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Harvesting solutions: Discover the evolution of agriculture wastewater treatment through comprehensive bibliometric analysis using scopus database 1971-2023

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ABSTRACT

This bibliometric study examines scholarly research on agricultural wastewater treatment using Scopus data from 1971 to 2023 by exploring publication trends, leading countries, prolific authors, and keyword co-occurrences. This study was conducted using VOSviewer software (version 1.6.17) which enables advanced bibliometric analysis and visualization, exploring the publication networks and patterns. By using various procedures to collect and refine data, 1908 research articles were retrieved. The findings indicate a steady growth in research on wastewater treatment since the 1970 s, with a significant surge in publications in recent decades. Research on wastewater treatment for agriculture has significantly increased, particularly focusing on technologies, reuse in agriculture, and environmental impacts. However, several research gaps to be addressed, including specific focus areas within agriculture wastewater treatment, underrepresented regions in the literature, interdisciplinary approaches, long-term environmental impacts, and policy effectiveness and implementation. The analysis also highlights influential authors, institutions, and countries driving research in this field, along with the most cited publications and journals. Additionally, the study identifies research gaps and suggests future research directions in wastewater treatment. Overall, this bibliometric analysis provides valuable insights into the landscape of wastewater treatment research, its evolution over the past five decades, and its economic and policy implications.

1. Introduction

Agriculture wastewater treatment has become an essential field of research in recent decades due to the urgent need for sustainable and efficient methods of managing wastewater. Agricultural activities generate a significant amount of wastewater, which contains various pollutants such as nutrients, pesticides [1–3] and heavy metals [4]. Untreated agricultural wastewater can have unfavorable ecological impacts. When released into water bodies, it can cause water pollution, leading to eutrophication and oxygen depletion, harming aquatic plants and animals. The recent challenges in water treatments are the elimination of water borne diseases. The focus shifted from the acute illnesses to the chronic health effects of trace quantities of organic, inorganic, and microbiological contaminants [5]. Habitats can be destroyed as excessive nutrients result in algal blooms and disrupt natural ecosystems. Besides, the wastewater that is used for irrigation leads to soil contamination triggering soil fertility and crop productivity [6]. Furthermore, the contaminated groundwater, causing threats to both human health and ecosystems [7]. Ecological imbalances can occur as nutrient cycles are disrupted, affecting species populations and community. Aquatic and terrestrial fauna are directly harmed by toxic chemicals and oxygen depletion structures [8]. Therefore, proper

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wastewater treatment and management are crucial to mitigate these impacts and protect ecosystems. Hence, wastewater treatment has become a crucial issue in the agricultural sector to ensure sustainable and environmentally friendly practices. It is essential to implement effective wastewater treatment and management strategies in agriculture to mitigate these ecological impacts. Proper treatment methods, including biological treatment systems, constructed wetlands, and appropriate irrigation practices, can help minimize the negative consequences of agricultural wastewater on ecosystems, protect water resources, and sustainably manage agricultural activities [9]. Several treatment technologies have been developed to treat agricultural wastewater, including physical, chemical, and biological methods [10]. Physical methods involve the removal of pollutants through sedimentation, filtration, and adsorption [11]. Chemical methods use chemical agents to remove contaminants, while biological methods including biosorption Azari et al., [12] rely on the use of microorganisms to degrade pollutants [13]. Besides, advanced oxidation processes (AOPs) also emerged as a treatment method and are extensively employed for the destruction of different toxic pollutants [14,15]. Furthermore, the watershed sustainability index is also important in the development of agricultural wastewater treatment. By integrating the Watershed Sustainability Index with agricultural wastewater treatment, you can develop holistic watershed management strategies that address the complex challenges of agricultural pollution while promoting sustainable agriculture and safeguarding water resources for future generations [16]. However, choosing the most effective and cost-efficient treatment method depends on the characteristics of the wastewater and the desired quality of the treated water. Furthermore, the effluent quality of the treatment process must meet the environmental regulations and reuse standards.

Over the past few decades, there has been a steady increase in the number of worldwide publications focusing on the treatment of wastewater from agricultural sources. However, to the best of the author's knowledge, no existing article has addressed the comprehensive analysis of the worldwide publication patterns in this specific field. This study aims to conduct a bibliometric analysis of wastewater agriculture treatment research based on Scopus data from 1971 to 2023. The analysis will focus on identifying the publication trends, research topics, influential authors, and leading institutions in the field of wastewater treatment. Besides, this study will also investigate the collaboration patterns among researchers and institutions and analyse the impact of research publications in the field. Over time, there has been a consistent rise in global publications addressing the subject of wastewater agricultural treatment. However, to the author's understanding, there is a dearth of published articles that comprehensively analyse the global publication trends regarding wastewater agriculture treatment. This paper explores the temporal patterns observed in research publications related to agriculture wastewater treatment and highlights the involvement of influential authors, top-ranking countries, and highly productive academic institutions. The findings of this study will provide insights into the evolution of wastewater treatment research over the past five decades and help identify research gaps and opportunities for future research. Additionally, this analysis can serve as a useful reference for researchers, policymakers, and practitioners working in the field of wastewater treatment.

2. Methodology

This study built on a bibliometric assessment relates the trends in agriculture wastewater treatment issue publication from the earliest date recorded in the Scopus database in 1971 to 2023 to evaluate worldwide growth and research focus. A bibliometric analysis approach offers an alternative perspective on the significance of a research trend than the traditional review article, which commonly focuses on describing the newest development and progress, as well as future recommendations of a certain research subject [17]. Besides, bibliometric analysis has emerged as preferred method due to its quantitative assessment of research impact and trends within a field [18]. Unlike review article, which rely on subjective opinions, bibiliometric analysis offers an objective evaluation based on citation metrics, allowing researchers to identify key authors [19], journals and institutions, and track the evaluation of research trend over time. Martín-Martín et al., [20] stated that Scopus is the central source of bibliographical data for the agricultural wastewater treatment literature due to its advanced searching function, indexed publishers, and leading sources of academic work in sciences. Furthermore, the English language used for the publication for most of the scientific output in Scopus led us to choose these databases over alternative sources [21]. Besides, Scopus is recognized as a trustworthy indexing database and contains high quality academic publications. This methodology enabled a comprehensive analysis of the research on wastewater agriculture treatment and provided valuable insights into the current state and future directions of the field.

