

Trends and insights in cannabis sativa-based wastewater treatment: A systematic review

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Abstract. This study conducts a bibliometric analysis of peer-reviewed articles published between 1994 and 2024, extracted from Web of Science and Scopus databases and analyzed using the “bibliometrix” tool in R, to examine advances in wastewater treatment technologies using hemp (*Cannabis sativa*) and hemp-based materials. Data visualization, conducted using “biblioshiny” and “VOSviewer”, revealed a steady increase in research output over the past three decades. The analysis details key patterns in scientific output, including the leading research fields, contributing countries, institutions, core journals, prolific authors, highly cited papers, and most frequent keywords. Environmental Sciences and Engineering were the most prominent fields, with China identified as the leading contributor. Among the authors, Crini G was recognized as the most influential, serving as the first author of the publication with the highest scholarly impact. The findings present valuable insights into the evolution, current state, and emerging trends of research on hemp-based applications in wastewater treatment.

Keywords. Adsorption, Bibliometric analysis, Cannabis sativa, Green adsorbent, Hemp, Wastewater treatment.

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1 Introduction

Wastewater composition is becoming increasingly complex due to the continuous introduction of new chemicals and products to meet growing population demands [1]. This includes emerging contaminants (ECs) such as dyes, heavy metals, and pharmaceuticals [2]. This situation is further exacerbated by rapid industrialization, which has led to a substantial increase in effluents contaminated with these compounds. Therefore, ECs call for stringent regulatory measures and effective treatment strategies [3]. Several treatment approaches have shown great potential, notably adsorption, membrane filtration, ozonation, advanced oxidation processes, constructed wetlands, and enzymatic treatments [2]. The adsorption process is distinguished by its cost-efficiency, adaptability, and operational simplicity. Among the most frequently used adsorbents, activated carbon emerges as a high-performing material for wastewater purification. Although effective, its use is constrained for large-scale wastewater treatment by its considerable cost and regeneration challenges [2]. Current research is, therefore, moving towards sustainable and economical alternatives, in particular plant-based biomaterials, natural or modified, such as hemp (*Cannabis sativa*). Industrial hemp grants high biomass yield, chemical efficiency and high adaptability [4], it appears to be a promising candidate for ECs mitigation, especially for the removal of heavy metals, dyes and various organic pollutants [5], [6], [7]. In particular, a study confirmed its performance in phytoremediation under cadmium stress, placing it among the most efficient bioenergy crops [8].

Over the past few decades, interest in the use of *Cannabis sativa* for wastewater treatment has increased, as it offers a synergistic approach that enhances contaminant removal, supports ecosystem protection, and promotes long-term water sustainability. However, despite the growing number of publications, a comprehensive understanding of research trends, leading authors and countries, and existing scientific gaps remains limited.

Bibliometric analysis is a quantitative method for evaluating scientific output through indicators such as the number of publications, the frequency of citations and the h-index [9]. Employing statistical techniques, it

highlights trends, relationships, and developments in a field, providing a comprehensive overview of the impact of peer-reviewed research.

In this context, this study conducts a bibliometric analysis of scientific publications on hemp-based materials for wastewater treatment between 1994 and 2024. It aims to identify key trends in scientific production, the most active authors and countries, highly cited publications, emerging themes, and current gaps, with the results intended to guide future research and support the development of sustainable, economically viable solutions.

2 Research methodology

Bibliometric analysis is a quantitative approach to evaluate scientific publications, citations, and related data. Several databases can serve as sources for pertinent bibliographical data compilation, such as Web of Science (WoS), Scopus, PubMed, and Google Scholar.

WoS and Scopus databases were used to extract academic studies related to hemp-based materials in wastewater treatment, providing a global view of peer-reviewed literature from various sources like scientific journals, books, and conference proceedings.

The search methodology was divided into five stages as illustrated in Fig. 1. The bibliometric analysis was conducted on April 20, 2025, covering publications from 1994 to 2024, as studies on the application of *Cannabis sativa* in wastewater treatment first appeared in 1994 in Scopus and WoS. Publications containing the terms “hemp” or “cannabis sativa” and “wastewater treatment” in their titles, abstracts, or keywords were retrieved. The analysis was limited to English and French-language publications and restricted to scientific fields such as Environmental Science, Engineering, and Chemistry, while disciplines including Economics, Physics, and Astronomy were excluded (Fig. 2 and Fig. 3).

Subsequent to data collection, the following stages involve the selection, analysis, visual representation, and interpretation of the acquired results.

This study employs Bibliometrix [10] and VOSviewer [11] to analyze and visualize bibliographic data. These tools enable researchers to process large datasets, identify key authors, uncover research trends, and map complex bibliometric networks.

