



Current Status and Future Research Trends of Biofiltration in Wastewater Treatment: a Bibliometric Review

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Abstract

Purpose of Review The development of various type of wastewater treatment technologies provides significant supports for environmental protection. Biofiltration, an attached growth system, shows remarkable performance in treating different types of wastewater worldwide. Differing from the existing comprehensive reviews published thus far, this review article focuses on the current prospects and future research trends of biofiltration in wastewater treatment through bibliometric analysis. The objective of the study is to analyze the applications of biofiltration in wastewater treatment in terms of the annual publications trend, most productive journals, leading authors, countries and affiliations, keywords, and the type of wastewater treated.

Recent Findings The findings clearly showed that there is an increasing trend in the annual publications of biofiltration in wastewater treatment in the period from 1969 to 2020. The analysis revealed that Water Research, Mr. Rocher, V (Rocher, Vincent), and China is the leading journal, author, and country in terms of total publications. Through the co-occurrence analysis of the author keywords, keyword such as “biofilter” was identified as the most frequently used author keywords with 213 occurrences and 178 links to other author keywords. Besides that, the findings also show that there are still lacking of studies related on the treatment of “refinery wastewater,” “pharmaceutical wastewater,” “coal gasification wastewater,” and “brewery wastewater” by using biofiltration system.

Summary Overall, the findings of this bibliometric analysis can be helpful information for industry practitioners and researchers that lead on water pollution control technologies.

Keywords Bibliometric analysis · Biofiltration · Biofilter · Wastewater treatment

Introduction

Untreated wastewater discharged into the natural water bodies creates serious environmental issues such as eutrophication and toxicity towards the aquatic organisms. In the past few years, innovation and technologies such as wastewater

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treatment plants that have low investment and operating cost were receiving attention from several researchers [1–3]. Various techniques such as physicochemical treatment (i.e., chemical oxidation, coagulation, and filtration) have been introduced in the removal of contamination from the wastewater [4–6]. However, limitations such as higher chemical consumption, higher capital and investment cost, higher chances of regenerating secondary contaminants, and higher energy requirement are accompanied with the used of physicochemical wastewater treatment [7, 8]. As an alternative, there is a need in investigating suitable biological treatment process in order to counter measure all of these drawbacks.

There are different types of biological treatment process that have been utilized in treating wastewater such as activated sludge system, anaerobic lagoon, and membrane bioreactors [6, 9, 10, 11]. Despite the remarkable removal efficiencies, the use of this biological treatment process still possesses several drawbacks. The suspended growth–activated sludge system has high sludge production, which requires larger spaces and higher operation and maintenance cost while anaerobic lagoon is usually accompanied with odor generation and longer hydraulic retention time and also requires larger land area for operation [9]. Moreover, membrane fouling tends to occur within membrane bioreactors which contribute to high-pressure requirement and affects the membrane performance [12]. Generally, the biofilm-based biofiltration system has been recognized as one of the promising biological wastewater treatment technologies due to the advantages such as smaller foot print, shorter retention times, lower sludge production, and effective removal performances [11, 13].

Biofilter is an attached growth treatment process where microorganisms are acclimatized on supporting media such as sand, gravel, and granular-activated carbon (GAC) to biodegrade contaminants instead of physical filtration [14]. Biofiltration exists in different types and forms such as biological aerated filter [15, 16], trickling filter [17], and slow sand filter [18]. Although the working principles are similar, the operation of these reactors is slightly different. For instance, biological aerated filters refer to the aeration supply in the reactor promoting the growth of the aerobic microorganisms and the removal process; trickling filter uniformly distribute the influent via rotary water distributor at the top of the reactor, while slow sand filters contain a biological green mat layer (Schmutzdecke) that developed and grow at the top of the sand medium where the influent flows slowly through it [12, 19, 20]. These biofilters have been widely utilized in the treatment of domestic wastewater [21], piggery wastewater [15], petrochemical wastewater [22], dyeing wastewater [23], and oil and gas–produced water [24]. Although the interests in the application and studies of biofiltration in various wastewater treatment process are increasing, the

comprehensive review and analysis on the global research trend are apparently missing.

It is necessary to investigate on the research trend and performance to identify the prominent and contribution of the authors as well as their impact on the specific research fields [25]. The identification of significant experts within the clusters paves the way for the discovery of new study fields by capturing the recent research areas covered by these researchers [26]. Moreover, it also act as a guiding resource in identifying novelty, future potential, and current trends in the evolution of research on recent themes [27]. Generally, bibliometric analysis is one of the research methods that is widely used in identifying the scope and the nature of research evidence, which provides indicators on the national and international contribution and mapping research gap on particular research fields [28, 29].

There are a few major recognized scientific databases and search engines which include Scopus, Science Direct, and Web-of-Science. Scopus was introduced by Elsevier in November 2004 and it contains several functions that make it suitable for bibliometric analysis such as document types, journal name, citation numbers, h-index, and others [28]. According to Fahimnia et al. [26], Scopus is the largest citations and abstract databases that consist of wide-range peer-reviewed literature published by Springer, Emerald, Elsevier, Taylor and Francis, Informa, and Inderscience. Compared to Web-of-Science database which only includes ISI-indexed journals, Scopus is more comprehensive and provides detail coverage and access to tens of millions of peer-reviewed academic journal papers [26]. Moreover, Scopus is updated daily [30], has a citation linking precision of 99.9%, and conducts continual evaluations of included and new journals to ensure the database's quality [31, 32]. In addition, to our best knowledge, there has been no studies that focus on the bibliometric analysis of biofiltration in wastewater treatment using Scopus database. Therefore, utilizing Scopus as the source of data mining for biofiltration of wastewater treatment would be a significant attempt in identifying the global research trend and the hot spot in the particular research area.