2.1. Data origin and exploration technique

The procedure of acquisition of data was accomplished between December 5 and 6 2023, applying the Scopus database, starting with the data collection. The first step was to collect the relevant data from the Scopus database. The search keywords used were "wastewater agriculture treatment" and "wastewater irrigation". The search was limited to articles and reviews published between 1971 and 2023. The entered search query was: TITLE-ABS (("wastewater" AND "treatment*") AND "agriculture* ") AND PUBYEAR > 1970 AND PUBYEAR < 2024 AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (DOCTYPE, "ar")). The initial search string yielded a total of 1994 articles. By incorporating an additional clause phrase like “review”, “recent”, “progress”, “critical”, “overview”, ‘‘bibliometric”, and “potentiometric” into the search query, a potential of 208 articles that may not be relevant to our study were identified. These articles contained terms such as “review” within their titles and abstracts. By utilizing the unique article identity (EID) of the review article, a subsequent search string was formulated to ascertain the inclusion of strictly research publications. The revised search query effectively eliminated standard literature reviews, book chapters, and any unrelated studies, decreasing the overall publication count to 1908 articles.

In order to compile Table 1, featuring the Top 10 most prolific journals within the domain of CI research and their respective highly cited articles in bibliometric studies, our initial step involves identifying the primary journals in this field and collecting the relevant bibliometric information for each journal. CI research typically refers to “Competitive Intelligence” research, that involves gathering, analyzing and interpreting information about competitors, consumers and industry trends to make strategic decisions. We can then sort the journals by the total number of publications in the field of CI research and select the top 10 most productive journals based on this metric. For each of the selected journals, we need to identify the most cited article in the field of CI research. Once we have this data, we can create a table with columns for the journal name, total number of publications in the field of CI research, and the most cited article in the field of CI research (including title, authors, and citation count). Additional columns, such as the impact factor of each journal or the year of publication of the most cited article, can be included. Upon gathering and arranging the outcomes based on the main subject, categorizing them by year, source, author, affiliation, country, topic area of interest, and document type, the remaining publications amounted to 1908 articles. The resulting table will offer a concise overview of the most prolific journals in CI research and highlight the articles that have exerted significant influence within them.

For data analysis, the remaining articles were analysed using bibliometric analysis software, including VOSviewer (version 1.6.18, Centre for Science and Technology Studies, Leiden University,

Table 1
The Top 10 most Productive Journals on CI research with their most cited article.

Rank	Journal	TP %	Cite Score 2022	The most cited Article	Time Cited	FWCI	Publisher
1	Science of The Total Environment	102 (5.3)	16.9	The fate of microplastics in an Italian Wastewater Treatment Plant (Magni et al. 2019)	335	13.51	Elsevier
2	Desalination and Water Treatment	56 (2.9)	2.3	Nutrient removal from aquaculture wastewater by vegetable production in aquaponics recirculation system (Endut et al. 2011)	79	0.37	Desalination Publications
3	Water Science and Technology	55 (2.9)	4.8	Sustainable water and waste management in urban areas (Otterpohl et al. 1997)	151	4.4	IWA Publishing
4	Chemosphere	39 (1.9)	15.2	Impact assessment of treated/untreated wastewater toxicants discharged by sewage treatment plants on health, agricultural, and environmental quality in the wastewater disposal area (Singh et al. 2004)	392	4.63	Elsevier
5	Water Research	35 (1.8)	20.1	Persistent organic pollutants (POPs) in the sewage treatment plant of Thessaloniki, northern Greece: Occurrence and removal (Katsoyiannis and Samara 2004)	162	4.75	Elsevier
6	Water Switzerland	34 (1.8)	5.6	Design of indicators of circular economy as instruments for the evaluation of sustainability and efficiency in wastewater from pig farming industry (Molina-Moreno et al. 2017)	65	3.41	Multidisciplinary Digital Publishing Institute (MDPI)
7	Environmental Science and Pollution Research	32 (1.7)	8.5	Organic contaminants from sewage sludge applied to agricultural soils false alarm regarding possible problems for food safety? (Laturnus et al. 2007)	123	3.28	Springer Nature
8	Journal Of Environmental Management	31(1.6)	13.1	Global nitrogen and phosphorus in urban waste water based on the Shared Socio-economic pathways	144	6.16	Elsevier
9	Journal of Cleaner Production	27(1.4)	19.5	Environmental impacts of food consumption in Europe	328	13.51	Elsevier
10	Desalination	26 (1.4)	14.1	Agricultural wastewater reuse in southern Italy (Lopez et al. 2006)	78	2.07	Elsevier

TP: Total Publication; FWCI: Field-Weighted citation impact

Netherlands). The analysis included the identification of the most productive countries, institutions, authors, and journals in the field. It also involved analysing the intellectual framework of the research landscape using co-citation and co-occurrence analysis. The general procedures of data collection and restriction are presented in Fig. 1. The list of search strings constructed for main theme are given in Table S1 of the supplementary material.

2.2. Bibliometric maps

Bibliometric maps can be used to provide a comprehensive understanding of the global progress in agriculture wastewater treatment. Bibliometrics is a quantitative method that uses data from scholarly publications to analyze the patterns of knowledge production, dissemination, and impact in a particular field [19]. Bibliometric visualizations (maps) were generated by employing 1908 publications from the Scopus database via the utilization of VOSviewer software (version 1.6.17, Centre for Science and Technology Studies, Leiden University, Netherlands). VOSviewer software can be downloaded from the following link: https://www.vosviewer.com/download. The software was selected as the fundamental mechanism for the analysis due to its cost-free policy and extensive compatibility with several databases, such as Scopus, Web of Science, Dimensions, Microsoft Academic, Lens, and PubMed [22].

Bibliometric maps, such as co-citation and bibliographic coupling maps, can visually represent the connections between articles, authors, journals, and research topics. Over the obtained data of 1908 articles, we can generate co-citation maps to visualize the most cited articles and their relationships, bibliographic coupling maps to show the most cited references in the same articles, or author co-citation maps to identify the most significant authors and their collaborations. The findings of the analysis were visualized using several techniques, including co-citation maps, bibliographic coupling maps, and keyword co-occurrence maps. These visualizations provided a diagrammatic depiction of the connections relating to the various authors, institutions, and research areas.

