be distinguished. The first cluster is composed by USA and European countries such as: Spain, Italy, Denmark, Holland, Belgium, Poland, among others. The second cluster is more related to Asian countries and includes terms such as: China, South Korea, Hong Kong, Saudi Arabia, and Germany, despite being a European country. Finally, the third cluster involves another group of Asian countries such as: Japan, Taiwan, Malaysia, Thailand, India, among others.

The WoS database shows a greater emphasis on collaboration between countries interested in water purification in the last decade. Likewise, China is consolidated as the country with the highest number of publications in both academic databases, its serious problems of contamination of drinking water and underground sources by arsenic and fluoride detected in recent years has guided research in the use of advanced technology for its treatment (Wu, 2020).

Fu et al. (2013) indicated that the United States of America occupied a leading position among 168 countries/territories, followed by Japan and Germany and that in this last decade continues to lead the United States of America, but there is an increase in other countries such as China that maintains a high ranking with the area of Water Science and Technology, among others (https://www.scimagojr.com/countryrank.php?category=2312&area=2300&region=Asiatic%20Region) followed by Canada, India, and Spain, the latter being emerging countries.

3.6. Productivity of water treatment articles by institution

In the WoS database, 3186 organizations were found to support research on the subject of water purification. It was determined that 22 organizations are linked to a minimum of 20 articles and scientific reviews. Meanwhile, in the Scopus database of 3155 articles, a total of 7321 organizations were found to be linked to these publications; likewise, 12 organizations were identified with at least 20 documents.

In WoS, the Chinese Academy of Sciences of Beijing in China stood out for its greatest contribution in this field of research with 153 documents. In second place Tongji University in Shanghai in China contributed 76 papers, and Tsinghua University in Beijing in China contributed 73 papers. There is a noticeable dispersion of organizations, mostly Asian and European, linked to the topic of water purification (see Figure 7a).

Figure 7. Visualization of the main institutions in drinking water treatment research: (a) WoS and (b) Scopus.
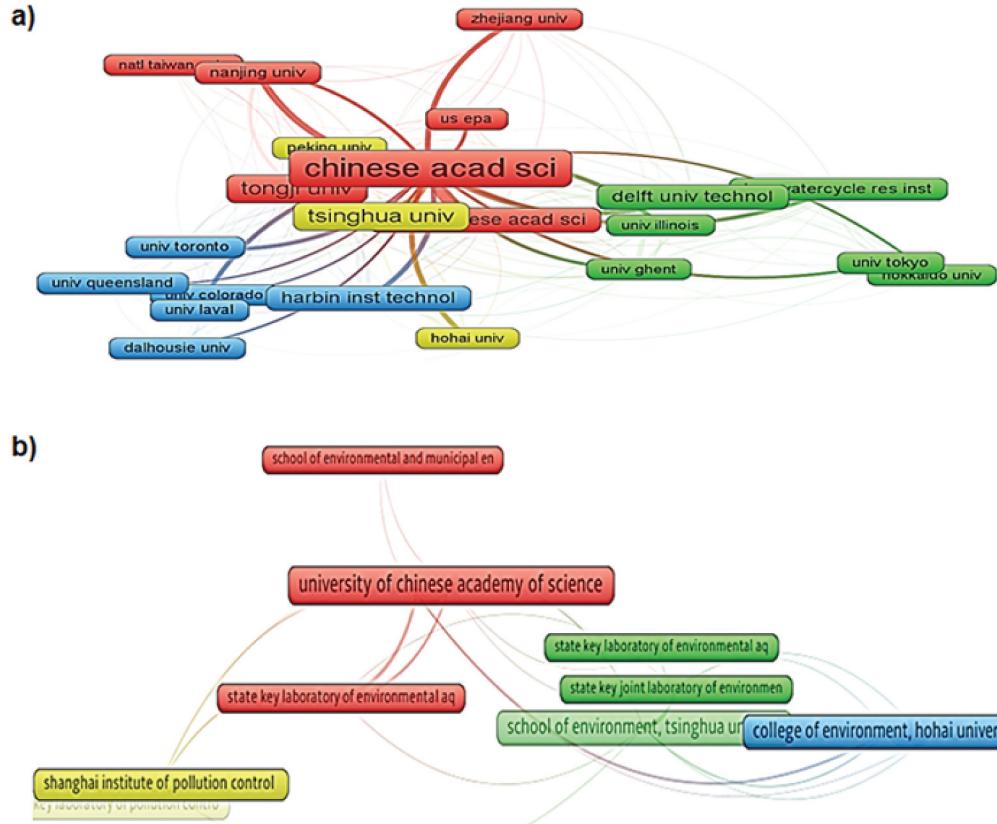

Figure 7b shows the main institutions that contributed to the potabilization studies according to the Scopus database. These institutions are those associated with the main authors: the first author and the corresponding author. Chinese Academy of Sciences of Beijing in China stood out for its major contribution in this field of research with 28 papers. In second place State Key Laboratory of Drinking Water Science and Technology of Beijing in China with 27 papers and College of Environment, Hohai University of Nanjing in China has contributed 22 papers. The research in these organizations is interdisciplinary. Besides, Chinese research centers and universities lead the scientific production in the last 10 years in both academic databases, while a greater diversity of institutions is observed in the WoS database compared to Scopus.