To fill the research gap in previous studies, this bibliometric analysis aims (1) to analyze the annual publications trends of biofiltration in wastewater treatment journal articles from 1969 to 2020, (2) to highlight the leading journals, authors, countries, and affiliation in wastewater treatment using biofiltration and thus determine the domination of countries and their respective collaboration, (3) to identify the common keywords and terms used in each journals, and (5) to discuss the applications of biofiltration in treating different types of wastewater. Overall, this bibliometric review analysis will provide quantitative and qualitative scientific insights for many researchers, with the current research trend and future direction of biofiltration in treating wastewater.

Bibliometric Procedures

The data mining process was conducted from 16th September 2021 until 10th October 2021 and the main theme of the analysis focused only on research articles with the words of “biofiltration,” “biofilter,” “biological aerated filter,” “trickling filter,” and “slow sand filter,” as these five keywords are the most popular terms in describing biofiltration in wastewater treatment system. The data collection period focused on journals and articles within year 1969–2020 and excluded the year 2021 and 2022. The initial query string used in this studies was TITLE-ABS (“biofilt*” OR “biological* aerated* filt*” OR “trickling* filt*” OR “slow* sand* filt*” AND “waste*water”) AND NOT (“gas” OR odo*) AND (LIMIT-TO (SRCTYPE, “j”)) AND (LIMIT-TO (DOCTYPE, “ar”)) AND (EXCLUDE (PUBYEAR, 2022)) OR EXCLUDE (PUBYEAR, 2021)) which resulted in 1571 documents. Additional phrases such as AND NOT (“gas” OR odo*) were included in the query string in order to focus solely on wastewater treatment. Besides that, the phrases and additional terms such as review, progress, recent, critical, revisit, advance, highlight [33], and others were included in the search strings to identify potential review articles and to remove the review articles from the searching. A total of 94 potential review articles were recorded, carefully screened, and excluded in the final query strings through their EID. The final query strings after removing the 26 review papers resulted in 1545 documents.

Figure 1 shows the procedure in identifying the query strings for this bibliometric review and Table 1 shows the related query strings used for each phase in Scopus. The final search results were analyzed in terms of the annual publication trend, most productive journals which included their total publications, cite score, category/subcategory, rank, percentile, quartile, title of the most-cited article, times cited, and the publisher. The leading authors, countries, and institutions were also summarized and discussed based on the final search results. Google my maps were also used to visualize the top 15 most productive countries and institutions for publications of biofiltration in wastewater treatment. In addition, the information for total publications of a country (TPC) and institution (TPI) was retrieved and ranked based on their number of total publications while the information for single-country publications (SPC) was retrieved by excluding other countries from the search results and only focused on documents that were affiliated with the targeted country.

The csv files which include citation information, bibliographical information, abstract, and author keywords from the finalized search results with 1545 documents were downloaded from Scopus and exported to VOSviewer (version 1.6.16, Centre for Science and Technology Studies, Leiden University, The Netherlands) to construct the bibliometric

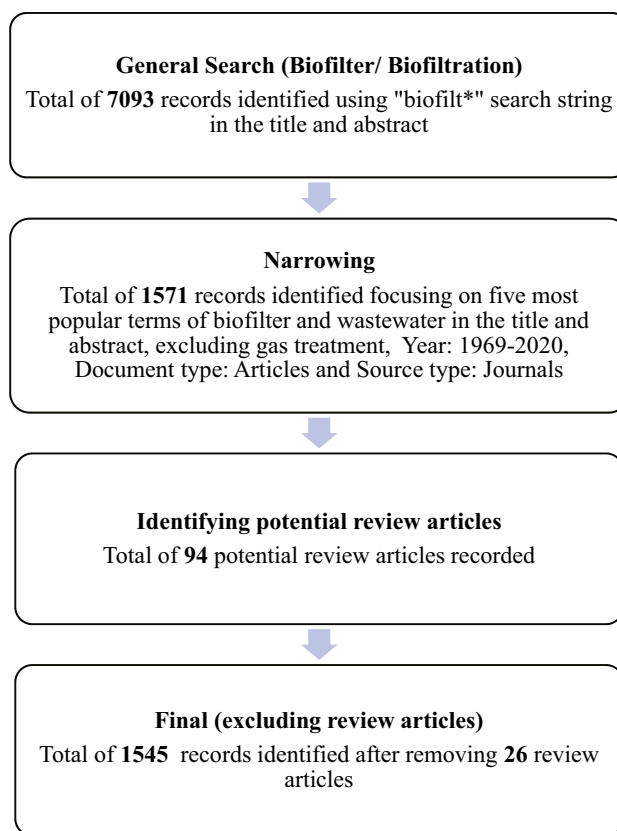


Fig. 1 Flow chart for the overall procedure in bibliometric data mining

maps. The VOSviewer software was selected as it focuses on the graphical representation of bibliometric maps and is effective in exhibiting huge and easy-to-understand bibliometric maps [34].

For co-authorship analysis, additional thesaurus files were uploaded together with the csv files to the VOSviewer to rename (i.e., Vietnam to Vietnam, Helena Lab to United States) and to remove any irrelevant countries or affiliation such as supply, insa-transfert/lipe, engineering, and others. The minimum number of documents of a country was set at 1 while minimum number of citations of a country was set at 0. The bibliometric maps were then edited, re-clustered based on continents (i.e., 1-Asia, 2-Europe, 3-America, 4-Africa, and 5-Oceania) and the 1st letter of the country name was capitalized. The total countries recorded without the thesaurus files were 92 while the final total countries with the thesaurus files recorded were 81. Prior to the co-occurrence analysis on the author keyword, synonym words and phrases such as wastewater, waste water, and wastewaters were identified and relabeled as wastewater using thesaurus files. In the VOSviewer, the minimum occurrences of a keyword were set at 3 which resulted in 345 keywords of the 3253 keywords meeting the threshold. The bibliometric map for co-authorship

