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Mapping Hotspots and Emerging Trends in Global Wetlands Research: A Scientometric Analysis (2002–2022)

Jingzhe Chi [1] , ***Syamsul Herman Mohammad Afandi*** [1*] , ***Nitanan Koshy A/L Matthew*** [2]

[1] *School of Business and Economics, Universiti Putra Malaysia, Serdang 43400, Malaysia*

[2] *Faculty of Forestry and Environment, Universiti Putra Malaysia, Serdang 43400, Malaysia*

ABSTRACT

Recent studies have focused on wetlands due to their benefits for human spiritual satisfaction and mental health. This paper conducted a scientometric analysis of 2,388 studies published in the Web of Science database between 2002 and 2022. Using VOSviewer, Origin, and CiteSpace software, this study identified research hotspots and emerging trends in wetland research. The analysis revealed an upward trend in global wetland research publications, with notable contributions from researchers in the United States, China, Australia, Canada, and India. Network keyword co-occurrence analysis highlighted primary research themes, including constructed wetlands, climate change, wastewater treatment, phytoremediation, restoration, and hydrology. The United States emerged as the central hotspot for wetland research, with China, Canada, Australia, and other countries following. Given the growing recognition of wetlands' importance, wetland research is expected to gain even more global attention. Moreover, improvements in the quality of wetland tourism research are recommended, as most related publications have low citation rates. This paper provides a methodological overview of scientometric techniques applicable to global wetland research, offering scholars a framework for using scientometric analysis to enhance their future research. The increasing recognition of wetlands' crucial role in human well-being, encompassing both spiritual satisfaction and mental health, has led to a surge in research interest in this field. This study presents a comprehensive scientometric analysis of 2,388 wetland-related publications indexed in the Web of Science database between 2002 and 2022. Employing VOSviewer, Origin, and CiteSpace software, we mapped research

*CORRESPONDING AUTHOR:

Syamsul Herman Mohammad Afandi, School of Business and Economics, Universiti Putra Malaysia, Serdang 43400, Malaysia;
Email: syamsulhma@upm.edu.my

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hotspots and identified emerging trends within global wetland research. Our analysis reveals a significant upward trend in the volume of publications, highlighting the growing international attention to wetland ecosystems. The United States, China, Australia, Canada, and India have emerged as leading contributors to this research landscape. A network keyword co-occurrence analysis identified core research themes such as constructed wetlands, climate change, wastewater treatment, phytoremediation, ecological restoration, and hydrology. The United States is a central hub for wetland research, with China, Canada, and Australia also demonstrating substantial research activity. Given the escalating importance of wetlands in addressing global challenges, this research area is expected to attract further scholarly attention. We recommend a greater emphasis on enhancing the quality and impact of wetland tourism research, which currently exhibits low citation rates. Furthermore, this paper provides a methodological framework, demonstrating the application of scientometric techniques in global wetland research, thus empowering scholars to utilise such analytical approaches to refine their research. Our study offers a valuable and comprehensive overview of the key research areas, emerging topics, and influential contributors within the field of global wetland research.

Keywords: Scientometrics Analysis; Global Wetlands; Citespace; VOSviewer; Web of Science Database

1. Introduction

Wetland ecosystems are one of the three major ecosystems on Earth, alongside land and sea. Despite covering only 7% of the Earth's surface, they offer various resources for human survival and production and significant environmental benefits such as flood control and storage [1], drought resistance [2], pollution control [3, 4], biodiversity maintenance [5], and beautification of the environment [6]. As a result, it is known as the "kidney of the earth" [7].

Wetlands play an important role in maintaining ecological equilibrium and contribute significantly to several Sustainable Development Goals (SDGs), particularly those related to clean water and sanitation (SDG 6), climate action (SDG 13), and life below water and on land (SDGs 14 and 15). Their ability to support biodiversity, regulate water cycles, and mitigate. Consequently, there has been an increase in research interest in wetlands in recent years, as evidenced by the numerous academic papers and reviews published on this subject [8]. For example, a literature review and bibliometric analysis of constructed wetlands-microbial fuel cells found embedding microbial fuel cells (MFC) within constructed wetlands (CW) can generate bioelectricity and maintain ecological integrity [9]. A meta-analysis of wetland classification using remote sensing presents the advancement of wetland classification methods [10]. However, comprehensive reviews of wetlands are lacking. Many scientific articles have been published on wetlands, including articles on the management of wetlands [11, 12], the recreational value of wetlands [13], and the evaluation of wetlands' value [14]. Although these studies provide preliminary insights in different directions for further research in the field of wetlands, there is a current gap in the literature when it comes to a systematic review of the overall status of wetlands. Additionally, our understanding of the evolutionary characteristics and development trends of hot spots in wetland research is currently inadequate. Regarding the limitations of the previous studies, this study utilizes bibliometric analysis to provide a comprehensive overview of the wetlands.