3.7. Authors' production

The Matthew Effect in scientific production reflects the existence of a small number of specialized authors who concentrate the flow of information and a large number of transitory authors with few publications (Merton, 1968). Figure 8 shows the participation of authors according to the number of documents published, considering 16 or more publications per author.

Figure 8a shows the participation of authors according to the number of published papers. Of the total 12,055 authors in WoS, of the top 5 authors one published 25 papers (Yang & Min), the second published 18 papers (Yu & Jianwei), and the other three published 16 papers each (Chen & Chao; Prevost & Michele; Gagnon & Graham). Gagnon & Graham are not related to the other authors (hence 4 authors are presented in Figure 8a). The top ten authors with the highest production in WoS in this field account for a total of 5.62%; that is, despite the small number of authors shown in Figure 8a, there is no concentration of publications per author in this database.

Figure 8. Visualization of the main authors in drinking water treatment research: (a) WoS and (b) Scopus.
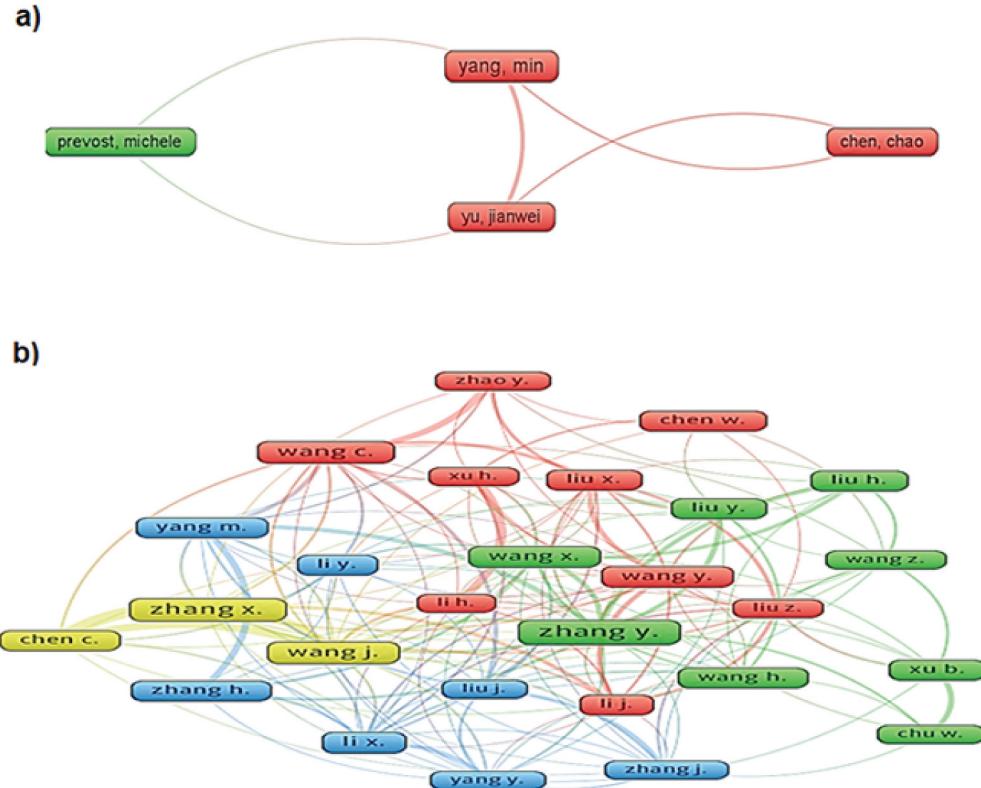
Of the total 10,502 authors in Scopus, 41 authors published 16 or more papers while a single author published 47 papers (Zhang Y.), followed by Zhang X. with 41 publications (1.30%), and Wang C. with 40 publications (1.27%) (Figure 8b). The top 10 authors with the highest Scopus output in this field comprise a total of 10.87%.

Greater diversity of authors is observed in Scopus; however, the greater production of scientific papers in this database is concentrated in a reduced number of researchers, while in WoS a more homogeneous distribution is observed among scientific production per author.

3.8. Most cited articles

In WoS there are ten articles with more than 256 citations. The most cited article is entitled "Removal of hazardous organics from water using metal-organic frameworks (MOFs): plausible mechanisms for selective adsorptions", which has 589 citations and was published in the Journal of Hazardous Materials of the Netherlands. The most cited articles in WoS can be seen in Table 4.

In the field of water purification during the last decade, there are ten articles in Scopus with more than 218 citations. The most cited article is entitled "Water-dispersible magnetite-reduced graphene oxide composites for arsenic removal", which has 1441 citations and was published in the American Chemical Society of the United States. The most cited articles in Scopus can be seen in Table 5. Besides, in the WoS database, the most cited articles are those published between 2010 and 2015, with the research by Hasan and Jhung (2015) having the highest number of citations (589 citations). In the Scopus database, the most cited articles were published between the years 2010 to 2013, highlighting the article by Chandra et al. (2010) with 1441 citations.