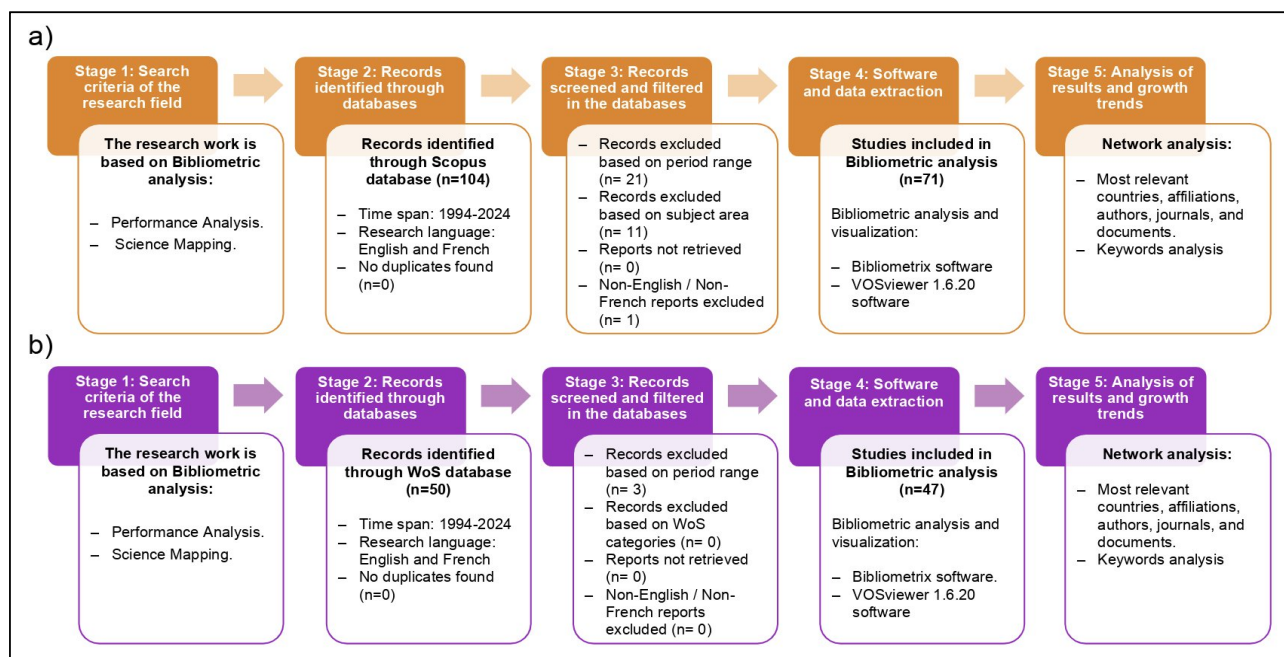


Fig. 1. Five-stage process for data collection, screening, and bibliometric analysis from Scopus (a) and WoS (b).

The search query TITLE-ABS-KEY ("hemp" OR "cannabis sativa"AND "wastewater treatment") was employed in the Scopus data base. The field of Environmental Science leads with 34 documents (28%) followed by Chemical Engineering and Engineering with 21 and 16 documents (17 and 13%), respectively. The field of Materials Science represents 10% of the total documents published while Agricultural and Biological Sciences, Chemistry, and Energy equally represent 7% each.

As for the data retrieval from WoS, the search query (((TS=(hemp)) OR TS=(cannabis sativa)) AND

TS=(wastewater treatment) was executed. The field of Engineering leads with 17 documents (24%) followed by Environmental Sciences Ecology and Materials Science with 15 and 11 documents (21 and 15%), respectively. The field of Science Technology represents 10% of the total documents published followed by the field of Agriculture with 5 documents (7%) and Water Resources with 4 documents, while Biotechnology Applied Microbiology, Chemistry, and Energy Fuels equally represent 4% with only 3 publications each.

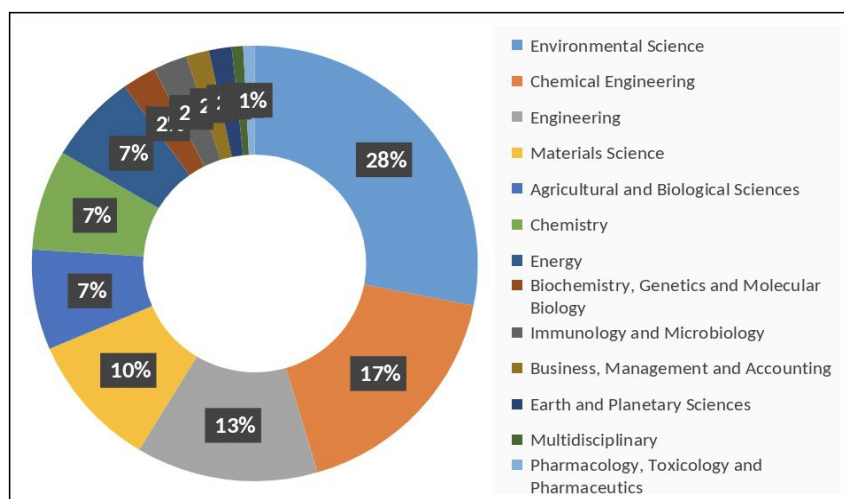


Fig. 2. Documents by research area in Scopus.

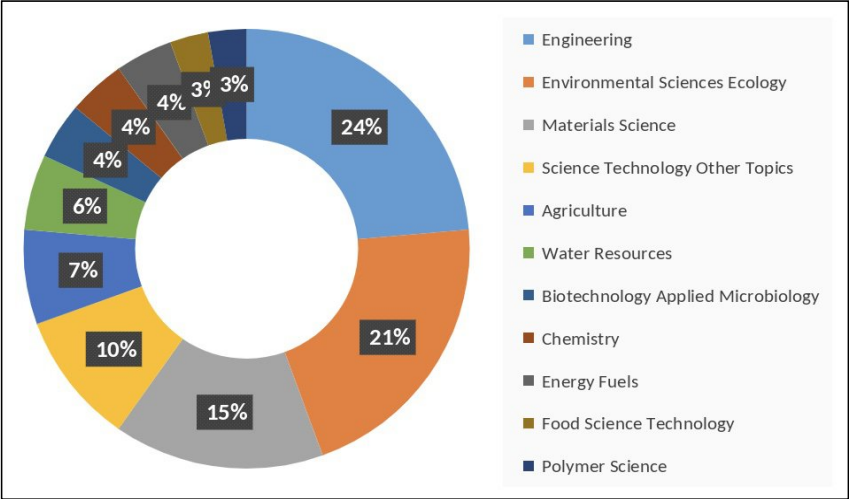


Fig. 3. Documents by research area in WoS.

3 Results and discussions

The collected data was meticulously screened to include published research manuscripts from 1994 until 2024 and written in English or French. For the Scopus

database, the initial results revealed 71 documents (see Table 1), 54 sources, 341 authors, 52 articles, and an annual growth rate of 8.32 %. As for the WoS database, the collected data revealed a total of 47 documents, 40 sources, 214 authors, 36 articles with an annual growth rate of 6.7 %.

Table 1. General information about the extracted data.

Description		Results in Scopus	Results in WoS
Main information about data	Timespan	1994:2024	1994:2024
	Sources	54	40
	Documents	71	47
	Annual Growth Rate %	8.32	6.7
	Document Average Age	7.55	8.57
	Average citations per doc	31.54	46.28
	References	3440	2787
Document contents	Keywords Plus (ID)	1291	249
	Author's Keywords (DE)	273	208
Authors	Authors	349	214
	Authors of single-authored docs	0	2
Authors collaboration	Single-authored docs	0	2
	Co-Authors per Doc	5.27	5.19
	International co-authorships %	23.94	25.53
Document types	Article	52	36
	Book	3	0
	Book chapter	3	0
	Conference paper	9	0
	Review	4	6
	proceedings paper	0	4
	Editorial material	0	1

3.1 Tendency of publications

To identify research trends, impact, and productivity in a given topic, a quantitative analysis of publications over time is an effective approach. The study revealed a significant growth in publication output starting 2017, with Fig. 4 illustrating a visual representation of the distribution from 1994 to 2024.