Table 1 Summary of query strings used for each phase in Scopus

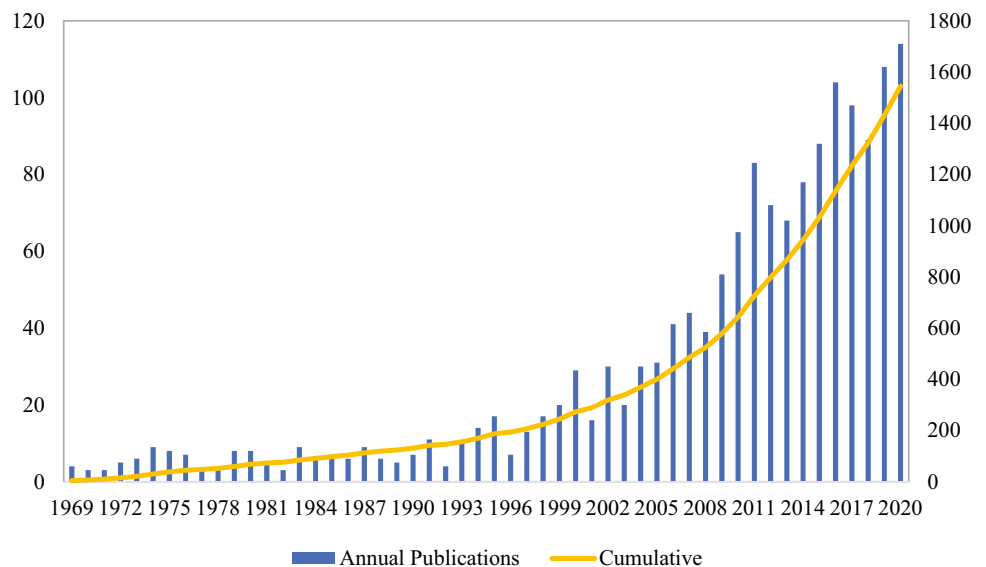
Remarks	Search string
General search	TITLE-ABS (("biofilt*"))
Narrowing	TITLE-ABS (("biofilt*" OR "biological* aerated* filt*" OR "trickling* filt*" OR "slow* sand* filt*" AND "waste*water") AND NOT ("gas" OR odo*)) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (EXCLUDE (PUBYEAR, 2022) OR EXCLUDE (PUBYEAR, 2021))
Potential review articles	TITLE-ABS (("biofilt*" OR "biological* aerated* filt*" OR "trickling* filt*" OR "slow* sand* filt*" AND "waste*water") AND NOT ("gas" OR odo*)) AND (TITLE ("recent" OR progress OR review OR critical OR revisit OR advance* OR highlight OR perspective OR prospect OR trends OR bibliometric OR scientometric OR insights OR overview OR "state of the art" OR challenges OR updates) OR ABS (progress OR review OR bibliometric OR scientometric)) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (EXCLUDE (PUBYEAR, 2022) OR EXCLUDE (PUBYEAR, 2021))
EID review articles	2-s2.0-85067173213 OR 2-s2.0-85071754802 OR 2-s2.0-85068658889 OR 2-s2.0-85059870267 OR 2-s2.0-85029902110 OR 2-s2.0-85009260890 OR 2-s2.0-85016121788 OR 2-s2.0-85049968613 OR 2-s2.0-84992618517 OR 2-s2.0-84925132571 OR 2-s2.0-84904018084 OR 2-s2.0-84877994189 OR 2-s2.0-84873419084 OR 2-s2.0-84862536836 OR 2-s2.0-84859832294 OR 2-s2.0-56549111673 OR 2-s2.0-33748784078 OR 2-s2.0-0033179671 OR 2-s2.0-0032912009 OR 2-s2.0-0023367329 OR 2-s2.0-0022732637 OR 2-s2.0-0023036194 OR 2-s2.0-0022046352 OR 2-s2.0-0021509958 OR 2-s2.0-0016724517 OR 2-s2.0-85041933012
Final	TITLE-ABS (("biofilt*" OR "biological* aerated* filt*" OR "trickling* filt*" OR "slow* sand* filt*" AND "waste*water") AND NOT ("gas" OR odo*)) AND NOT EID ((2-s2.0-85067173213) OR (2-s2.0-85071754802) OR (2-s2.0-85068658889) OR (2-s2.0-85059870267) OR (2-s2.0-85029902110) OR (2-s2.0-85009260890) OR (2-s2.0-85016121788) OR (2-s2.0-85049968613) OR (2-s2.0-84992618517) OR (2-s2.0-84925132571) OR (2-s2.0-84904018084) OR (2-s2.0-84877994189) OR (2-s2.0-84873419084) OR (2-s2.0-84862536836) OR (2-s2.0-84859832294) OR (2-s2.0-56549111673) OR (2-s2.0-33748784078) OR (2-s2.0-0033179671) OR (2-s2.0-0032912009) OR (2-s2.0-0023367329) OR (2-s2.0-0022732637) OR (2-s2.0-0023036194) OR (2-s2.0-0022046352) OR (2-s2.0-0021509958) OR (2-s2.0-0016724517) OR (2-s2.0-85041933012)) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (EXCLUDE (PUBYEAR, 2022) OR EXCLUDE (PUBYEAR, 2021))

analysis was based on network visualization mode while the map for co-occurrence was based on overlay visualization mode. Furthermore, keywords such as different types of wastewaters and their occurrences in the author keywords were extracted from the bibliometric map of co-occurrence analysis and discussed to identify the research trend on types of wastewaters treated in the years 1969–2020.

Bibliometric Overview

A total of 1545 documents were retrieved by focusing on bio-filtration in wastewater treatment within 52 years. The data extracted was grouped and arranged on chronological order to identify the trends and the annual growth of the publications from years 1969 to 2020. Figure 2 shows the annual and

Fig. 2 Annual and cumulative publications of research articles on biofiltration for wastewater treatment indexed in Scopus



cumulative publications of research articles on biofiltration for wastewater treatment indexed in Scopus. Based on the figure, the oldest publication on biofiltration for wastewater treatment began in 1969 and there was a total of 4 annual publications in that year. It clearly shows that the research trend in the first 31 years (1969–1999) did not receive a very high attention as the annual publications for each year is lower than 21 publications. The publications within 1969–1999 were 244, accounting for only 16% of total cumulative publications from the year 1969 to 2020.