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Table 4. Top ten most cited papers related to drinking water treatment in WoS				
Nº	Authors	Citations	Title	Journal
1	Hasan and Jhung (2015)	589	Removal of hazardous organics from water using metal-organic frameworks (MOFs): plausible mechanisms for selective adsorptions	Journal of Hazardous Materials
2	Loos et al. (2010)	487	Pan-European survey on the occurrence of selected polarorganic persistent pollutants in ground water	Water Research
3	Matilainen et al. (2011)	357	An overview of the methods used in the characterisation of natural organic matter (NOM) in relation to drinking water treatment	Chemosphere
4	Yang et al. (2017)	344	Occurrences and removal of pharmaceuticals and personal care products (PPCPs) in drinking water and water/ sewage treatment plants: A review	Science of the total environment
5	Hughes et al. (2013)	334	Global Synthesis and Critical Evaluation of Pharmaceutical Data Sets Collected from River Systems0	Environmental Science & Technology
6	Wang et al. (2013)	332	Adsorptive remediation of environmental pollutants using novel graphene-based nanomaterials	Chemical Engineering Journal
7	Liu et al. (2016)	302	Rapid water disinfection using vertically aligned MoS_2 nanofilms and visible light	Nature Nanotechnology
8	Post et al. (2012)	277	Perfluorooctanoic acid (PFOA), an emerging drinking water contaminant: a critical review of recent literature	Environ Research
9	Murray et al. (2010)	277	Prioritizing Research for Trace Pollutants and Emerging Contaminants in the Freshwater Environment	Environmental Pollution
10	Evgenidou et al. (2015)	256	Occurrence and removal of transformation products of PPCPs and illicit drugs in wastewaters: a review.	The Science of the Total Environment

N°	Authors	Citations	Title	Journal
**Table 5. Top ten documents with more citations related to potabilization in Scopus**				
1	Chandra et al. (2010)	1441	Water-dispersible magnetite-reduced graphene oxide composites for arsenic removal	American Chemical Society
2	Hashim et al. (2011)	480	Remediation technologies for heavy metal contaminated groundwater	Journal of Environmental Management
3	Yang et al. (2017)	397	Occurrences and removal of pharmaceuticals and personal care products (PPCPs) in drinking water and water/sewage treatment plants: A review	Science of the total environment
4	Matilainen et al. (2011)	396	An overview of the methods used in the characterisation of natural organic matter (NOM) in relation to drinking water treatment	Chemosphere
5	Liu et al. (2016)	312	Rapid water disinfection using vertically aligned MoS_2 nanofilms and visible light	Nature Nanotechnology
6	Dankovich and Gray (2011)	289	Bactericidal Paper Impregnated with Silver Nanoparticles for Point-of-Use Water Treatment	Environmental Science & Technolog
7	Baghoth et al. (2011)	288	Tracking natural organic matter (NOM) in a drinking water treatment plant using fluorescence excitation-emission matrices and PARAFAC	Water Research
8	McGuigan et al. (2012)	230	Solar water disinfection (SODIS): a review from bench-top to roof-top	Journal of Hazardous Materials
9	Rahman et al. (2014)	220	Behaviour and fate of perfluoroalkyl and polyfluoroalkyl substances (PFASs) in drinking water treatment: a review	Water Research
10	Bedoux et al. (2012)	218	Occurrence and toxicity of antimicrobial triclosan and by-products in the environment	Environ Sci Pollut Res

Table 6. Articles most cited in WoS and Scopus: drinking water treatments

Author/s	Year	Age	Title	WoS						Scopus			
				R		C		C/Age		R		C	C/Age
Loos et al. (2010)	2010	10	Pan-European survey on the occurrence of selected polarorganic persistent pollutants in ground water	3		487		48.7					
Chandra et al. (2010)	2010	10	Water-dispersible magnetite-reduced graphene oxide composites for arsenic removal							1		1441	144.1
Hasan and Jhung (2015)	2015	5	Removal of hazardous organics from water using metal-organic frameworks (MOFs): plausible mechanisms for selective adsorptions	2		589		117.8					
Hashim et al. (2011)	2011	9	Remediation technologies for heavy metal contaminated groundwater							4		480	53.3

(Continued)

Table 6. (Continued)

Author/s	Year	Age	Title	WoS				Scopus		
				R	C	C/Age	R	C	C/Age	
Yang et al. (2017)	2017	3	Occurrences and removal of pharmaceuticals and personal care products (PPCPs) in drinking water and water/sewage treatment plants: A review	5	344	114.7	5	397	132.3
Matilainen et al. (2011)	2011	9	An overview of the methods used in the characterisation of natural organic matter (NOM) in relation to drinking water treatment	6	357	39.7	6	396	44.0
Hughes et al. (2013)	2013	7	Global Synthesis and Critical Evaluation of Pharmaceutical data sets Collected from River Systems	7	334	47.7			
Wang et al. (2013)	2013	7	Adsorptive remediation of environmental pollutants using novel graphene-based nanomaterials	8	332	47.4			

(Continued)

Table 6. (Continued)

| Author/s	Year	Age	Title	WoS			Scopus		
				R	C	C/Age	R	C	C/Age
Liu et al. (2016)	2016	4	Rapid water disinfection using vertically aligned MoS2 nanofilms and visible light	9	302	75.5	9	312	78
Dankovich and Gray (2011)	2011	9	Bactericidal Paper Impregnated with Silver Nanoparticles for Point-of-Use Water Treatment				10	289	32.1
Baghoth et al. (2011)	2011	9	Tracking natural organic matter (NOM) in a drinking water treatment plant using fluorescence excitation-emission matrices and PARAFAC				11	288	32
Post et al. (2012)	2012	8	Perfluorooctanoic acid (PFOA), an emerging drinking water contaminant: a critical review of recent literature	12	277	34.6			
Murray et al. (2010)	2010	10	Prioritizing Research for Trace Pollutants and Emerging Contaminants in the Freshwater Environment	13	277	27.7			