It is apparent that the number of publications (TP) has consistently risen in both Scopus and WoS over the last 30 years, with very few publications before 2009 and a noticeable growth from 2017 onwards, reaching

the highest output in 2024 (11 in Scopus and 6 in WoS). Furthermore, data analysis revealed that the earliest study addressing the subject of “hemp” within the field of wastewater was published in 1994 in the Scopus and WoS databases. This trend underscores rising interest in hemp-based wastewater treatment as a sustainable alternative to conventional materials.

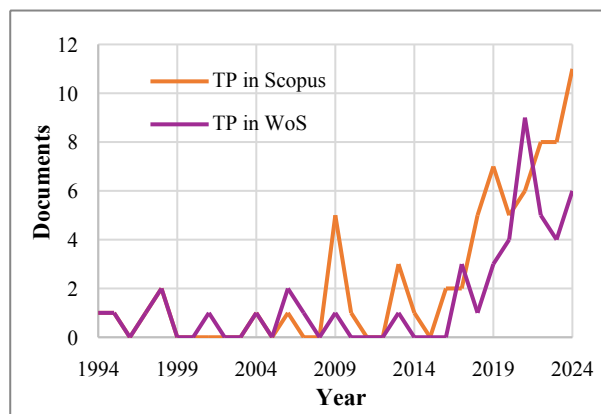


Fig. 4. Publications by year in Scopus and WoS from 1994 to 2024.

3.2 Most relevant countries

Table 2 presents ten most productive countries in Scopus and WoS data. Countries are ranked primarily by total publications (TP). In the event of identical TP, a secondary ranking is applied based on citation counts (TC). Furthermore, the study introduces the average citations per publication (CPP) parameter, which serves as key indicator in evaluating the scholarly influence of countries within the academic community. This metric enables the distinction between consistent academic quality from quantitative output alone.

It is apparent that China leads in both databases in terms of TP, contributing with 27 and 11 documents in Scopus and WoS, respectively. In the Scopus database, China is followed by USA (8), India (6), Malaysia (5), and France (4). However, in the WoS database, China

is followed by USA (4), Canada (3), England (3), and India (3).

Based on the average CPP, in Scopus, France emerges as the most impactful contributor to the field of cannabis studies (72.25), followed by Portugal (43.50), and Pakistan (41.67). The lowest CPP is observed with India (9.83). However, in WoS, Canada demonstrates the highest research impact with a CPP of 343.33, followed by France (113.50), and Romania (47.50). The lowest CPP is recorded with Czech republic (9.67).

When both Scopus and WoS data are carefully examined, it can be deduced that China is the most productive along with being the fourth most impactful country in terms of TP and average CPP, respectively. Although India ranks third and fifth among the top ten most productive countries, it is the least impactful receiving the lowest CPP (in Scopus data).

Overall, China leads in publication output in both Scopus and WoS data, while Canada and France show the highest citation impact (CPP = 343.33 and 113.50, respectively). Other active contributors include the USA, India, and Malaysia, reflecting strong global research interest in the field.

Fig. 5 and Fig. 6 display network visualizations of collaboration between countries in Scopus and WoS, respectively. These figures showcase similar trends, highlighting a compilation of developed and developing nations contributing to this field of research, albeit the scope of contributions by developing countries is narrow. As it is clearly displayed, China, USA, India, the Netherlands, and Italy represent the backbone of research related to studies about cannabis sativa applications in promoting sustainable development and innovative approaches for wastewater treatment.

Table 2. Ten most productive countries over time in Scopus and WoS.

Scopus				WoS			
Countries	TP	TC	CPP	Countries	TP	TC	CPP
China	27	1103	40.85	Peoples r China	11	333	30.27
United States	8	242	30.25	USA	4	65	16.25
India	6	59	9.83	Canada	3	1030	343.33
Malaysia	5	118	23.60	England	3	76	25.33
France	4	289	72.25	India	3	63	21.00
Pakistan	3	125	41.67	Italy	3	41	13.67
Netherlands	3	108	36.00	Poland	3	32	10.67
Canada	3	62	20.67	Czech republic	3	29	9.67
Turkey	3	30	10.00	France	2	227	113.50
Portugal	2	87	43.50	Romania	2	95	47.50

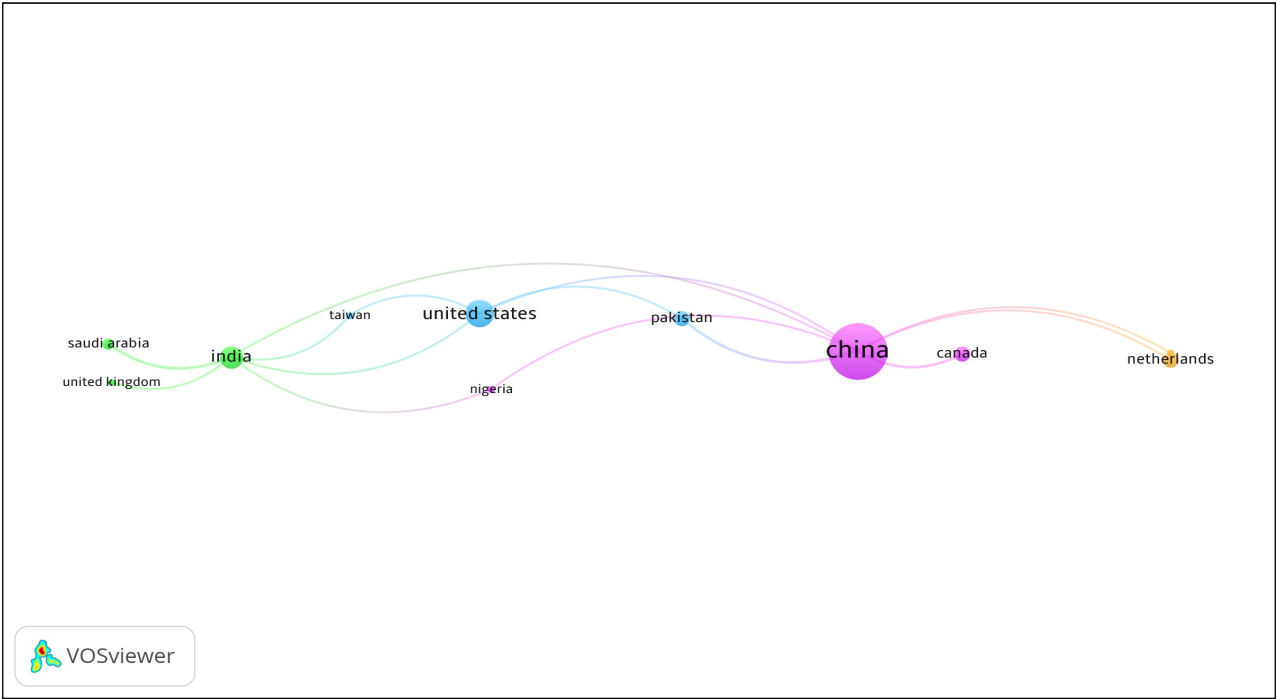


Fig. 5. Countries collaboration network in Scopus.