The strong interest in biofiltration for wastewater treatment started from 2000 as there was a significant and rapid increase in the total publications from that years onwards. Since 2000, the annual publications started to increase from 29 to 114 in years 2020 which resulted in approximately 400% growth. The annual publications in years 2019 and 2020 should be highlighted as the annual publications in the 2 years were 108 and 114, respectively, which are the highest within years 1969–2020. Moreover, the steady non-linear increase of the cumulative numbers of publications also indicates that the research trend for the annual publications will continue to rise in the future. The drastic increase in the number of publications since 2019 is believed to be due to the rising in new innovations on biofiltration system such as utilizing organic waste materials as carbon source and filter media that enhance the economic value [35] and their remarkable efficiency in treating different types of pollutants (i.e., COD, NH₃-N and antibiotic compounds) [36].

The retrieved data were analyzed based on the most productive journals on biofiltration in wastewater treatment in terms of journal name, total publications, cite score, category/subcategory, quartile, title of the most-cited article, times cited, and the relative publisher. Table 2 summarizes the top 10 most productive journals on biofiltration in wastewater treatment and their most-cited article. It can be observed there were 7 different publishers for the top 10 most productive journals which includes Elsevier, IWA publishing, Taylor & Francis, Desalination Publications, Science Press, Water Pollution Control Federation, and Springer Nature. Among all the publishers, Elsevier had the highest number of journals (3 journals). By ranking the journals according to the total publications, Water Research was at the top position with 94 total publications, followed by Water Science and Technology with 90 publications and Bioresource Technology with 70 total publications while the total publications for the remaining 7 journals were less than 50.

According to the CiteScore 2020, there were 5 journals with the CiteScore above 5. Water Research had the highest CiteScore (15.6) and the highest-cited articles (1007) while the lowest CiteScore (0.5) and cited articles (3) belonged to Chinese Journal of Environmental Engineering. It could also be noticed that although Water Science and Technology had the second highest publications, the CiteScore was only 3.3 which is the

third lowest among all the top 10 journals. The main reason is that although this journal publishes a lot of articles related to the biofiltration for wastewater treatment, but, most of it does not receive a large number of citations. Moreover, although the Chinese Journal of Environmental Engineering ranked at 7 with 24 total publications, the CiteScore, quartile and total citations were the lowest among all the journals. This results are similar to the results reported by [33] and was most likely owing to the fact that the major language of publication was Chinese, which made it less accessible to the English readers.

Aside from being written in Chinese, most articles published in Chinese journals lack sufficient English information (i.e., title, abstract, and key words) to appear in the abstract search. Although several Chinese scientific journals published an English-language edition, they are lacking of effective distribution methods outside of China [37]. The results also reflected that 50% of the journals were located in the first quartile (Q1), 20% of the journals were located in the second quartile (Q2), and 10% each for Q3 and Q4 journal while Journal of the Water Pollution Control Federation did not have any quartile and cite score as the coverage was discontinued in Scopus after 1989. Besides that, by looking at the category, Environmental Science is made up of 90% of the category while the other 10% was Engineering. For subcategory, Water Science and Technology made up of 40%, Environmental Engineering 20%, Pollution 20%, and 10% each for Ocean Engineering and Nature and Landscape Conservation. These summarized results and data could provide a clear insight and guidance in the selection of journals for the researcher that are interested in biofiltration of wastewater treatment in the future.

The retrieved data from the Scopus were analyzed based on the corresponding authors that were involved in the publication of research articles related to biofiltration for wastewater treatment. The authors are ranked based on their number of total publications. Table 3 summarizes the list of the 10 most prolific authors in biofiltration for wastewater treatment. It could be observed that the top 10 most prolific authors were affiliated to 5 different countries. Four of the top 10 prolific authors were from China, another two were from France and Italy while there was one author each affiliated to Australia and the UK. Rocher, V. from France and Di Iaconi, C. from Italy were among the top 2 most prolific authors with 25 and 23 total publications in research on biofiltration for wastewater treatment. Compared to the other authors, both of them were the earlier authors published in the field of biofiltration after year 2000, where the trend of biofiltration research starts to increase. In addition, these authors have the highest h-index and total citation.

The analyzed results also show that the authors in the list have strong correlation and relationship in the publications either as first authors or co-authors. For example, Rocher, V. collaborated with Azimi, S. in the publications of “Municipal wastewater treatment by biofiltration: comparisons of various

Table 2 The top 10 most productive journals on biofiltration in wastewater treatment process and their most cited article

Rank	Journal	Total publication	Cite score 2020	Category/subcategory	Quartile	Title of the most cited article	Times cited	Publisher
1	Water Research	94	15.6	Environmental science/water science and technology	Q1	The removal of pharmaceuticals, personal care products, endocrine disruptors and illicit drugs during wastewater treatment and its impact on the quality of receiving waters [55]	1007	Elsevier
2	Water Science and Technology	90	3.3	Environmental Science/Water Science and Technology	Q2	Membrane bioreactors and their role in wastewater reuse [56]	86	IWA Publishing
3	Bioresource Technology	70	14.8	Environmental Science/Environmental Engineering	Q1	A novel UASB-MFC-BAF integrated system for high strength molasses wastewater treatment and bioelectricity generation [57]	189	Elsevier
4	Science of the Total Environment	49	10.5	Environmental Science/Environmental Engineering	Q1	Occurrence and removal of estrogens and beta blockers by various processes in wastewater treatment plants [46]	155	Elsevier
5	Environmental Technology (United Kingdom)	43	4.2	Environmental Science/Water Science and Technology	Q2	Determination of changes in wastewater quality through a treatment works using fluorescence spectroscopy [58]	57	Taylor& Francis
6	Desalination and Water Treatment	39	1.6	Engineering/Ocean Engineering	Q3	Impact of organic fractions identified by SEC and fluorescence EEM on the hydraulic reversibility of ultrafiltration membrane fouling by secondary effluents [59]	31	Desalination Publications
7	Chinese Journal of Environmental Engineering	24	0.5	Environmental Science/Water Science and Technology	Q4	Microbial community structure and the performance of biological aerated filter under different temperatures [60]	3	Science Press
8	Ecological Engineering	24	7.8	Environmental Science/Nature and Landscape Conservation	Q1	A high-performance compact filter system treating domestic wastewater [61]	76	Elsevier