(Continued)

Table 6. (Continued)

Author/s	Year	Age	Title	WoS				Scopus			
				R	C	C/Age		R	C	C/Age	
Evgenidou et al. (2015)	2015	5	Occurrence and removal of transformation products of PPCPs and illicit drugs in wastewaters: a review	14	256	51.2					
McGuigan et al. (2012)	2012	8	Solar water disinfection (SODIS): a review from bench-top to roof-top					15	230	28.8	
Rahman et al. (2014)	2014	6	Behaviour and fate of perfluoroalkyl and polyfluoroalkyl substances (PFASs) in drinking water treatment: a review					16	220	36.7	
Bedoux et al. (2012)	2012	8	Occurrence and toxicity of antimicrobial triclosan and by-products in the environment					17	218	27.3	
Total					**3555**				**4271**		
Average						**60.5**				**60.9**	

R, rank; C, the total number of citations per year; C/Age, average citations received by years.

As shown in Table 6, the 10 most cited and indexed articles in WoS received 3,555 citations and the average number of citations of the 10 most cited articles in the last decade was 355.5 citations/document. As for the figures for Scopus articles, although they are higher, they follow a similar behavior to WoS, whose 10 most cited articles received 4,271 citations, with an average of 427.1 citations/document. It should be emphasized that the articles, despite being ten years old, continue to be cited. Moreover, only three top ten articles from both Wos and Scopus are found in these two databases (Liu et al., 2016; Matilainen et al., 2011; Yang et al., 2017).

A more detailed citation analysis shows that only 0.34% of WoS articles and 0.32% of Scopus articles have received more than 200 citations in the last decade. The article "Water-dispersible magnetite-reduced graphene oxide composites for arsenic removal" published by Chandra et al. in 2010 averaged 144.1 citations per year; meanwhile, the article "Occurrences and removal of pharmaceuticals and personal care products (PPCPs) in drinking water and water/sewage

Figure 9. Technologies used: (a) WoS and (b) Scopus.
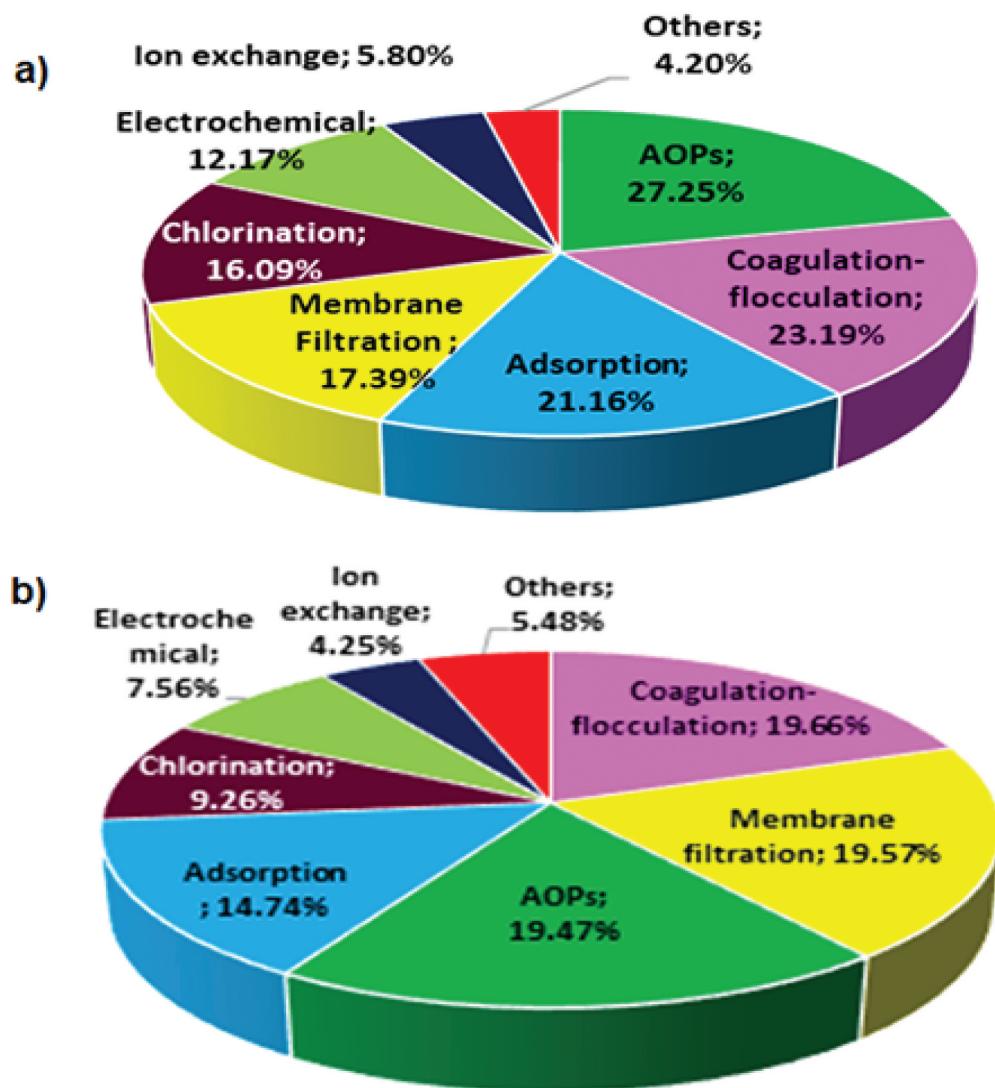
treatment plants: A review" published by Yang et al. in 2017 had an average of 132.3 citations per year; however, the latter article had 3 years of publication, while the former had 10 years of publication.