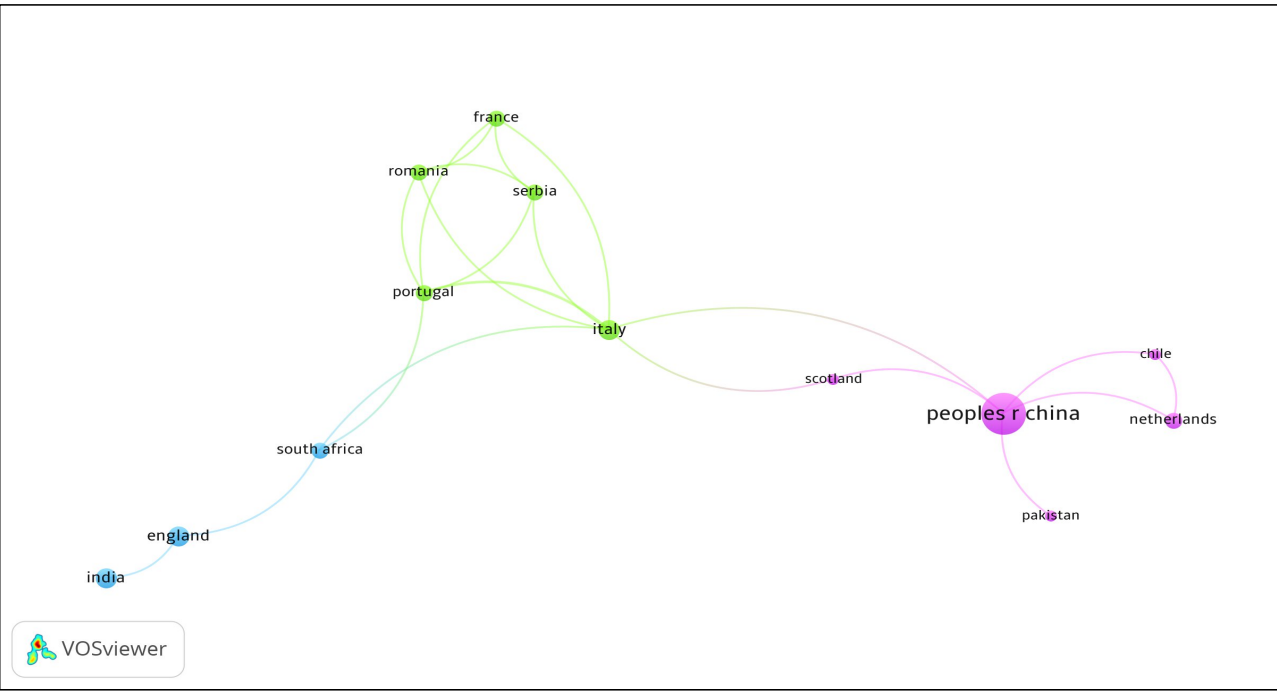


Fig. 6. Countries collaboration network in WoS.

3.3 Most relevant authors

The study further analyzed the productivity of authors in wastewater research, with a particular focus on the integration of cannabis as a bio-adsorbent for pollutant reduction. Table 3 lists the most relevant authors in both Scopus and WoS. Authors are ranked primarily according to the total number of their manuscripts. In the event of identical TP, a secondary ranking is applied based on their TC received. Furthermore, their average CPP were presented in order to asses and identify

authors’ influence, revealing the most prominent figures in this field.

For the Scopus data, the most prominent researcher, in terms of output, is Yu C with 4 contributions and 219 citations. Closely followed by Meng C with 3 publications and 80 citations. The list is further enriched to include Crini G (TC = 279), Lichtfouse E (TC = 279), Morin-Crini N (TC = 279), Field Ja (TC = 84), Kortekaas S (TC = 84), Yan-Ling H (TC = 57), Guan Q (TC = 50), and He L (TC = 50), contributing equally, each with 2 manuscripts.

For the WoS data, the most notable authors are Field Ja, Kortekaas S, and Lettinga G, making equal contributions, each with 3 publications, followed by Brtnicky M, Trojan V, Winkler J, and Zloch J with identical publication counts (TP = 3, TC = 29). Each of the three researchers, Crini G, Chanet G, and Morin-Crini N, participate with 2 publications receiving 227 citations.

The most influential author in Scopus data based on the CPP are : Crini G, Lichtfouse E, and Morin-Crini N, equally encompassing 139.50 CPP, followed by Yu C, Field Ja, and Kortekaas S. The lowest CPP is observed with Guan Q and He L (25.00). As for the WoS data, Crini G , Chanet G, and Morin-Crini N are the top three researchers with the highest CPP of 113.50.

Overall, Crini G, Lichtfouse E, and Morin-Crini N are clearly distinguishable in Scopus (CPP = 139.50) and WoS (CPP = 113.50) with the highest citation

impact per publication. These researchers are key contributors to the field, indicating strong collaboration and impact across both databases.

With the aim of gaining insight into the collaborative environment of the field of wastewater management, the VOSviewer software tool was used. The results indicate an extensive network of authors in Scopus data (349 authors), as well as in WoS data (214 authors).

Fig. 7 and Fig. 8 showcase the collaborative networks of authors with a minimum of 1 document. For each author meeting the thresholds, the total strength of co-authorship links with other authors has been calculated; subsequently, authors with the greatest total link strength (TLS) have been selected. These individuals are prominent for both their high-output and their key role in connecting diverse areas of wastewater treatment research.

Table 3. Ten most relevant authors in Scopus and WoS databases.