Table 2 (continued)

Rank	Journal	Total publication	Cite score 2020	Category/subcategory	Quartile	Title of the most cited article	Times cited	Publisher
9	Journal of the Water Pollution Control Federation	23	-	Environmental Science/ Pollution	-	Characterization of the size distribution of contaminants in wastewater: treatment and reuse implications [62]	211	Water Pollution Control Federation
10	Environmental Science and Pollution Research	22	5.5	Environmental Science/ Pollution	Q1	Nitrite accumulation during denitrification depends on the carbon quality and quantity in wastewater treatment with biofilters [63]	38	Springer Nature

treatment layouts. Part 1: Assessment of carbon and nitrogen removal” in 2012 [38••]. Moreover, Bao, T. from the University of Technology Sydney also co-authored with Chen, T. and Chen, D. from Hefei University of Technology in the publications with the title “Simultaneous removal of nitrogen and phosphorus using autoclaved aerated concrete particles in biological aerated filters” [39]. Besides that, it is observed that almost all the authors had h-index larger than 5 and total publications larger than 100. According to Saravanan et al. [27], the h-index and the article’s impact as a source of information were shown to be highly correlated. Therefore, this analysis provides clear direction on the articles to follow and review for researchers that are interested in exploring biofiltration for wastewater treatment.

The top 15 countries and their respective institutions are summarized and ranked in Table 4 based on the numbers of publications while Fig. 3 visualize the leading countries on Google My Maps. From the analysis, China and its respective institutions, Harbin Institute of Technology, shined in both total publications with 420 and 64 documents each. Although the USA was ranked at number two with 221 total publications, its most productive institutions, Iowa State University, only recorded a total of 9 publications and ranked at 9th among the 15 institutions. It should be noted that the direct comparison of the affiliations may be biased and unfair as some of the affiliations have a huge numbers of branch compared to the other affiliations [33].

Besides that, the results also clearly showed that approximately 93% of the countries had more than 50% of single-country publications. Among the 15 countries, India and Iran secured the top 2 rank with 89.6% and 88.9% of single-country publications. Australia ranked at the last with only 40.4% of single-country publications and 28 out of 47 publications of Australia were affiliated with 9 different countries such as China, South Korea, Jordan, UK, Ireland, Norway, Romania, Switzerland, and the USA. Various factors have been attributed to the motivation to engage in international collaborative research, ranging from desires to broadening across research area, changing funding patterns and increasing human resources, complexness of certain research works that requires complex instrumentation, and desire to collaborate with researchers from all over the world [40].

Furthermore, Fig. 4 shows the bibliometric map created in VOSviewer based on co-authorship and countries as unit analysis in network visualization mode. Network visualization has shown to be a valuable tool for analyzing a wide range of bibliometric networks, including networks of citation relationships between publications, networks of co-authorship relationships between researcher, and networks of keyword co-occurrence relationships [41]. From the VOSviewer map, it is noticed that there were a total of 81 items, 5 cluster, 207 links, and 360 total link strength. Red cluster 1 represents Asia, green cluster 2 represents Europe,

Table 3 List of the 10 most prolific authors in biofiltration for wastewater treatment

Rank	Author	Scopus author ID	Year of 1st publication	Total publication	h-index	Total citation	Current affiliation	Country
1	Rocher, V	6603553098	2006	25	10	331	SIAAP	France
2	Di Iaconi, C	6601979179	2005	23	13	519	Istituto di Ricerca Sulle Acque, Bari	Italy
3	Bao, T	55359983200	2012	14	7	137	University of Technology Sydney	Australia
4	De Sanctis, M	35236840300	2010	14	10	302	Istituto di Ricerca Sulle Acque, Bari	Italy
5	Chen, T	7405544838	2014	12	8	196	Hefei University of Technology	China
6	Feng, Y	56440529700	2008	12	8	199	University of Jinan	China
7	Peng, Y	7403418825	2011	12	7	262	Beijing University of Technology	China
8	Azimi, S	6603962956	2007	11	5	126	SIAAP	France
9	Cartmell, E	55944940600	2005	11	9	288	Scottish Water, UK	UK
10	Chen, D	56912523900	2012	11	6	104	Hefei University of Technology	China

blue cluster 3 represents America, yellow cluster 4 represents Africa, while purple cluster 5 represents Oceania. The density of the publications is indicated by the size of the nodes (items), while the strength of the collaboration is revealed by the thickness of the links. The highest country per continent came from Europe with 31 countries followed by Asia (25), Africa (12), America (11), and Oceania (2). Moreover, 50% of the countries among the top 10 most productive countries in Table 4 were from Europe and this clearly indicates that biofiltration for wastewater treatment receives high attention in European countries.

In addition, from the bibliometric map, the USA recorded 35 links, 6375 citations, and with a total link strength of 81 which surpassed all the other clusters in terms of links, total link strength, and number of citations. The total link strength

in the co-authorship analysis indicates the total strength of a given country’s or institution’s co-authorship links with other countries and institutions, whereas the link strength between countries and institutions reveals the total number of publications that two affiliated countries and institutions have co-authored [42]. Among all the countries, the USA and China had the strongest relationship with link strength of 10, followed by Canada and South Korea both with the link strength of 8. In addition, it is also noticed that there were 10 countries such as Botswana, Oman, Croatia, Moscow, Hungary, Venezuela, Slovenia, Serbia, Cyprus, Libya, and Ukraine that did not collaborate with other countries in the publications of biofiltration for wastewater treatment which were indicated by the 0 links that appeared in these countries. Lastly, it can be summarized that almost 88% of the countries

Table 4 List of the 15 most productive countries and institutions for biofiltration in wastewater treatment