In this article, we discuss scientometric analysis in terms of bibliometric and manual analysis. Bibliometric analysis involves using mathematical and statistical methods to examine scientific publications, including papers, books, and other forms of communication [15]. Bibliometrics helps scientists evaluate papers and spot research trends [16]. Additionally, bibliometric analysis is a powerful tool for literature summarization and synthesis. By utilizing a large bibliometric corpus, researchers can review the past, present, and future of a particular field of research.

Bibliometric analysis tools such as Gephi, Bibliometrix, CiteSpace, and VOS Viewer facilitate the analysis of such data easily and pragmatically. CiteSpace and VOSViewer are among the most widely used applications, which have contributed to increased interest in bibliometric analysis (**Figure 1**).

Although scientometrics has methodological limitations, it remains an invaluable tool for assessing scientific research quality in a subject or field [17]. When comparing

systematic reviews like scientometrics with conventional reviews such as descriptive literature reviews, it becomes evident that the former offers certain advantages. It can offer a complete picture of a study topic's intellectual structure and tendencies quickly and efficiently [18]. For example, through a bibliometric analysis of research on the topic "Marine and Coast Tourism", James Cook University was the most prominent institution in the field of marine and coast tourism research. The study also revealed that coastal zone management and tourism management were major topics, followed by environmental management and environmental protection [19]. According to an analysis of global research on hospitality and tourism, tourism and hospitality studies have increased since 1999. Most of these publications came from the United States, and the relational research concerns hotel performance, strategic management, and smart tourism [20]. A bibliometric analysis of journal trends, such as Wetlands, can be very useful in creating new directions for periodical publishing [21, 22]. Based on the above statement, it can be inferred that bibliometric analysis of wetlands can reveal useful information. Science mapping can effectively showcase bibliometric visualization and provide insights into the current state and future development of the discipline [23].

In this article, we propose a scientometric method for wetlands and suggest future research directions. Using scientometric analysis with historical reviews will reveal critical evidence and highlight emerging trends in wetland research.

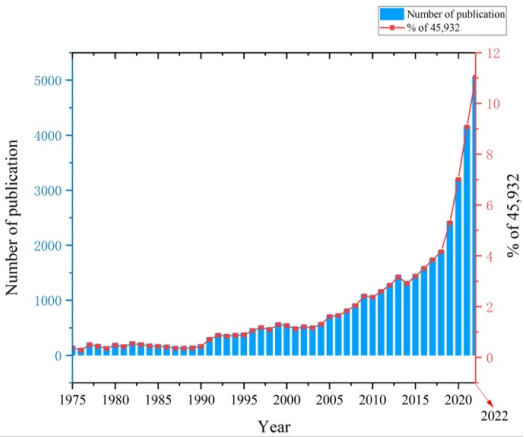

Figure 1. Bibliometric papers published by year. Note(s): **Figure 1** shows the number of publications based on bibliometrics published during 1975–2022. The data were obtained from the Web of Science using the keyword "bibliom*."

2. Data and Methodology

2.1. Source of Data

The citation data used for bibliometric analysis in this paper was obtained from SCI-E, which is a database of the Science Citation Index Expanded available on the Web of Science (WOS). The Web of Science is considered the oldest, largest, and most authoritative research publication database in the world, and it provides researchers with access to daily publications, analytical data sets, and raw data specialized for bibliometric partners [24] (Birkle et al., 2020). The Web of Science has been widely used in previous research for various bibliometric investigations [25–27], and hence, all the data in this paper is derived from this database. Additionally, **Figure 2** illustrates the scientometric research process.