Scopus				WoS			
Authors	TP	TC	CPP	Authors	TP	TC	CPP
Yu C	4	219	54.75	Field Ja	3	92	30.67
Meng C	3	80	26.67	Kortekaas S	3	92	30.67
Crini G	2	279	139.50	Lettinga G	3	92	30.67
Lichtfouse E	2	279	139.50	Brtnicky M	3	29	9.67
Morin-Crini N	2	279	139.50	Trojan V	3	29	9.67
Field Ja	2	84	42.00	Winkler J	3	29	9.67
Kortekaas S	2	84	42.00	Zloch J	3	29	9.67
Yan-Ling H	2	57	28.50	Crini G	2	227	113.50
Guan Q	2	50	25.00	Chanet G	2	227	113.50
He L	2	50	25.00	Morin-Crini N	2	227	113.50

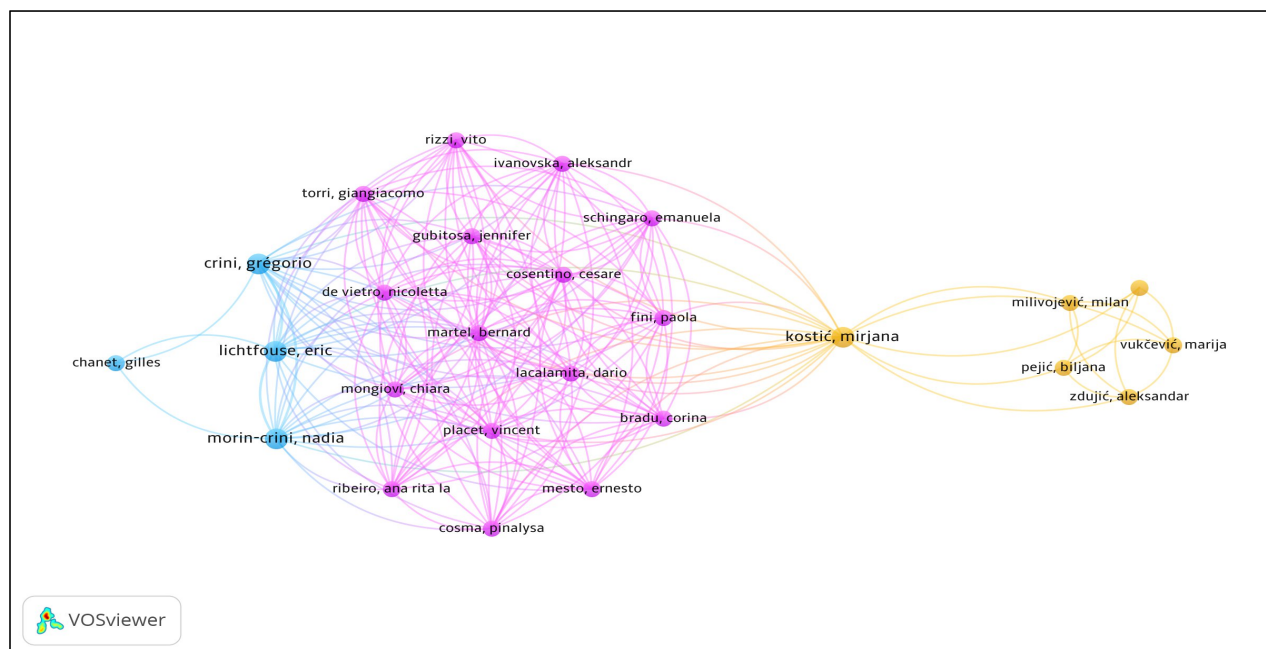


Fig. 7. Collaborative network among authors in Scopus.

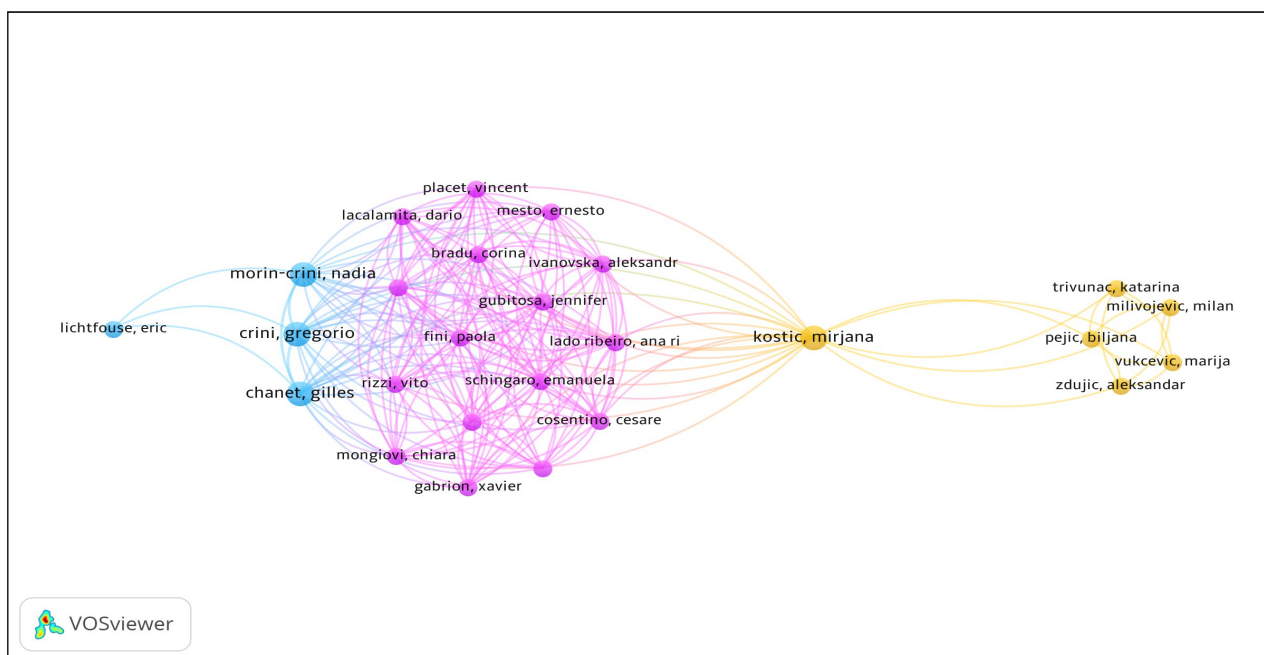


Fig. 8. Collaborative network among authors in WoS.

3.4 Highest productive journals

This dataset provides a comparative analysis of several prominent journals in Scopus and WoS, focusing on their TP, TC, CPP, and quartile rank (Q) (Table 4).

Among the 54 sources identified in the Scopus data, the "Journal of Environmental Chemical Engineering" tops the list with 4 publications, encompassing 88 citations. With the same number of publications, "Industrial Crops and Products" follows closely receiving 73 citations. "Cellulose" contributes with 123 citations across 3 publications. The list goes further to include the "Journal of Cleaner Production", the "Journal of Colloid and Interface Science", "Environmental Technology", "Water Science and Technology", "Bioresource Technology", "Fibers and Polymers", and "Environmental Monitoring and assessment", contributing equally, each with 2 publications. Conversely, and based on the average CPP, the "Journal of Cleaner Production" emerges as

the most prominent (CPP = 95.00). Followed by "Journal of Colloid and Interface Science" (CPP = 42.00), and "Cellulose" (CPP = 41.00).