2.2.1. Assessment of co-authorship

Evaluating co-authorship involves investigating the collaborative relationships among authors in academic publications. The procedure begins by collecting publishing details and identifying co-authors. A co-authorship network is then created, where authors are represented as nodes and connections indicate co-authorship. Various network measures, such as the number of co-authored publications and centrality, can be calculated to understand the co-authorship network's structure. Relationships in collaboration, such as regular collaborations or interdisciplinary partnerships, can be identified. Visualizations aid in comprehending the network. The findings provide insights into collaboration strength, research productivity, and potential collaborative opportunities. This information helps in making informed decisions regarding collaborations, research evaluation, and resource allocation. This study encompasses a comprehensive analysis of 103 countries. The countries were grouped based on the continents of Asia, Europe, America, Africa, and Oceania. The graphical depictions were displayed utilizing a complete counting system in the mode of network visualization.

2.2.2. Analysis of co-occurrence

The co-occurrence study employed author keywords from the article, eliminating the indexed keywords assigned from the Scopus database. Based on the scrutiny conducted on the assembled author keywords, a total sum of 5173 keywords from 1908 articles were recognized. The construction of co-occurrence maps originated by entering the author keywords into VOSviewer, following a 'filtering method' to remove any instances of redundancy. As a result of this process, a total of 5149 keywords were obtained, which served as the

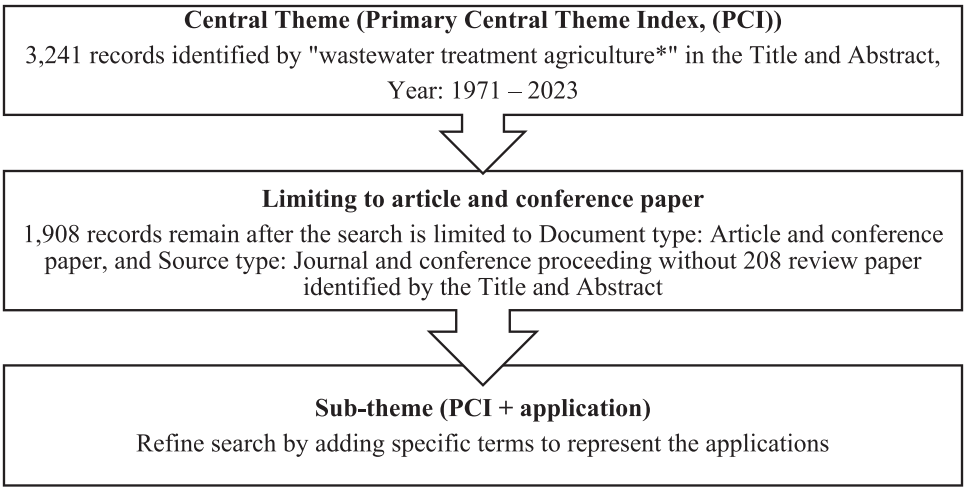

Fig. 1. Approach to research methodology regarding the procedure of collecting data for the main and sub-themes.

basis for generating the maps. Considering the substantial quantity of keywords, the threshold for co-occurrence frequency was set to 5 (the default setting), resulting in the identification of 217 keywords. The generated maps were presented in superimposed visualization mode, where the colour of the elements and the intensity of the connections represent the average number of yearly published articles that encompassed the selected keywords.

3. Results and discussion

3.1. Research focus and publishing activity trend

Analysing research focus and publishing pattern of agriculture wastewater treatment using bibliometrics can provide insights into the evolution of the field over time. With a final document count of 1908, we can use bibliometric techniques to identify the key publications, authors, journals, and research topics that have shaped the field of agriculture wastewater treatment. Over 52 years, from 1971 to 2023, a total of 1908 articles have been reached, mainly focused on agriculture wastewater treatment (Fig. 2). The observation of publication trends concerning agricultural wastewater treatment between 1971 and 2023 revealed fluctuations in interest in the PCI topic, leading to a limited number of published articles, fewer than 20, from 1971 to 2003. It is important to note that the number of published articles in any field can be influenced by various factors, such as funding availability, technological advancements, and societal priorities. Besides, it is also because of the limited research funding, challenges associated with treating agricultural wastewater, and the lack of regulatory pressure on the agricultural sector. However, it is important to note that the situation has significantly improved since then, and there is now a growing body of research in agricultural wastewater treatment. Subsequently, starting in 2004, the publication output experienced further fluctuations until 2018. In 2019, there was a significant increase in the number of publications on agricultural wastewater treatment with the increment of 50 articles as compared to 2018. However, the increase failed to stabilize and declined in 2020 before showing subsequent fluctuations until 2023.

The increases for 2012 - 2017 can be attributed to various factors. One of the major influences for this increase could be the growing recognition of the importance of sustainable agriculture and the need for effective wastewater treatment methods to reduce the environmental impact of agriculture. Additionally, advancements in technology and research have made it easier to develop more efficient and cost-effective treatment methods. However, the decline in publications related to agricultural wastewater treatment in 2018 and the subsequent fluctuation may be attributed to various factors. It could be due to changes in funding priorities or fluctuations in the availability of research funding. It could also be due to changes in the research priorities of

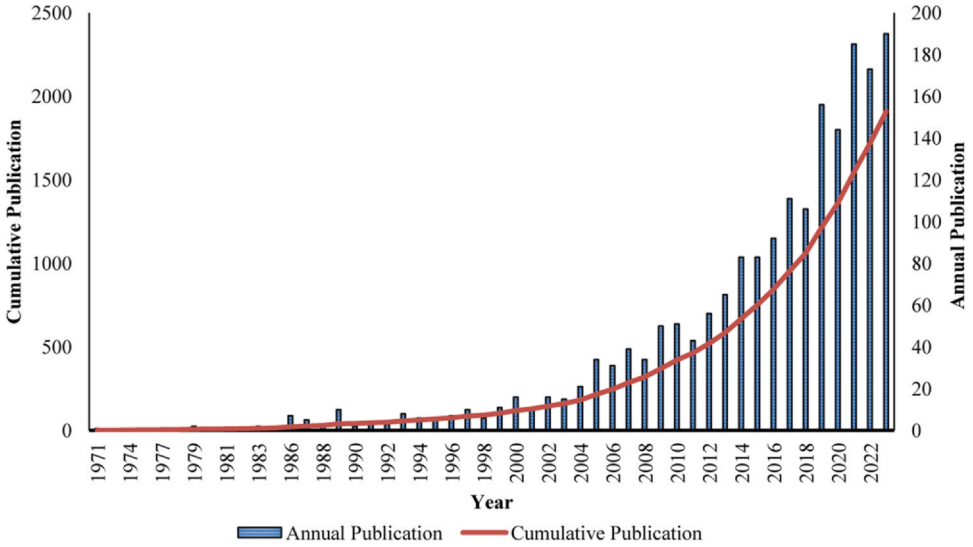

Fig. 2. The numbers of research articles and conference papers on PCI indexed in Scopus from 1971 to 2023.