For the WoS database (Figure 9a), advanced oxidation processes (27.25%) represent the most studied technique for making water potable, followed by coagulation-flocculation (23.19%), adsorption (21.16%), and membrane filtration. On the other hand, in the Scopus database (Figure 9b), similar to that observed in WoS, the four most used technologies are coagulation-flocculation (19.66%), membrane filtration (19.66%), advanced oxidation processes (19.66%), and adsorption (14.74%). Similarities are observed in both databases with respect to the frequency of technologies applied in drinking water treatment and included in the scientific papers of the last decade.

The application of advanced oxidation processes is due to the interest in using technologies that do not generate chemical traces as disinfection by-products and whose constant consumption could cause negative effects on humans (Gilca et al., 2020). Also, advanced oxidation processes have shown their effectiveness in the treatment of many emerging pollutants. However, this technology is applied in places that can afford the use of advanced technology due to its high cost (Hylling et al., 2019).

3.9. Trends in research related to drinking water purification

Drinking water treatment plants face an important challenge regarding the optimization of existing technology and the introduction of non-conventional technologies capable of removing persistent and emerging contaminants. Figure 9(a,b) shows the technologies frequently reported in articles and reviews in the last 10 years, highlighting processes of advanced oxidation, membrane filtration, coagulation/flocculation, among others.

Another widely used technology is filtration. Hussain and Al-Fatlawi (2020) manufactured water filters using proportions of 85%, 80% and 75% of kaolin clay with jute fibers, to treat contaminated water consumed directly at rural and domestic level and for their purpose, they tested proportions of 85%, 80% and 75% of clay and achieved significant removals of Chloride (71. 54%), calcium (70.5%), total hardness (70.5%), magnesium (80.7%), alkalinity (77.9%), sulfates (85.5%), sodium (71.64%), and potassium (69.6%), demonstrating its efficiency and lower cost as an added value of this application.

Regarding membrane filtration, the studies include: microfiltration, nanofiltration, ultrafiltration, and reverse osmosis, aiming the efficient retention of organic micropollutants or salts and its main limitation is membrane fouling (Chang et al., 2020), which decreases the permeability significantly and raises the cost of its application; therefore, many studies are oriented to achieve higher resistance to fouling (Wang et al., 2017). Besides, although membrane filtration and advanced oxidation processes are widely used technologies in developed countries, it is not without inconveniences that motivate further research, such as: new materials and membrane fouling, costs in UV and ozone generation (the latter associated with its short half-life), and the generation of highly toxic by-products after the application of advanced oxidation processes (Deng et al., 2019; Hylling et al., 2019).

Coagulation-flocculation is the most commonly employed process in water treatment due to its simplicity and effectiveness (Teh et al., 2016). Mejía et al. (2020) demonstrated that the extraction of lipids from Moringa oleifera seeds used as a coagulant at a dose of 0.5 g/l improves the removal of turbidity (up to 97.8%) and chemical oxygen demand COD (51.4%), compared to the seed applied without pretreatment (turbidity: 87.3%; COD: 26.3%) in wastewater. However, the production and toxicity of sewage sludge and the ineffectiveness in the removal of metals and emerging pollutants (including the increase of chemical oxygen demand in the application of natural coagulants) are the reason for a rich scientific production seeking improvements in these processes (Teh et al., 2016). In addition, coagulation-flocculation is applied as pretreatment in the control of particulate matter,

microorganisms, natural organic matter (NOM), synthetic organic carbon, disinfection by-product pre-cursors (DBP), some inorganic ions, and metals (Kalaitzidou et al., 2020; Trinh & Kang, 2011).

3.10. Trends in the study of contaminants

The main cause of innovation in water purification is the presence of a wide variety of contami-nants. Figure 10 shows the ranking of the main contaminants investigated by different purification techniques, as indicated above. In the WoS database (Figure 10a), emerging contaminants (31%), cyanobacteria and pathogens (22%), natural organic compounds (15%), fluorinated compounds (7%), phosphates (4%), and other contaminants were identified. On the other hand, with respect to the Scopus database (Figure 10b), the most studied contaminants were the following: heavy