As for the WoS data, which uncovered a total of 40 sources, the "Journal of Environmental Chemical Engineering" leads with the highest output of 3 publications. Followed by "Ecological Engineering", the "Journal of Bioscience and Bioengineering", "Heliyon", and "Fibers and Polymers", participating in the same measure, with 2 papers. The list is further enriched with journals contributing with only 1 publication, yet receiving the highest TC and CPP, including "Science of the Total Environment" (TC= 831), "Environmental Chemistry Letters" (TC = 215), the "Journal of Cleaner Production" (TC = 145), and the "Journal of Environmental Management" (TC = 117).

A close examination of publications' sources hosting hemp in wastewater treatment reveals that the subject is frequently featured in high quality journals (Q1 and Q2), reflecting its substantial contribution and influence within the research landscape.

Table 4. Top Ten most relevant journals in Scopus and WoS.

Scopus					WoS				
Journal	TP	TC	CPP	Q	Journal	TP	TC	CPP	Q
Journal of Environmental Chemical Engineering	4	88	22.00	Q1	Journal of Environmental Chemical Engineering	3	59	19.67	Q1
Industrial Crops and Products	4	73	18.25	Q1	Ecological Engineering	2	86	43.00	Q1
Cellulose	3	123	41.00	Q1	Journal of Bioscience and Bioengineering	2	67	33.50	Q2
Journal of Cleaner Production	2	190	95.00	Q1	Heliyon	2	18	9.00	Q1
Journal of Colloid and Interface Science	2	84	42.00	Q1	Fibers and Polymers	2	10	5.00	Q2
Environmental Technology (United Kingdom)	2	46	23.00	Q2	Science of the Total Environment	1	831	831.00	Q1
Water Science and	2	33	16.50	Q2	Environmental	1	215	215.00	Q1

Technology					Chemistry Letters				
Bioresource Technology	2	21	10.50	Q1	Journal of Cleaner Production	1	145	145.00	Q1
Fibers and Polymers	2	14	7.00	Q2	Journal of Environmental Management	1	117	117.00	Q1
Environmental Monitoring and assessment	2	7	3.50	Q2	Applied Surface Science	1	83	83.00	Q1

3.5 Highly cited publications

Citation analysis of publications is a fundamental technique for identifying the core themes within a particular academic discipline, highlighting the most influential research contributions. Table 5 and Table 6 present ten most globally cited documents in Scopus and WoS, arranged in descending order of TC. The tables are organized with columns for first author, year of publication, paper title, type, source, TC, and reference.

The most cited document in Scopus, "Applications of hemp in textiles, paper industry, insulation and building materials, horticulture, animal nutrition, food and beverages, nutraceuticals, cosmetics and hygiene, medicine, agrochemistry, energy production and environment: a review" by Crini G [12], has received 273 TC. The authors provided an extensive overview of hemp's multi-functional applications across several sectors, showcasing its role as a sustainable and green resource promoting circular economy objectives. The second article with 267 TC is "Cadmium tolerance and accumulation in eight potential energy crops" by Shi G [8], investigating the phytoremediation potential of various bioenergy crops under cadmium stress, where

hemp emerges as the most efficient. The third most cited document is a review titled "Preparation of Straw Activated Carbon and Its Application in Wastewater Treatment: A Review", by Wang H [13] has received 165 TC. Where the authors focused on preparation methods, adsorption mechanisms, and the effectiveness of straw-derived activated carbon in removing various pollutants. The list is further enriched with articles by Terzic S [14], Li Z [15], Nabais Jmv [16], Bolton L [17], Sajid M [18], Hina K [19], and Cerqueira A [20].

As for the WoS data, the article by Pokhrel D [21] titled "Treatment of Pulp and Paper Mill Wastewater - A Review", emerges as the most influential publication, receiving 831 TC. The authors reviewed conventional and advanced methods for treating highly polluted pulp and paper mill effluents. In second place comes the review by Crini G [12], which garnered 215 TC. The list is expanded with further contributions by Wang H [13], Zhang Q [22], Tofan L [23], Sadrmanesh V [24], Sajid M [18], Bolton L [17], Cerqueira A [20], and Kortekaas S [25].

Overall, the most cited articles across Scopus and WoS underscore hemp's versatile applications, especially in heavy metal, phenolic and pharmaceutical compounds remediation, and its significant role in environmental sustainability.

Table 5. Top ten highly cited documents in Scopus.

First author	Year	Paper title	Type	TC	Ref.
Crini G	2020	Applications of Hemp in Textiles, Paper Industry, Insulation And Building Materials, Horticulture, Animal Nutrition, Food and Beverages, Nutraceuticals, Cosmetics And Hygiene, Medicine, Agrochemistry, Energy Production and Environment: A Review	Review	273	[12]
Shi G	2009	Cadmium Tolerance and Accumulation in Eight Potential Energy Crops	Article	267	[8]
Wang H	2021	Preparation of Straw Activated Carbon and Its Application in Wastewater Treatment: A Review	Review	165	[13]
Terzic S	2010	Illicit Drugs in Wastewater of the City of Zagreb (Croatia) – Estimation of Drug Abuse in a Transition Country	Article	146	[14]
Li Z	2016	High-Efficiency Ramie Fiber Degumming and Self-Powered Degumming Wastewater Treatment Using Triboelectric Nanogenerator	Article	139	[15]
Nabais Jmv	2009	Phenol Removal Onto Novel Activated Carbons Made From Lignocellulosic Precursors: Influence of Surface Properties	Article	81	[16]
Bolton L	2019	Phosphorus Adsorption Onto an Enriched Biochar Substrate in Constructed Wetlands Treating Wastewater	Article	77	[17]
Sajid M	2022	Adsorption Characteristics of Paracetamol Removal Onto Activated Carbon Prepared From Cannabis Sativum Hemp	Article	77	[18]
Hina K	2018	Preparation and Performance Comparison of Cellulose-Based Activated Carbon Fibres	Article	72	[19]
Cerqueira A	2009	Electrofloculation for Textile Wastewater Treatment	Article	68	[20]

Table 6. Top ten highly cited documents in Scopus.