Rank	Country	TPc	S.C.P (%)	The Most Productive Academic Institution	TPi
1	China	202	64.9	Chinese Academy of Sciences	46
2	United States	192	56.8	NC State University	8
3	Spain	143	59.4	Universidad de Almería	10
4	Italy	140	58.6	Università degli Studi di Catania	10
5	India	122	74.6	Indian Institute of Technology Roorkee	5
6	Brazil	108	77.8	Universidade Estadual Paulista Júlio de Mesquita Filho	13
7	Germany	97	45.4	Technische Universität Braunschweig	3
8	Iran	77	90.9	Hamadan University of Medical Sciences	9
9	United Kingdom	75	33.3	Cranfield University	3
10	France	68	36.8	Sorbonne Université	7
11	Egypt	65	53.8	Beni-Suef University	3
12	Poland	61	80.3	Częstochowa University of Technology	5
13	Canada	57	47.4	Dalhousie University	4
14	Sweden	55	41.8	Sveriges lantbruksuniversitet	8
15	Netherlands	52	40.4	Wageningen University and Research	14

Fig. 3. The top 15 countries and academic institutions that make the most agricultural wastewater treatment publications. TPc: total publications of a given country; TPi: total publications of a given academic institution; SCP: single country publications.

individual researchers or institutions. Furthermore, changes in the editorial policies of academic journals where these articles were published could have been a factor in the fluctuation of publication rates. Overall, the fluctuation in the publication rate of agriculture wastewater treatment between 2018 and 2023 could be attributed to a combination of factors, including changes in funding priorities, editorial policies, research priorities, and the interdisciplinary nature of this field. Further research and collaboration among researchers from different disciplines could potentially help establish a more stable trend of publication in this area in the future.

3.2. Preferred journal

Based on Table 1 which shows the top 10 most productive journals in the field of agriculture wastewater treatment research, along with their respective publishers, total publications (TP%), Cite Score for 2023, most cited article, time cited, and FWCI (Field Weighted Citation Impact). The table ranks the journals in descending order of TP%, which represents the percentage of total publications in the field of agriculture wastewater treatment that each journal has published. Based on the information presented in this table, Elsevier emerges as the publisher with the most extensive representation, featuring a total of 5 out of the 10 journals listed. Additionally, six out of the ten most cited articles listed in the table were published by Elsevier journals: Science of The Total Environment, Chemosphere, Water Research, Journal of Environmental Management, Desalination and Journal of Cleaner Production. The other 4 journals were published by Desalination Publications, IWA Publishing, Multidisciplinary Digital Publishing Institute (MDPI) and Springer Nature.

According to the table, the journal Science of the Total Environment is the most productive journal in this field, with 102 publications, representing 5.3 % of the total publications. The most cited article from this journal is "The fate of microplastics in an Italian Wastewater Treatment Plant," which has been cited 335 times. Followed by Journal of Desalination and Water Treatment (56 articles; 2.9 %), Journal of Water Science and Technology (55 articles; 2.9 %), Journal of Chemosphere (39 articles; 1.9 %), Journal of Water Research (35 articles; 1.8 %), Journal of Water Switzerland (34 articles; 1.8%), Journal of Environmental Science and Pollution Research (32 articles; 1.7 %) and Journal of Environmental Management (31 articles; 1.6 %). The remaining journals contributed fewer than 30 articles each.

Following the analysis of the CiteScore, the citation score for each journal is calculated based on the total number of citations received by articles published in that journal during the previous year (2023). According to the CiteScore 2023 report, a total of 9 journals attained a CiteScore of 5 or higher. The journal that obtained the highest CiteScore was Water Research, with a citation score of 20.1, although it was in the 5th rank on the list of most productive journals. The journal with the lowest CiteScore was Desalination and Water Treatment (2.3). The Journal of Desalination and Water Treatment was first published in 2009, which means it is a relatively new journal compared to other journals in the same field. Established journals may have had more time to build up their reputation and attract high-quality research papers, leading to a higher CiteScore [23]. Moreover, the scope of the journal was also affecting the Cite Score. The Journal of Desalination and Water Treatment focuses specifically on research related to desalination and water treatment, whereas other journals may have a broader scope covering other related topics. This could limit the number of papers published in the journal and, consequently, limit the number of citations. Overall, it is important to keep in mind that CiteScore is just one metric used to evaluate the impact of a journal, and there may be other factors that contribute to a journal's overall value and impact in the field.