Rank	Country	TPC*	SPC* (%)	Institutions	TPI*
1	China	420	362 (86.2%)	Harbin Institute of Technology	64
2	United States	221	158 (71.5%)	Iowa State University	9
3	Canada	78	48 (61.5%)	Université Laval	13
4	France	73	50 (68.5%)	Laboratoire Eau–Environnement–Systemes Urbains	12
5	United Kingdom	69	44 (63.8%)	Cranfield University	24
6	Germany	60	37 (61.7%)	Technical University of Munich	11
7	Spain	50	27 (54%)	Universidad de Granada	12
8	Italy	49	40 (58%)	Consiglio Nazionale delle Ricerche	25
9	India	48	43 (89.6%)	Indian Institute of Technology Madras	6
10	Australia	47	19 (40.4%)	Queensland University of Technology	11
11	South Korea	46	27 (58.7%)	Chungbuk National University	6
12	Japan	45	29 (64.4%)	Nagaoka University of Technology	5
13	Brazil	44	34 (77.3%)	Federal University of Espirito Santo	7
14	Poland	38	29 (76.3%)	Uniwersytet Warminko-Mazurski w Olsztynie	5
15	Iran	27	24 (88.9%)	Tehran University of Medical Sciences	7

*TPC total publications by the countries, SPC single-country publications, TPI total publications by the institutions

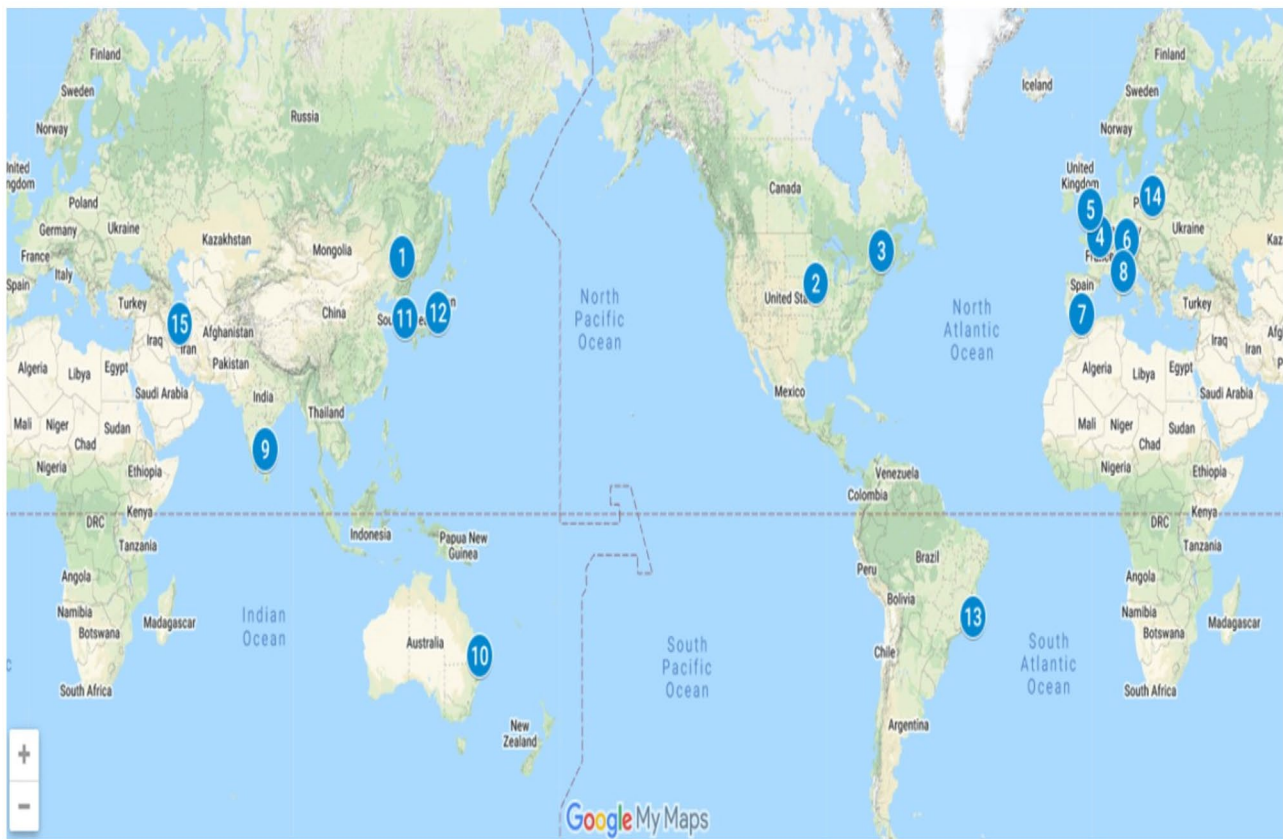


Fig. 3 15 most productive countries and institutions for biofiltration in wastewater treatment

had international collaboration in publications. This international collaboration in the journal publications would help in exploring knowledge and improve the coverage on the biofiltration for wastewater treatment through idea and resources sharing by different researchers throughout the world.

The choice of relevant keywords has a significant impact on the mechanism and efficiency of document search. These keywords serve as a vital link that distinguish the sources of information from the large number of publications available [27]. Figure 5 shows the overlay visualization of the bibliometric map based on co-occurrence of author keywords. A total numbers of 3285 author keywords were identified at the initial phase. After relabeling the synonym words and phrase, a total of 345 keywords fulfilled the threshold of VOSviewer mapping criteria (at least 3 occurrences). The results showed that the terms “biofilter” was the most commonly used authors keywords with 213 occurrences, 178 links to others authors keywords, and average publication years of 2012.24. Among all the links, the “biofilter” author keywords had strong link strength with author keywords such as “wastewater,” “nitrification,” and denitrification.” Besides that, there were a total of 33 publications with the co-occurrence of “biofilter and wastewater,” 24 publications with the publications of “biofilter and

nitrification,” and 23 publications with the publications of “biofilter and denitrification.” Besides that, author keywords such as “biological aerated filter,” “wastewater,” “wastewater treatment,” and “trickling filter” were among the top 5 most popular author keywords. Compared to slow sand filtration with only 21 occurrences, biofilter, biological aerated filter, and trickling filter are clearly the more popular terms in biofiltration process.