This paper analyzes academic publications related to wetlands using the Web of Science database. Enter "wetland" in the search range (Article title, Abstract, Author Keywords, Keywords Plus). After reviewing the abstract of each paper, refer to the full text of the paper whose research content cannot be determined as wetland research. After the above operations, 2,388 papers that met the requirements were selected. The data is saved as a plain text file as part of the dataset. Data was collected from review articles in the WOS database from 2002 to 2022.

This paper collects and analyzes data according to research questions and answers the following research questions:

Q1. What is the development trend in global research on wetlands?

Q2. Which topics have received the most attention in research on wetlands?

Q3. Who is engaged in wetland research around the world and how is it funded?

Q4. What kinds of publications have been devoted to the wetlands in recent years, and how are they cited?

2.2. Analytical Tool

Bibliometric analysis is a highly valuable approach for mapping and interpreting the accumulation of scientific knowledge within established fields and tracking the evolution of disciplines through large volumes of unstructured data [28]. In this study, we employed a combination of network visualization and analysis tools to conduct a comprehensive scientometric analysis of wetland research. VOSviewer

facilitated network visualization, enabling us to identify key research trends, themes, and outliers via an interactive and user-friendly graphical interface [29]. CiteSpace developed by Professor Chaomei Chen, was utilized to undertake a time-sliced analysis from 2002 to 2022, concentrating on the top 50 most cited or frequently occurring items in each period, which allowed for an in-depth temporal analysis of influential topics. Origin was utilized to enhance and refine the visual representation of bibliometric data, providing high-quality graphical outputs [30]. Additionally, Publish or Perish (PoP) assisted in retrieving and analyzing academic citations, while impact factors (IF) and H-index scores were computed to assess the influence and reputation of journals in this field. Collectively, these tools enabled a systematic and multidimensional scientometric analysis of global wetland research, with results presented in various diagrams.

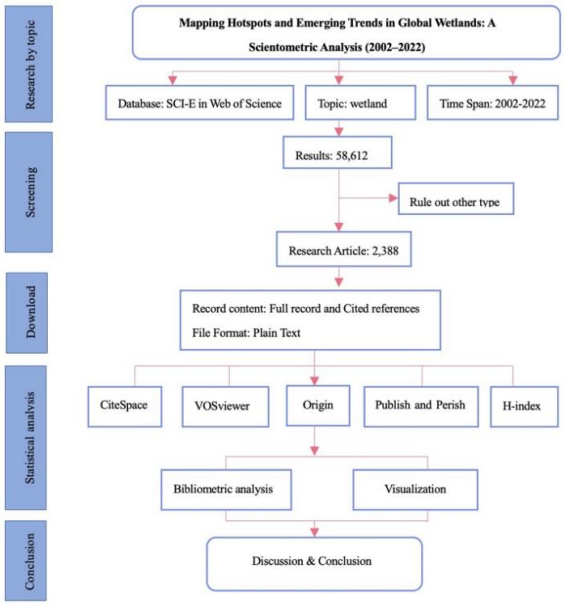

Figure 2. An overview of the scientometric analysis process. Note(s): SCI-E = Science citation index expand; H index = high citation index; VOSviewer: Provides visual representations of networks to uncover trends and themes; CiteSpace: Conducts a time-sliced analysis from 2002 to 2022 on the 50 most cited items; Origin: Creates visuals of high quality; PoP: Gathers and evaluates citation information; H-index: Assesses the impact of journals.

3. Results and Analysis

3.1. Publication Activity by Year

Gupta & Foster [31] published their article, "Economic Criteria for Freshwater Wetland Policy in Massachusetts," the oldest wetland article on the Web of Science. Wetland has attracted increasing attention over the past several decades, with an increasing amount of research being conducted. The following characteristics of stage changes are apparent in wetland research, as shown in **Figure 3**:

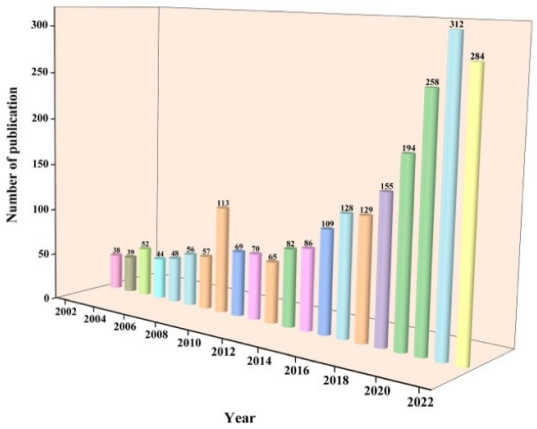

Figure 3. Publications by year from 2002 to 2022 Note(s): The data are derived from review articles. Proceeding papers, letters, book chapters, data papers, book reviews, books, and retracted publications are not included.