Figure 10. Main pollutants stu-died: (a) WoS and (b) Scopus.
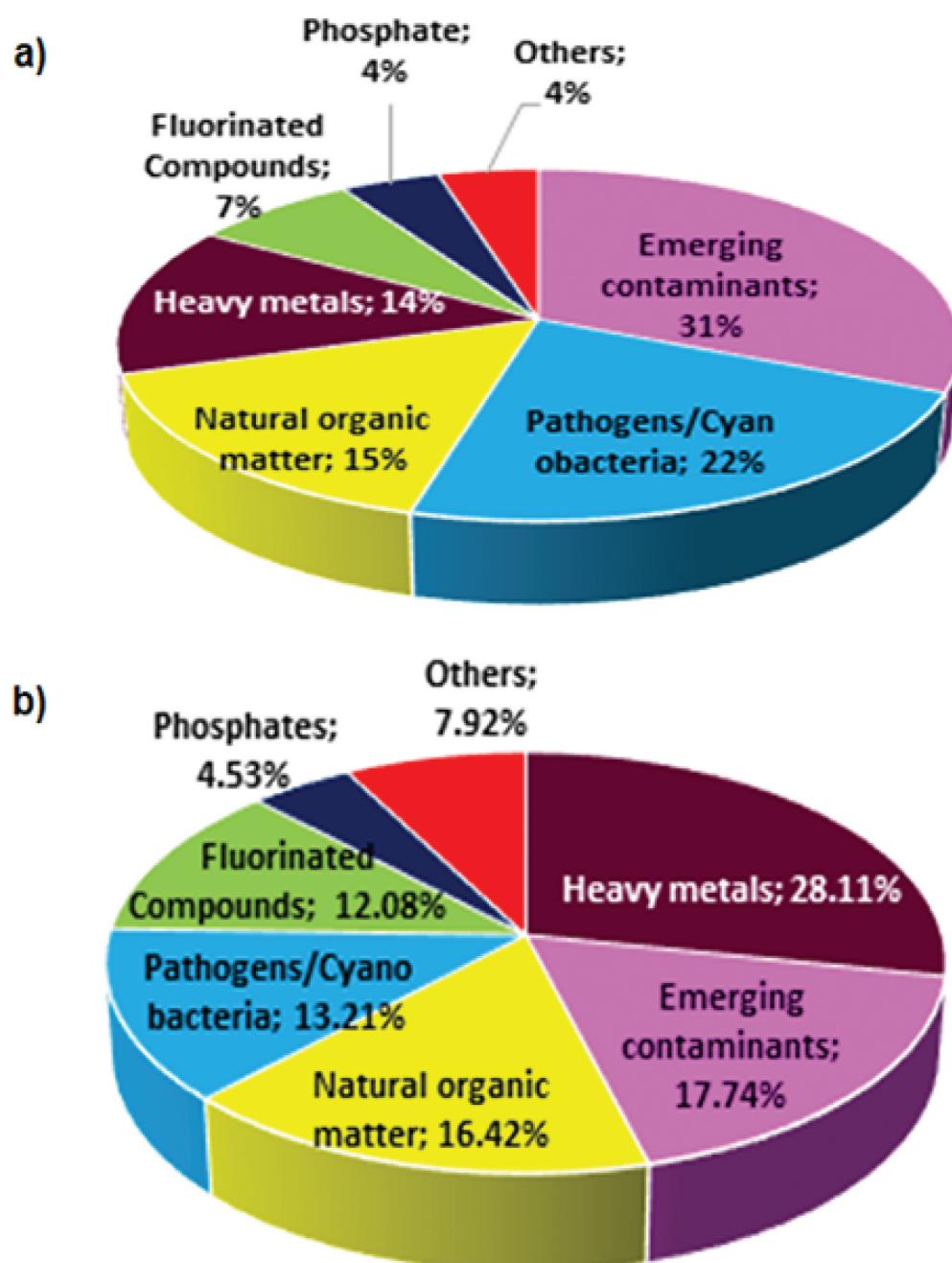
metals (28.11%), emerging contaminants (17.74%), and natural organic matter (16.42%), and in lower frequency of study are pathogens/cyanobacteria (13.21%), fluorinated compounds (12.08%), phosphates (4.53%), and others (7.92%).

Emerging contaminants include pharmacological residues, pesticides, personal care products, and organic compounds, as well as recalcitrant organic compounds, among others, that are hardly removed in conventional treatment and are discharged to receiving bodies causing acute toxicity in aquatic organisms (Singh et al., 2019), and a risk to human health; hence, they are being recognized as a global threat. The use of advanced oxidation processes and membrane filtration are related to the removal of emerging contaminants (Cuerda-Correa et al., 2019; Teodosiu et al., 2018) and organic pollutants.

Algal cells are not easily removed by conventional treatment processes which can generate their growth in treatment systems up to the distribution network, implying decreased treatment efficiency and pipe corrosion (Jian et al., 2019); similarly, pathogenic microorganisms such as Cryptosporidium (an enteric pathogenic protozoan in water) presents resistance to chlorine treatments for disinfection, so it is considered a high risk to public health (Monis et al., 2017), which is why researchers are interested in the elimination of cyanobacteria, pathogens, and organic matter. The treatment frequently employed in the removal of these contaminants is membrane filtration (Dixon et al., 2020).

Likewise, the presence of heavy metals in water sources represents a high risk hazard for aquatic organisms and public health worldwide, so the presences of nickel, lead, copper, cadmium, zinc, arsenic, chromium, and manganese, among others are common (Moldovan et al., 2020; Vidu et al., 2020). These elements can contaminate both ground and surface water as a result of natural processes (erosion of mineral deposits) and various anthropogenic activities (contaminated agricultural runoff). They are considered persistent, bioaccumulative, and toxic pollutants (Hu et al., 2020), hence the interest of researchers regarding these pollutants.

In the removal of metals, techniques such as adsorption, ion exchange, electrolysis, and also including final treatments with membrane filtration techniques: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), reverse osmosis (RO), and polymeric membranes are usually used (Peydayesh et al., 2020). Likewise, Natural Organic Matter (NOM), reported in WOS (15%) and Scopus (16.42%), is present in surface water and is composed of hydrophilic compounds and hydrophobic acids, and is considered one of the main pollutants in water purification. Several treatments have been developed for these contaminants, among which the advanced oxidation processes (AOP) stand out because they mitigate the fouling of the filtration membranes which become saturated very quickly, although they can retain these contaminants in the first instance (P. Li et al., 2020).