Moreover, the keywords “biofilm” and “biomass” were used 61 and 21 times, respectively, as the performance of biofilter is largely dependent on the biofilm that is attached on the filter media [43]. According to Liao et al. [44], active, stable, and thin biofilm is ideal for a biofiltration system as the diffusion of oxygen and nutrients through the biofilm will be limited when the biofilm thickness exceeds a certain threshold values. It can also be noticed that the keyword “backwashing” was among the top 50 author keywords with 11 occurrences. The overgrowth of the biofilm will create negative impacts towards the biofiltration system. Therefore, effective backwash that removes excess biomass is necessary as it prevents the clogging in the system while at the same time ensuring sufficient attached biomass and restoring the biofilter treatment capacity [45]. This explained the high occurrences of the author keywords “biofilm,” “biomass,” and “backwashing.”

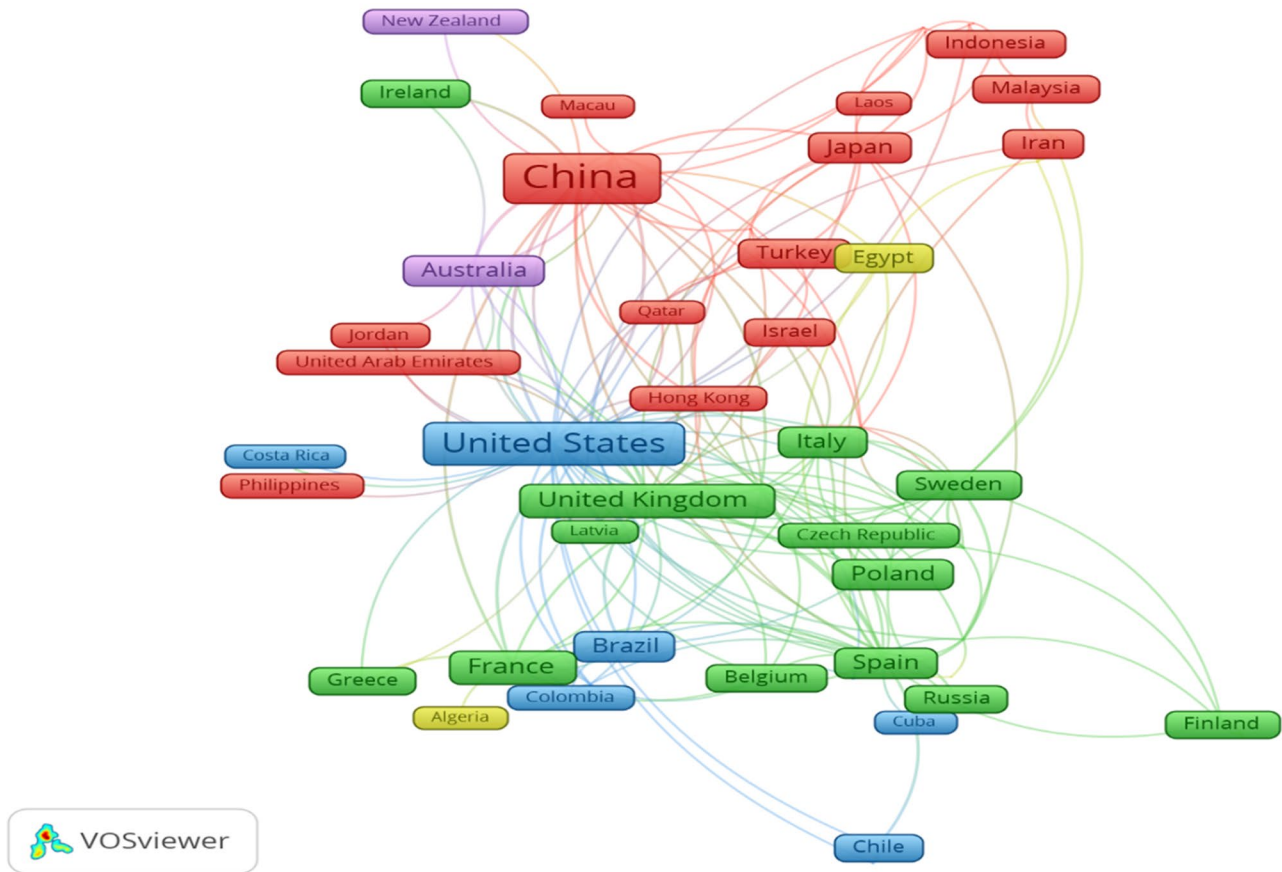


Fig. 4 Network visualization of the bibliometric map based on co-authorship

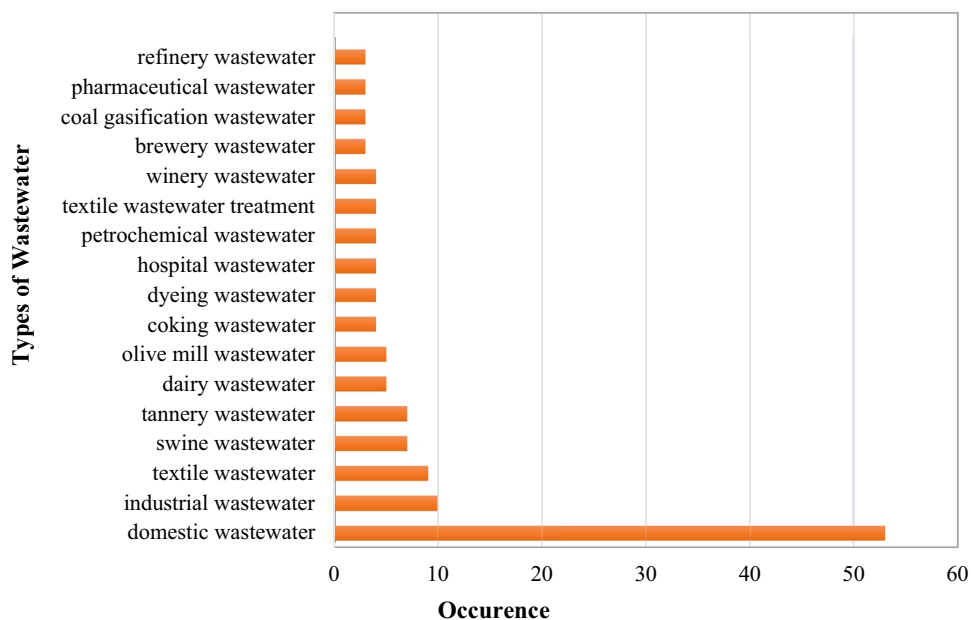
Besides that, there is a lot of information that researchers can actually retrieve from the author keywords. The relationship between the author keywords and the biofiltration process provides an insight for the researcher in identifying the current research trends. It can be observed that there were actually quite a number of articles that compare the performance of biofiltration with activate sludge system in wastewater treatment [46] and also coupling ozonation process with biofiltration in order to enhance the removal performance [47]. For example, “activated sludge” and “ozonation” were among the top 15 author keywords in terms of occurrence in biofiltration for wastewater treatment. Moreover, biofiltration also shows promising potential as a treatment technology in wastewater recycling and reused based on the occurrence of the keywords “wastewater reuse” and “water reuse.” Li et al. [48] utilized the combined procedure of denitrification biofilter, ozonation, and biologic aerated filter for reclaimed water production. The combined process was able to remove the conventional pollutants effectively, where concentrations of total nitrogen (TN) and chemical oxygen demand (COD) in the final effluent met the local discharge regulations which allows for water recycle and reuse.

Furthermore, kinetic modelling is an important tool in explaining the bioreaction and transport mechanism that take place within a bioreactor [49]. The biokinetic coefficients which are determined from the kinetic modelling are valuable in forecasting system performance and are influenced by number of variables including microbial species and environmental conditions (i.e., pH, temperature, dissolved oxygen, nutrients) [50]. The author keyword with the words such as “model,” “mathematical model,” and “kinetic model” should be highlighted in this review. The total occurrence of these keywords was 34 with average publication year greater than 2012, which indicates the interest of researcher in modelling the biofiltration system in the recent 10 years.

Application of Biofiltration in the Treatment of Wastewaters

To trace the trend of different types of wastewaters treated by biofiltration, a list of different types of wastewaters together with their occurrences is extracted and summarized in Fig. 6. There were a total of 17 different types of wastewater identified

Fig. 6 Occurrences of different types of wastewaters in co-occurrence analysis of author keywords



such as resistant to corrosion and biodegradation, appropriate specific weight, large specific surface area, and does not cause clogging to the reactor [53]. Furthermore, the packing materials of the biofiltration system can also be categorized either as floating or submerged media. Unlike submerged packing materials that remove pollutants through adsorption followed by biodegradation process, floating packing materials simply serve as attachment support for the biofilm, and the removal process is only limited to the biofilm role [12].