First author	Year	Paper title	Type	TC	Ref.
Pokhrel D	2004	Treatment of Pulp and Paper Mill Wastewater - A Review	Review	831	[21]

Crini G	2020	Applications of Hemp in Textiles, Paper Industry, Insulation And Building Materials, Horticulture, Animal Nutrition, Food and Beverages, Nutraceuticals, Cosmetics And Hygiene, Medicine, Agrochemistry, Energy Production and Environment: A Review	Review	215	[12]
Wang H	2021	Preparation of Straw Activated Carbon and Its Application in Wastewater Treatment: A Review	Review	145	[13]
Zhang Q	2001	Adsorption of Organic Pollutants From Effluents of a Kraft Pulp Mill on Activated Carbon and Polymer Resin	Article	117	[22]
Tofan L	2013	Cobalt (II) Removal From Aqueous Solutions by Natural Hemp Fibers: Batch and Fixed-Bed Column Studies	Article	83	[23]
Sadrmanesh V	2019	Bast Fibres: Structure, Processing, Properties, and Applications	Review	82	[24]
Sajid M	2022	Adsorption Characteristics of Paracetamol Removal Onto Activated Carbon Prepared From Cannabis Sativum Hemp	Article	67	[18]
Bolton L	2019	Phosphorus Adsorption Onto an Enriched Biochar Substrate in Constructed Wetlands Treating Wastewater	Article	66	[17]
Cerqueira A	2009	Electrofloculation For Textile Wastewater Treatment	Article	60	[20]
Kortekaas S	1998	Anaerobic-Aerobic Treatment of Toxic Pulping Black Liquor With Upfront Effluent Recirculation	Article	48	[25]

3.6 Keyword co-occurrence analysis

A keyword co-occurrence analysis was performed with VOSviewer using full counting process. Keywords with at least four occurrences and the highest total link strengths (TLS) were selected. Table 7 presents the top fifteen most frequent keywords, in Scopus and WoS, ranked by descending order of occurrences.

The keyword with the highest number of occurrences in Scopus data is "Wastewater treatment" (63) which also exhibits the highest TLS, bearing 518. Followed by "Hemp" (43), "Wastewater" (22), "Cannabis sativa" (18), and "Adsorption" (18), indicating a strong focus on integrating hemp as a sustainable adsorbent material into wastewater treatment research. The list is further expanded to include the keywords "Article", "Waste water management", "Cannabis", "Chemical oxygen demand", "Water pollution", "Chemicals removal", "Bioremediation", "Heavy metals", "Adsorption capacities", and "Biochar".

As for the WoS data, "Adsorption" (17), "Removal" (8), "Hemp" (7), "Wastewater treatment" (6), and "Equilibrium" (5), emerge as the most frequent keywords, showcasing the growing interest in the use of adsorption isotherms to evaluate hemp's efficiency for pollutant removal from wastewater matrices. The list proceeds to include "Heavy-metal ions", "Kinetics", "Activated carbon", "Wastewater", "Heavy-metals", "Waste-water", "Biosorption", "Sorption", "Carbon", and "Cadmium".

Out of a total of 1402 keywords identified in Scopus data, 80 met the inclusion criteria set by VOSviewer. Fig. 9 presents keyword co-occurrence network map, revealing five distinct clusters, each distinguished by color and size. The purple cluster (20 items) is

particularly prominent, emphasizing the keywords "Cannabis sativa", "waste water management", and "Bioremediation" which are interconnected with other domains, representing the largest and leading cluster within the research area. The second highlighted cluster (16 items), identified by green, include the keywords "drug", "drug products", and "methamphetamine". In the third cluster (14 items), represented by blue, the keywords "Adsorption capacities" and "Biochar" are prominent. The fourth cluster (12 item), in orange, highlights the keywords "Article", and "Effluents". The fifth cluster (11 items), in brown, include the keywords "Hemp", "Wastewater", and "Chemical oxygen demand". The sixth cluster (7 items), identified by red, emphasize the keywords "Bacteria", "Nitrogen", and "Nutrients".

Among a total of 434 keywords analyzed from the WoS data, 18 keywords met the inclusion criteria and yielded three clusters (see Fig. 10). The purple cluster (6 items) underscores the keywords "Removal", "Heavy-metal ions", "Biosorption", and "Sorption" which have strong associations with other fields. The second highlighted cluster (6 items), identified by green, include the keywords "Adsorption", "Wastewater treatment", and "Activated carbon", positioning at the core of the map and showing robust connectivity with neighboring clusters. In the third cluster (6 items), represented by blue, the keywords "Hemp", "Wastewater", and "Heavy-metals" emerge as particularly significant.

Collectively, the most frequent keywords, across both databases, showcase the increased focus of research on wastewater management by targeting chemicals and heavy metals, employing processes such as bioremediation and adsorption with biomaterials, including Cannabis and biochar, as sustainable and efficient solutions.

Table 7. Top fifteen frequent keywords in Scopus and WoS.

Scopus				WoS			
Keywords	Cluster	Occurrences	TLS	Keywords	Cluster	Occurrences	TLS
Wastewater treatment	3	63	518	Adsorption	2	17	49
Hemp	5	43	362	Removal	1	8	25
Wastewater	5	22	258	Hemp	3	7	14

Cannabis sativa	1	18	207	Wastewater treatment	2	6	12
Adsorption	3	18	178	Equilibrium	1	5	27
Article	4	16	232	Heavy-metal ions	1	5	20
Waste water management	1	10	154	Kinetics	1	5	18
Cannabis	1	10	132	Activated carbon	2	5	14
Chemical oxygen demand	5	10	91	Wastewater	3	5	9
Water pollution	1	10	90	Heavy-metals	3	5	5
Chemicals removal	3	9	109	Waste-water	3	5	3
Bioremediation	1	9	102	Biosorption	1	4	24
Heavy metals	3	9	94	Sorption	1	4	24
Adsorption capacities	2	9	73	Carbon	3	4	15
Biochar	2	8	125	Cadmium	3	4	8