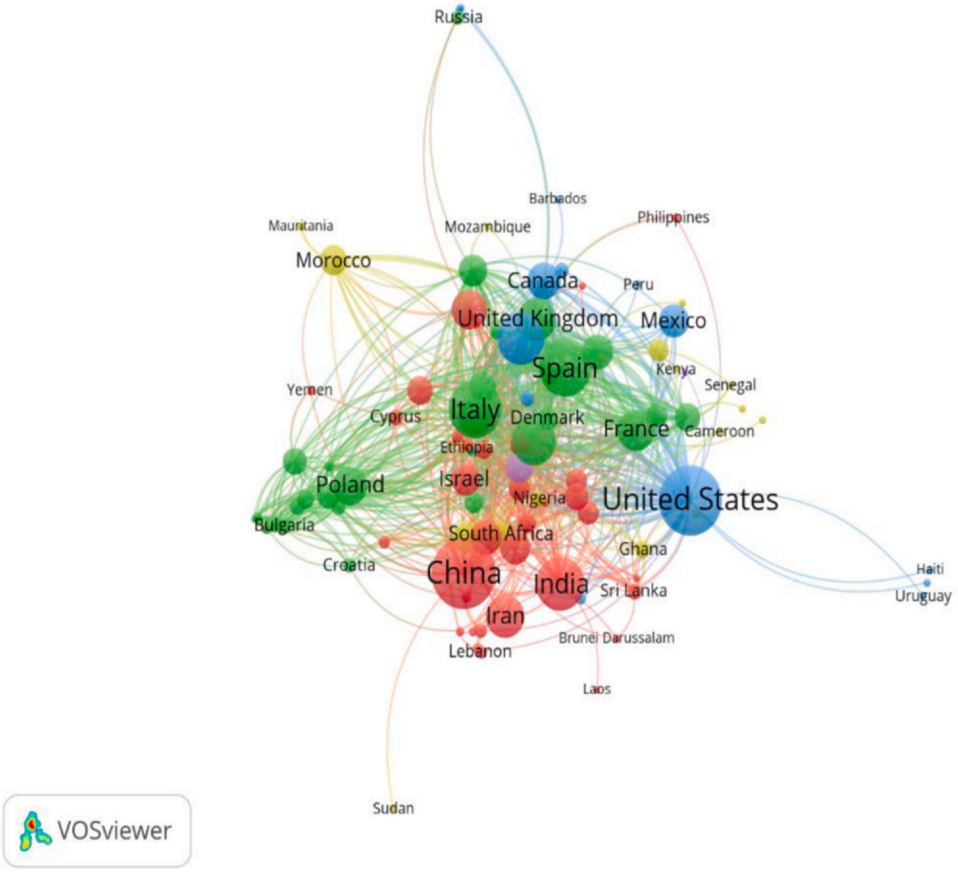

Fig. 4. Co authorship mapping in network visualization mode. The following URL can be used to open Fig. 4 in online VOS viewer: http://tinyurl.com/yo8xhtr8.

The FWCI value in the table is a metric indicating the relative impact of article citations within a specific journal compared to the average citation impact of articles in the same field. Therefore, when the FWCI value reaches 1, it indicates that the article published in the journal has received the anticipated or typical coverage on a global level. If the value surpasses 1, it suggests that the article has garnered more citations than expected, serving as an indication of a higher-than-anticipated impact. It considers the variation in citation practices across different fields, so a high FWCI value indicates that the article has been cited more frequently than average for its field. For example, in the table, the article "The fate of microplastics in an Italian Wastewater Treatment Plant" published in the journal Science of the Total Environment, has been cited 335 times and has an FWCI value of 13.51. This indicates that the article has been cited more frequently than average for articles in the field of environmental science and has had a significant impact on research in this field. Similarly, other articles in the table with high FWCI values have also been influential in their respective fields.

3.3. Noteworthy countries and top-tier institutions

Fig. 3 shows information on the top 15 countries that have revealed the highest productivity in contributing to the development of research in the field of agriculture wastewater treatment. This figure illustrates the top 15 countries ranked by the total number of publications (TPc) in the agriculture wastewater treatment research area and the Self-Citation Percentage (SCP) along with the Most Productive Academic Institution (TPi) for each country. The China tops the list with 202 publications in the field of agriculture wastewater treatment research, followed closely by United States with 192 publications. Spain is third on the list with 143 publications, and Italy follows closely behind with 140 publications. India ranks fifth with 122 publications, and Brazil is sixth with 108 publications. Despite Netherlands having a lowest total number of publications (TPc) and ranked 15th among 15 countries, it is worth highlighting that the most productive academic institution, Wageningen University and Research, has a high total publication count (TPi) of 14 publication after the University of Chinese Academy of Sciences, an academic institution from China, that holds the highest total publication count (TPi) of 16 publications. This is due to the Wageningen University and Research is known for its specialization in agriculture, food, and environmental sciences. Institutions that focus on specific areas tend to attract experts and researchers in those fields, leading to more concentrated efforts and contributions in those particular areas. Other productive institutions include the Beni-Suef University in Egypt, Częstochowa University of Technology in Poland, Dalhousie University in Canada and Sveriges lantbruksuniversitet in Sweden.

The Self-Citation Percentage (SCP) represents the proportion of citations within a country's publications that come from other publications within the same country. It is calculated by dividing the number of self-citations by the total number of citations and multiplying the result by 100. For instance, Iran has an SCP of 90.9 %, which indicates that 90.9 % of the citations in their agriculture wastewater treatment research publications are from other publications within Iran. This suggests that researchers in Iran are heavily reliant on their own previous work when citing sources in their publications. On the other hand, the United Kingdom has a relatively low SCP of 33.3%, indicating that researchers in the UK tend to cite sources from other countries more frequently than they do their own work. The SCP is an important metric for evaluating the scientific impact of a country's research output. While self-citation is a natural part of the research process, excessive self-citation can be seen as an attempt to boost a country's citation metrics, which can undermine the credibility of their research. Therefore, a lower SCP is generally viewed as more desirable in the academic community.

Fig. 4 demonstrates the distribution of countries by continent based on their involvement in PCI research. The coloured items represent countries from Asia (red), Europe (green), America (blue), Africa (yellow), and Oceania (purple). The thickness and distance of the lines connecting countries indicate the strength of their relationship and collaboration in PCI research. The highest number of countries contributing to PCI research interest are from Asia (38), followed by Europe (31), Africa (20), America (14), and Oceania (1). The analysis performed on co-authorship has revealed that the United States has the highest affiliation with 61 countries, having been linked 152 times in co-authorship. Following United States on the list are China with 51 links and 138 co-authorships, France (47 links and 82 co-authorships), Portugal (42 links and 60 co-authorships), Germany (41 links and 101 co-authorships), India (39 links and 71 co-authorship), Spain (38 links and 92 co-authorships), Italy (34 links and 89 co-authorship), Poland (33 links and 42 co-authorships), Brazil (31 links and 53 co-authorships), Saudi Arabia (30 links and 60 co-authorships) and Canada with 30 links and 54 co-authorships. The study also found that over two-thirds of the countries listed (91 countries) had fewer than 30 collaborative publications.

The strength of a country's international collaboration can be influenced by a variety of factors, including funding, which can play a significant role in promoting international collaborations. Countries that capitalize on research and development and have robust funding provisions for academic institutions and researchers are more likely to have high levels of international collaboration. Besides, a country's research infrastructure, including the availability of advanced facilities, equipment, and technology, can attract international researchers and collaborations. Then, language barriers can occasionally hinder international collaboration. Countries with a large English language user base or a good level of English proficiency may benefit from fascinating international collaborators.

3.4. Leading authors

Table 2 lists the top 10 authors in CI (Computational Intelligence), along with their ranking, Scopus Author ID, year of first publication, total publications (TP), h-index, total citation, current affiliation, and country. The ranking is based on the number of total publications, with the most prolific author listed as number 1, and so on. The Scopus Author ID is a unique identifier assigned to each author by the Scopus database. The list of 10 most famous authors in the field of PCI, affiliated with six different countries: France (3 authors), Italy (3 authors), Israel (1 author), Ghana (1 author), Iran (1 author), and Sri Lanka (1 author).