Fluorinated compounds and Poly- and Perfluoroalkyl Substances (PFAS) have also attracted the attention of researchers. The former components are common in groundwater and surface water and have also merited special attention in Scopus and WoS. Fluorinated compounds are generally due to geological sources, materials such as fluorspar and apatite, among others (Onipe et al., 2020). Their presence is related to diseases such as fluorosis and adsorption, AOP and ion exchange are used for their removal, while PFAS substances comprise a wide number of persistent organic compounds of industrial origin and with great impacts on human health and ecosystem (Gagliano et al., 2020), being the techniques used in the treatment of adsorption, anion-exchange (AE), high pressure nanofiltration and reverse osmosis, and membrane processes (Kucharzyk et al., 2017). Similarities were observed in WoS and Scopus with respect to the frequent pollutants investigated. It is related to the technologies used in the treatment that were previously presented.

Figure 11. Pollutants removed in the year 2010 and 2019: (a) WoS and (b) Scopus.
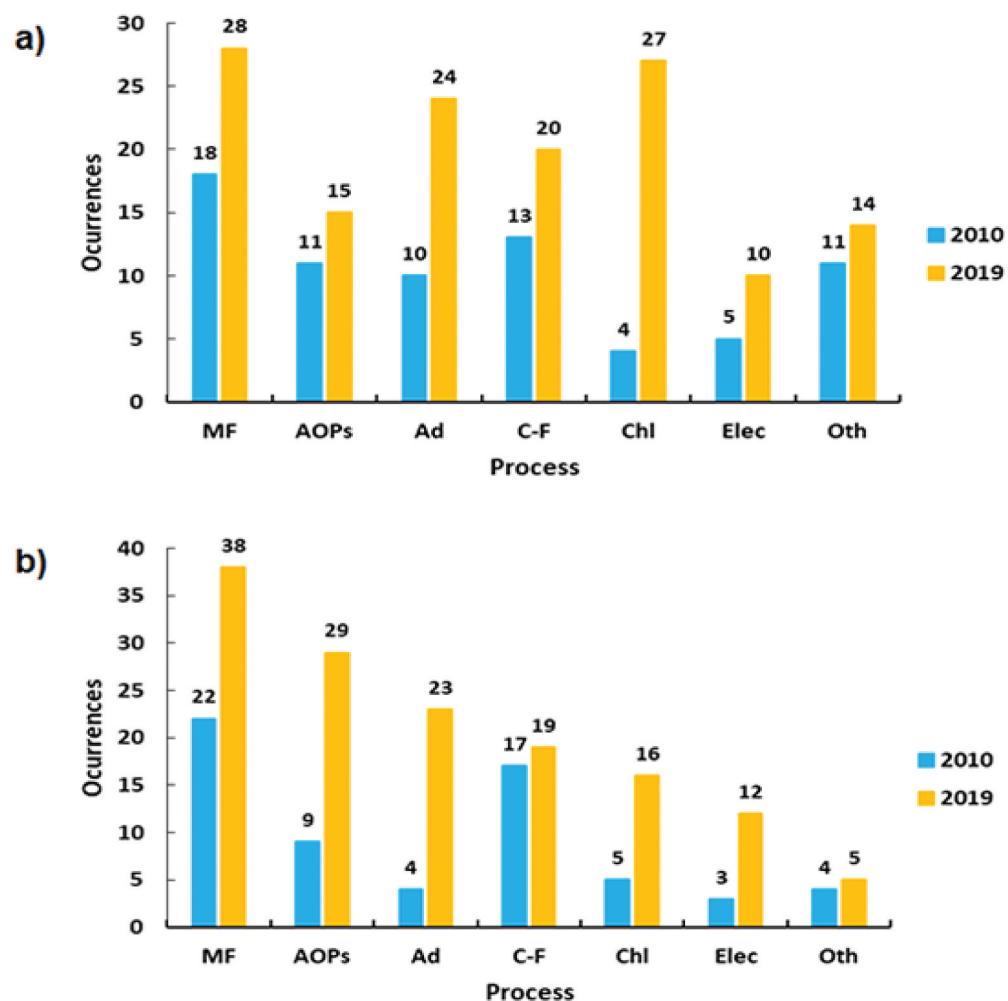
3.11. Evolution of the technologies used in Water Treatment (2010–2019)

Regarding Figure 11(a,b), some changes can be observed in the development of the most studied techniques in WoS and Scopus from 2010 to 2019. An increase in the number of studies in each technology is noticeable, being it more prominent in the Scopus base.

It is observed in WoS and Scopus that the predominance in the number of publications on filtration membranes has been maintained and a growth in the publications of advanced oxidation techniques due to the emergence of new organic contaminants, synthetics, etc., applied in the various commercial products whose residues end up in the water courses and are then used for their potabilization (Ahuja, 2018). However, as time goes on, it is likely that membrane filtration will become the most widely used means of water filtration.

Also, research linked to chlorination, adsorption, and electrochemicals have gained notoriety and interest from researchers. Reports indicate a growing interest in developing technologies for the treatment of emerging contaminants especially through electrochemical practices and advanced oxidation processes (Seibert et al., 2020).

Electrochemical processes are being compared to other processes because of their efficiency and because in most cases they are automated. For example, electrochemical membrane filtration (EMF) is proposed to degrade emerging contaminants in drinking water (Sun et al., 2018), as well

as electro coagulation, electro fenton, and electro dialysis; for example, the coupling of chemistry and electron transfer science generates an excellent combination to oxidize more recalcitrant contaminants (Drogui et al., 2007).