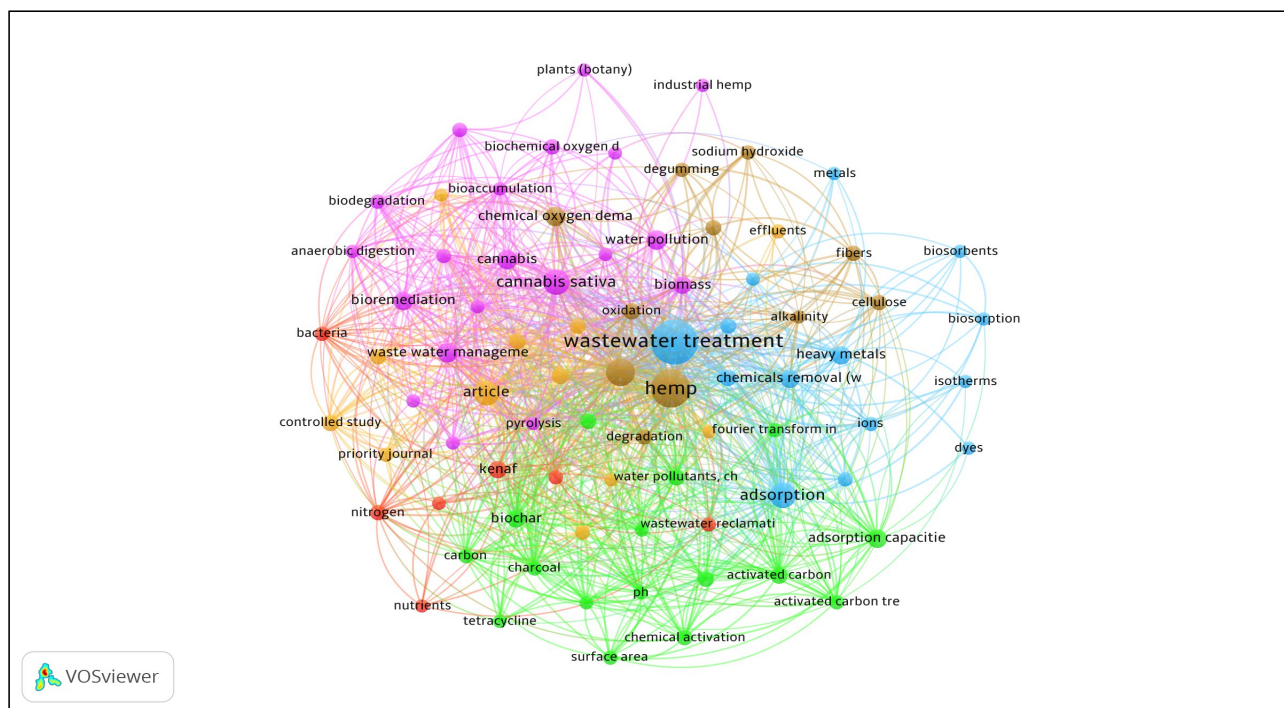


Fig. 9. Co-occurrence network of keywords extracted from Scopus data.

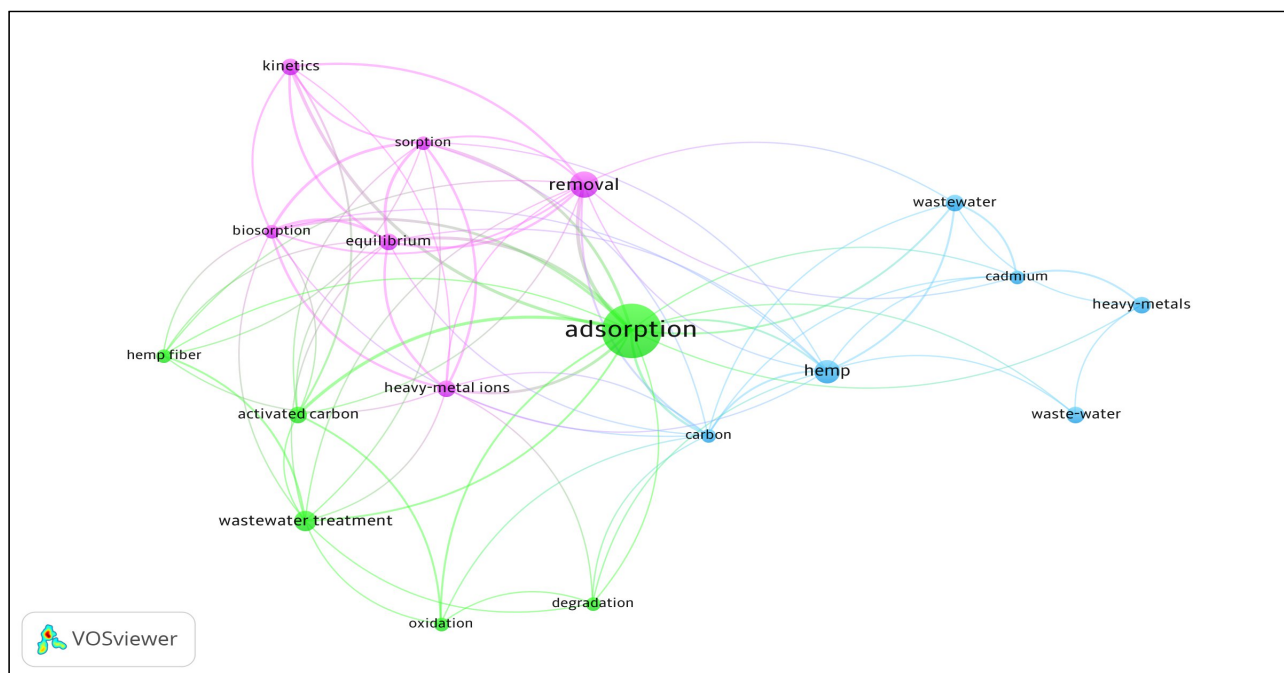


Fig. 10. Co-occurrence network of keywords extracted from WoS data.

4 Conclusion

This article offers a bibliometric review of studies on the use of hemp for wastewater treatment between 1994 and 2024, based on the Scopus and WoS databases. The analysis focuses on the distribution of research areas, the evolution of scientific production, the most active countries and authors, the most cited journals and documents, as well as the analysis of keywords.

The results show a growing interest in the use of hemp in wastewater treatment. China dominates in terms of TP, while Canada and France have the highest impact (CPP = 343.33 and 113.50, respectively). Crini G, Lichtfouse E, and Morin-Crini N appear as key contributors, and the most productive journals are the Journal of Environmental Chemical Engineering, Industrial Crops and Products, and Cellulose.

This study provides insight into the evolving research priorities and collaboration patterns within the field of wastewater. Therefore, it presents a useful basis for researchers and practitioners to comprehend the evolution of the field, guide future research, encourage interdisciplinary collaboration, and promote sustainable water treatment technologies. Conversely, its reliance on Scopus and WoS imposes certain limitations, which may exclude relevant publications not indexed by these databases.

Future bibliometric analyses could incorporate additional databases to gain more comprehensive understanding of scholarly dynamics.

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