Despite the outstanding performances of the conventional packing materials in wastewater treatment, they still have limitations and drawbacks such as higher material cost, clogging problems, longer start-up period, and the needs of external carbon sources [6]. As mentioned earlier, it can be observed that there is a rising of the interest of several researchers in utilizing waste organic packing materials in biofiltration system in the past few years. Biofilter with waste organic packing materials actually shows promising potential due to its advantages such as higher specific surface area, lower density, higher void fraction, and cost-effectiveness in terms of raw materials [1, 54]. Moreover, utilizing the waste organic packing materials in biofiltration system will also support the waste minimization strategies and promote the sustainable development in the future.

Limitation of the Study and Future Outlook

Despite the fact that this bibliometric review provides a comprehensive picture of the key trends in the research of biofiltration for wastewater treatment, there are still some limitations in this review. The search string used in the systematic

review was chosen based on preliminary testing which gives the best combinations of biofiltration in wastewater treatment. By limiting the search of this review to the 5 most popular terms such as biofiltration, biofilter, biological aerated filter, trickling filter, and slow sand filtration in the titles and abstract, the results may not include all biofiltration-related studies on Scopus. This is due to the fact that some researchers referred their system by other terms such as aerobic filter, anaerobic filter, and packed-bed reactor.

Besides that, the applications of biofiltration also involve the treatment of gaseous compound and odors. In order to remove the unwanted results, search string such as “AND NOT (“gas” OR odo*)”) were included. However, some related articles on biofiltration focusing in wastewater treatment may contain the word gas and odors in their title and abstract. Therefore, using “AND NOT (“gas” OR odo*)”) search string would exclude them from the search results. These limitations may be remedied in the future when bibliometric analysis searches are able to incorporate the whole contents of published papers utilizing advanced technologies such as big data and artificial intelligence, rather than relying on a limited and selective set of keywords [42].

Conclusion

The evolution of global research trend in the field of biofiltration and its applications for wastewater treatment has been highlighted in this bibliometric review. This analysis covers the bibliometric review in different aspects such as annual publication trend, journals, authors, countries, affiliation, and keywords. The results show that there was a significant increase in the annual publications since the year 2000 and recorded the highest annual publications in year 2020 with 114 articles per year. The Q1

journal of Water Research ranked at the top of journals with the highest numbers of publications while Mr. Rocher, V. (Rocher, Vincent) shined as the most prolific author in biofiltration for wastewater treatment with 25 total publications.

Among others, China leads the other countries with 420 total publications and Australia had the strongest international collaboration compared to the other countries. These results could provide an insight to the researcher in expanding their international collaboration with different countries or affiliations in their publications. Moreover, the high occurrence on keywords such as nitrification and denitrification also indicates that biofilter is popular in the removal of nitrogenous compounds from wastewater. Lastly, studies should focus more on the treatment of “refinery wastewater,” “pharmaceutical wastewater,” “coal gasification wastewater,” and “brewery wastewater” as the studies regarding on these types of wastewaters are still less compared to the others.

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Compliance with Ethical Standards

Conflict of Interest The authors declare no competing interests.

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- Of importance
- Of major importance

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