The year of first publication refers to the year in which the author's first paper in the field of CI was published. As a whole, the initial publications of these authors spanned from 2004 to 2012, with 6 out of 10 authors assuming the role of the first author. It is essential to acknowledge that, although the list is derived from the Scopus database findings, no specific rules were applied to establish the author sequence. It depends on the readers to determine whether they will judge the author based on their total citation, h-index, or any other criteria. The h-index is a metric that measures both the productivity and impact of an author's research based on the number of citations received by their papers. A higher h-index indicates that an author has published more papers that have received more citations.

The top-ranked author with an impressive record of 240 publications since 2015, 74 h-index, and 19,148 total citations is Billen, Gilles F., from France. Besides, Sorbonne Université also recorded impressive achievements, with their authors ranking 1st 2nd and 7th in the list of the most prolific authors. There are several factors that may have contributed to Sorbonne Université 's excellence in research, including their strong research culture, access to funding, talented faculty members, and collaborative research initiatives with other institutions.

Additionally, Sorbonne Université has a long history of academic excellence and has consistently ranked highly in various international rankings, which may have attracted top researchers and students to the

institution. Despite having only 1845 total citations, which is lower than the 5th (6341), 7th (34871), 9th (1874) and 10th (2917) ranked authors, Giuseppe Luigi Cirelli from Italy still managed to secure the fourth position among the best authors.

3.5. Author keywords

The collected database was analyzed using VOSviewer, resulting in 5173 author keywords. To prevent redundancy, similar or related keywords were relabeled (5149 keywords). In order to construct bibliometric maps, only keywords that occurred at least 5 times were included, resulting in a total of 217 keywords meeting the threshold.

3.5.1. Terminology and concept

The analysis of Fig. 5 revealed a beginning point regarding the most commonly used keywords. It was discovered that "wastewater" had the highest number of instances, with a total of 204, and was linked to 123 other words. Following "wastewater" were "wastewater reclamation" with 75 occurrences and 58 links, "recycling" with 69 occurrences and 60 links, "irrigation" with 67 occurrences and 60 links and "wastewater treatment plant" with 60 occurrences and 56 links. The term "wastewater" may be a high selection as an author keyword for several reasons, depending on the specific context. The decision to use "wastewater" as an author keyword may depend on the nature and scope of the research, the target audience, and the conventions of the publishing venue. However, in many cases, "wastewater" is a relevant, consistent, and searchable term that can help increase the visibility and impact of the article [24].

In addition to the term "irrigation", we found a few alternative keywords associated with instruments and methodologies employed for analysis. The most frequent term was "recycling" with 69 occurrences, followed by "wastewater treatment plant (WWTP)" with 60 occurrences, "nutrient" with 57 occurrences, "adsorption" with 36 occurrences, and "constructed wetland" with 31 occurrences. These words describe instruments and techniques commonly used for the treatment and management of agricultural wastewater, which may include physical, chemical, biological, and ecological approaches. They can be used to remove pollutants, nutrients, and contaminants from agricultural wastewater or to transform them into useful forms.

3.5.2. Topic of interest

From the map of co-occurrence of author keywords in density visualization mode (Fig. 6), keywords containing “irrigation” were repeated 67 times from the collected database, showing that irrigation is an important process in agricultural wastewater treatment. Irrigation is the process of disposing of treated wastewater in an environmentally friendly and sustainable manner. Rather than simply discharging the treated wastewater into nearby waterways or the environment, the water can be reused for agricultural purposes, which reduces the demand for freshwater resources. Furthermore, irrigation helps to promote plant growth and increase crop yields [25]. The treated wastewater contains essential nutrients such as nitrogen, phosphorus, and potassium, which can provide a valuable source of fertilizer for plants. Additionally, irrigation water can help to maintain soil moisture levels, which is essential for plant growth in arid or semi-arid regions [26]. Nevertheless, the implementation of a filtration system in highland irrigation would lead to alterations in the properties of the water [27]. Finally, the use of treated wastewater for irrigation can reduce the pollution load on nearby waterways and groundwater resources. By recycling (69 occurrences) the water for agricultural purposes, the amount of wastewater that is discharged into the environment is reduced, which can help to protect water quality (66 occurrences) and prevent the contamination of aquatic ecosystems.

Nutrients, Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) are three other important parameters involved in agricultural wastewater treatment. These parameters were mentioned

Table 2
List of the most prolific authors in CI research area.

Rank	Author	Scopus Author ID	Year of 1st publication	TP	h-Index	Total citation	Current Affiliation	Country
1	Billen, Gilles F.	7003799164	2005[b]	240	74	19,148	Sorbonne Université	France
2	Garnier, Josette A.	7201815156	2005[a]	236	64	13,990	Sorbonne Université	France
3	Tarchitzky, Jorge	6603193455	2010[a]	56	24	2376	Hebrew University of Jerusalem	Israel
4	CIRELLI, GIUSEPPE LUIGI	6602946376	2006[b]	61	26	1845	Università degli Studi di Catania	Italy
5	Drechsel, Pay	55904341200	2010[a]	148	41	6341	Kwame Nkrumah University of Science and Technology	Ghana
6	Marzo, Alessia	50262544300	2012[b]	15	11	475	Università degli Studi di Catania	Italy
7	Sharafi, Kiomars	57194516056	2012[a]	183	51	34,879	Kermanshah University of Medical Sciences	Iran
8	Thieu, Vincent	26327147000	2010[a]	37	20	1104	Sorbonne Université	France
9	Toscano, Attilio	12647482300	2004[b]	61	26	1874	Alma Mater Studiorum Università di Bologna	Italy
10	Amerasinghe, Priyanie H.	35585695700	2010[a]	76	27	2917	University of Peradeniya	Sri Lanka