Research on coagulation-flocculation has been maintained (Scopus) or shows a slight increase (WoS) in these years. It is because both techniques are able to achieve high efficiencies in the removal of various pollutants, such as: chemical oxygen demand, turbidity, color, and metals (Verma & Naresh Kumar, 2016), arsenic (Kumar & Quaff, 2019), among others. Little research has been conducted regarding the use of sedimentation, clarification and integrated processes with more than one technology in water treatment. In addition, sedimentation/decanting despite being one of the major and most common processes used in drinking water treatment did not have a great interest in recent years, being able to resume this research topic.

Membrane filtration: MF, Coagulation-flocculation: C-F. AOPs, Chlorination-Chl, Adsorption-Ad, Electrochemical-El and Others-Oth

Fu et al. (2013) indicated that the main research related to drinking water in the period 1992–2011included water treatment methods and related contaminants; however, the trend in these research topics has not changed for this last decade. In this same period, ozonation and chlorination in disinfection and adsorption were common techniques and became popular. In this last decade the trend is on membrane filtration, advanced oxidation processes, and adsorption. Studies on "adsorption" have been maintained in recent years, which could be attributed to the wide application of adsorption, as well as the feasibility and low cost of adsorption experiments.

Sustainable or appropriate technologies are low-cost technologies that are evaluated according to the population that they will serve (Mac Mahon & Gill, 2018; Zaman et al., 2014). Appropriate technologies for drinking water treatment are essential to achieve integrated and sustainable water management (Sorlini et al., 2015; Tussupova et al., 2016). In addition, drinking water supply problems are scarce in rural areas (Tussupova et al., 2016); therefore, research is needed to provide appropriate solutions for water potabilization, with the selection of technologies that are feasible in these areas and thus achieve an adequate supply of drinking water (Sorlini et al., 2015). Research has shown that the development and implementation of water treatment technologies have been driven primarily by factors such as the discovery of new contaminants, the promulgation of new water quality standards, and the cost of implementing each treatment technique (Khodakarami & Bagheri, 2021).

The drinking water industry has been slowly adapting to new technologies. In the last 10 years there has been a rapid increase of new technologies that have been introduced in municipal drinking water treatment. Some of these technologies are membrane filtration, UV irradiation, advanced oxidation, ion exchange; all of which have gone a long way towards demonstrating their reliability and applicability to large scale municipal water treatment plants. Furthermore, as the cost of these technologies continues to decrease, their applicability will steadily increase. Also, as conventional water sources become less and less available, the need for innovative and cost-effective treatment technologies will steadily increase (Fu et al., 2013; Di Iaconi et al., 2020).

4. Conclusions

The results of the study indicate that there is a growing number of annual publications from January 2010 to August 2020. This increase is mainly due to concerns about emerging pollutants, of which relatively little is known and therefore research is required.

China is the country with the largest number of documents published on purification. China currently faces numerous challenges in water management, such as: droughts, floods, water pollution, and soil erosion and these challenges require research in this field. The largest number

of documents published on this subject is mainly in journals from The Netherlands, such as Water Research and Science of the Total Environment. Chinese magazines do not appear within the top ten despite being the first producing country; however, most of the top 10 journals are international if is defined by the composition of their editorial boards.

Seven of the 10 scientific journals with the highest number of published documents are located in quartile 1 (Q1). Furthermore, the article with the highest number of citations is called "Water-dispersible magnetite-reduced graphene oxide composites for arsenic removal" and was published by Chandra et al. (2010) in American Chemical Society. Additionally, the institution with the highest number of published documents is the Chinese Academy of Sciences in Beijing, China.

The relationships analyzed by means of keywords show how it continues to be a challenge to account for interdisciplinaries in a concentrated field of knowledge. The study in the last decade has leaned towards advanced oxidation, coagulation-flocculation, adsorption, and membrane filtration processes. Furthermore, it is important to note that arsenic, other heavy metals, and emerging pollutants are important health-related problems and have therefore been studied in the last decade. Additionally, the use of advanced physicochemical and biological treatments to remove heavy metals and emerging pollutants has been investigated.

Countries with problems in infrastructure, pollution, and water scarcity do not seem to be at the forefront of the production of research on purification. Therefore, world research on this subject depends on the scientific results produced in China and the USA. This study used bibliometric data that are readily available in WoS and Scopus, which allowed a summarized analysis. Therefore, it is possible to reproduce these analyzes for evaluating a specific geographic region.

5. Recommendations for future research

After the analysis of the articles related to the topic of water treatment in the last decade, it can be evidenced the need of the research about different technologies that positively contribute to obtaining quality water for consumption and for the use of routine activities, especially in the rural population; in other words, the purpose of new research should aim to identify which are the appropriate technologies that meet the basic needs of diverse populations, especially rural ones, using water resources in a sustainable way.

Among the different types of technologies that should be investigated are: (a) sand filtration, (b) biochar filtration, (c) ceramic filter, (d) photocatalysis or sodis disinfection, (e) tubular flocculation, and (f) sedimentation. Further research into water treatment technologies using integrated processes (more than one technology) should also be pursued to ensure that everyone has access to clean water. It will have a major impact on reducing the number of people worldwide who are affected by waterborne diseases and morbidity.

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