*Role in co-authorship, superscripts. a First author.
b Co-author

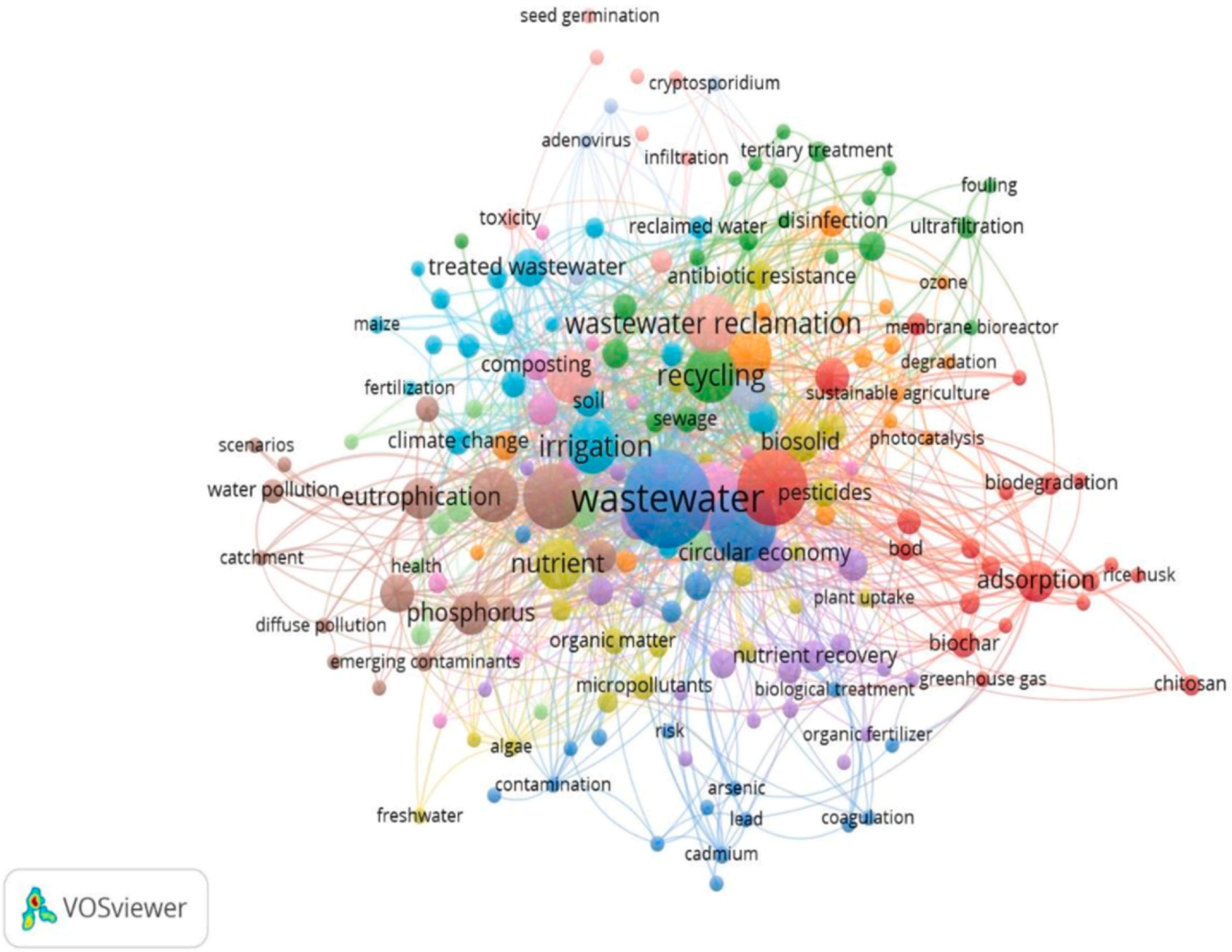

Fig. 5. Author keywords co-occurrence bibliometric map in network visualization mode. The following URL can be used to open Fig. 5 in online VOSviewer: http://tinyurl.com/yp2b5h4h.

57, 9, and 9 times, respectively, showing that those three parameters are important to consider in the treatment of agricultural wastewater to ensure that the treated water is safe for discharge or reuse in agricultural applications [28,29]. Adsorption is one of the physical-chemical treatment methods that can be used for the treatment of agriculture wastewater. It is a procedure by which pollutants or contaminants are eliminated from wastewater through their adsorption onto a solid substance referred to as an adsorbent material [30–32]. In agricultural wastewater treatment, adsorbents such as activated carbon [32], zeolites, Chitosan nanocomposite [33] and clays are commonly used. The author keywords “activated carbon” and “zeolite” appeared 10 and 5 times, respectively. These adsorbents have a high surface area and a porous structure, which allows them to absorb pollutants effectively. Adsorption is an effective treatment method for agricultural wastewater but should be used with other treatment methods to achieve the best removal of pollutants and contaminants. The terms “treatment” and “removal” have appeared 11 and 5 times, respectively in the database. This situation illustrated that these two terms have become commonly utilized by authors in the realm of research on agricultural wastewater treatment.

Using the terms "agriculture wastewater treatment" to search for literature in titles and abstracts in a bibliometric study has some limitations. Firstly, this search strategy may not capture all relevant literature on agriculture wastewater treatment. There may be relevant literature that does not use these exact terms in the title or abstract, which would be missed by this search strategy. Secondly, this search strategy may include irrelevant literature that uses the terms "agriculture", "wastewater", and "treatment" in other contexts. For example, literature on agriculture in general, wastewater management, or other types of wastewater treatment may be included in the results, which could dilute the relevance of the study. Thirdly, this search strategy may not capture new or emerging research on agriculture wastewater treatment that uses different terminology or focuses on specific aspects of the treatment process. This could result in a biased or incomplete picture of the research landscape on agriculture wastewater treatment. Finally, this search strategy may not take into account the nuances or complexities of the treatment process. For example, it may not capture literature on specific types of agricultural wastewater (e.g., livestock or crop production), treatment technologies (e.g., biological, physical, or chemical treatments), or factors that affect the treatment process (e.g., climate, geography, or economics).

Therefore, while using the terms "agriculture wastewater treatment" to search for literature in titles and abstracts can provide a starting point for a bibliometric study, it should be supplemented with other search strategies and sources of information to ensure a comprehensive and accurate analysis of the research landscape on agriculture wastewater treatment.

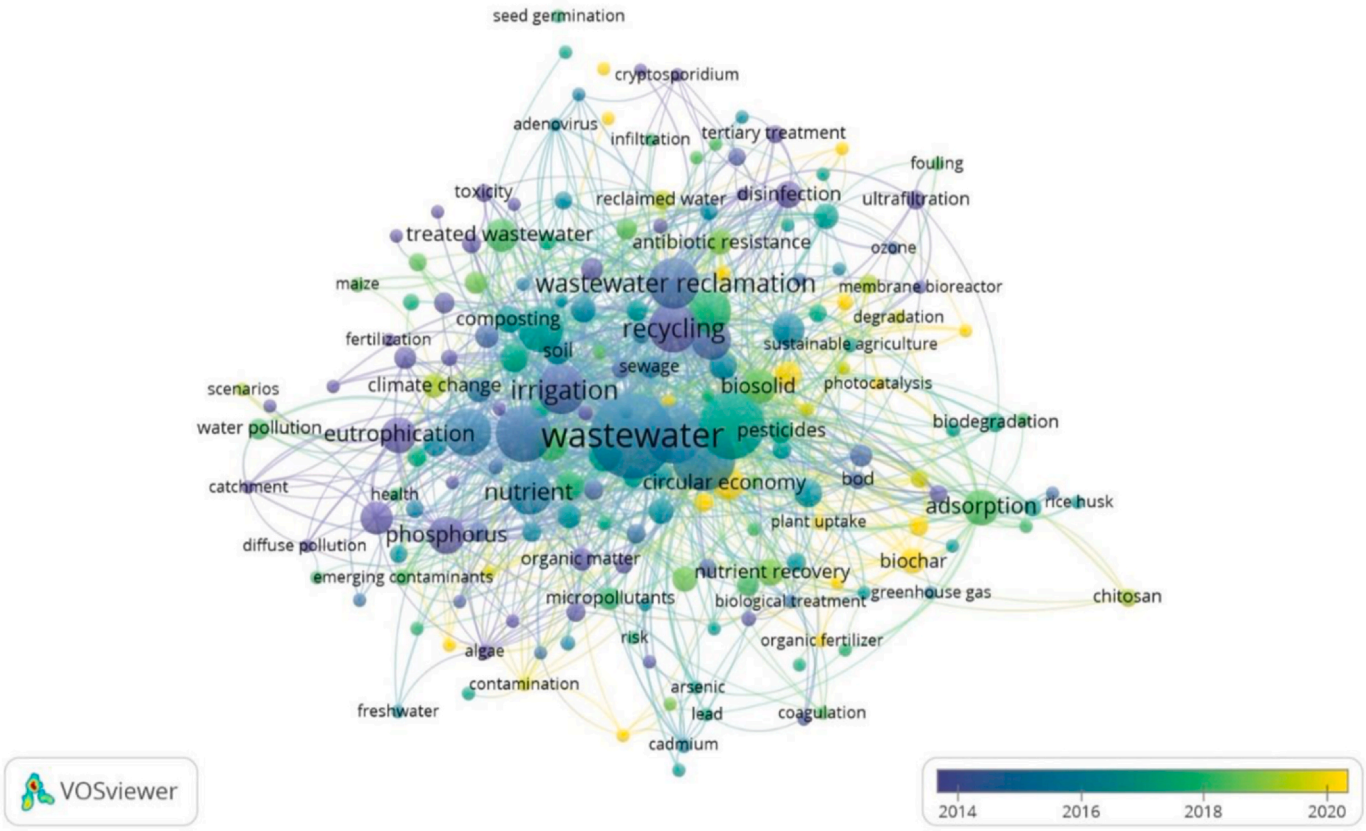

Fig. 6. Author keywords co-occurrence bibliometric map in overlay visualization mode. The following URL can be used to open Fig. 6 in online VOSviewer: http://tinyurl.com/yudqqo4m.

3.6. Limitation of study and future research perspectives

The results given by the Scopus database may not include all the agricultural wastewater treatment publications because of certain limitations. The keyword selection and search phrases can affect the extensiveness of the study. Applying incorrect or limited keywords results in missed publications. Boarder information may be obtained by using synonyms of the word wastewater, such as "effluent", however, extensive work on paper inclusion is then needed to provide focused discussion. Besides, the precision of the information retrieved from databases can be a limitation. Variations in author names, publication titles, and affiliations can affect the quality of the bibliometric evaluation. Furthermore, research on agriculture wastewater treatment is often interdisciplinary, spanning fields such as agriculture, environmental science, and engineering. A bibliometric study may struggle to capture the full breadth of relevant literature due to its focus on specific keywords or categories. Therefore, to relieve these constraints, researchers conducting bibliometric studies should design their search strategies precisely, including the use of multiple databases, considering alternative languages, and being aware of potential biases and data quality issues. The development of artificial intelligence and big data may offer new possibilities in performing bibliometric analysis, especially in accommodating related articles with no specific word and keywords.

4. Conclusion

In summary, this bibliometric analysis examined 1908 publications on agricultural wastewater treatment. These publications crossed distinguished journals and conference proceedings from 1971 to 2023. By analyzing this extensive dataset, the study provides valuable insights into the current research landscape within this field. The results emphasize a prominent flow in publication output since the 1990 s, indicating a rising interest and recognition of the significance of agricultural wastewater treatment. Predominant research themes center around treatment technologies, pollutants, and treatment efficiency. Geographically, Asia emerges as the primary focal point of research activity in this field, closely followed by Europe and North America. However, apparent research gaps have been identified, warranting further exploration. Specifically, there is a pressing need for more extensive studies concerning emerging contaminants, the consolidation of treatment technologies, and the repercussions of climate change on the treatment process. Furthermore, fostering interdisciplinary research that encompasses social, economic, and environmental dimensions related to agriculture wastewater treatment is imperative. By bringing insight into these research gaps, this study provides guidance for future research endeavors. It highlights the importance of collaborative initiatives in addressing the challenges of agricultural wastewater treatment. These findings contribute to the advancement of knowledge in these fields, assisting researchers, policymakers, and stakeholders in making informed decisions and implementing viable solutions for agricultural wastewater treatment.

CRediT authorship contribution statement

Nurfarahana Mohd Nasir: Writing – review & editing. **Setyo Budi Kurniawan:** Writing – review & editing. **Nurulhuda Zakaria:** Software, Methodology. **Siti Mariam Muhammad Nor:** Methodology, Conceptualization. **Hajjar Hartini Wan Jusoh:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Formal analysis, Conceptualization. **Hafizan Juahir:** Writing – review & editing, Supervision, Conceptualization. **Nur Hanis Mohamad Hanapi:** Methodology, Conceptualization. **Nur Zulaikha Mohd Afandi:** Software, Methodology, Conceptualization.

Data Availability

Data will be made available on request.

Declaration of Competing Interest

No conflict of interest with any person, institution or organization.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.dwt.2024.100291.

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