a)During the years 2002–2008, there were only a few publications in double digits on WOS, with a very low number of relevant documents. The average number of articles published during this period was 47.71 per year, with 334 articles.

b)During the period between 2009 and 2015, the number of articles published experienced a significant increase. Specifically, in 2009 and 2015, 113 and 109 articles were published, respectively. This was an average of 73.4 articles annually during this period.

c)In the period from 2016 to 2022, the number of publications increased steadily, averaging 191.9 publications per year. The average number of publications during this stage is 4.02 times and 2.61 times greater than in the first and second stages, respectively. Additionally, **Figure 3** illustrates that wetland research publications were lacking before 2009. Nevertheless, the number of wetland research documents has increased significantly since then.

3.2. Publishing Activity by Country/Region

This paper examines publication numbers by country or region based on authors' affiliations. 194 countries published wetland articles. As shown in **Figure 4**, 30 countries have

contributed to wetland publications. The figure shows that the United States accounts for 32.51% of wetland publication contributors. China is ranked second (21.17%), followed by Canada (7.22%), Australia (6.22%), and Germany (4.99%).

Jorge Hirsch[32] proposed the H index to measure scientists' research output. The H index is a reliable number representing a scientist's lifetime achievement. The H-index is measured by counting the number of citations that researchers receive for their work. The higher the H-index, the more influential the work is considered to be[33]. **Figure 4** shows the US has a H-index of 2880. This indicates that American researchers publish more articles on wetlands, and their articles are more influential. Additionally, this indicates that the US is a leader in wetland research. There are also notable contributions to wetland research made by Canada (1460), Australia (1276), and China (1210) as well.

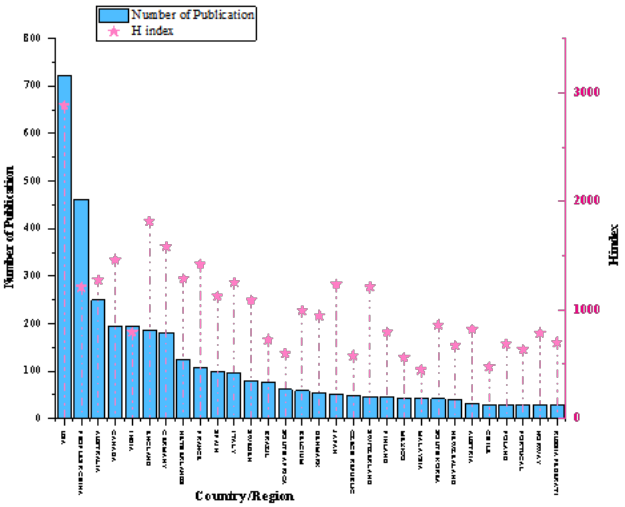

Figure 4. Leading countries or regions contributed to wetlands publications. Note(s): The x-axis of the graph represents different countries and regions, while the left y-axis shows the number of publications. The right y-axis indicates the H-index scores.

3.3. Publishing Activity by Journal and Co-Cited Journal

Table 1 lists the leading journals on wetlands. Science of the Total Environment has published 97 publications (4.062%). The second-most publications are attributed to Water (70 publications, 2.931%), and the third to the Journal of Environmental Management (64 publications, 2.68%). Among the top 20 journals, six are from the United Kingdom, four are from the Netherlands, and four are from Switzerland. The number of publications in the top 20 is more than 700. Among the top 20 journals in the field, there are 11 with impact factors of 5 or higher. These include Science of the Total Environment (10.94), Journal of Environmental Management (8.7), Environmental Science and Pollution Research (5.8), Critical Reviews in Environmental Science and Technology (12.6), Chemosphere (8.8), Remote Sensing (5), Bioresource Technology (11.4), Environmental Reviews (5.7), Global Change Biology (11.6), Water Research (12.8), and Frontiers in Ecology and the Environment (10.3). Marine and Freshwater Research, on the other hand, has the lowest impact factor among the top 20 journals at 1.80.

Based on the number of cited publications (**Table 2**), Science of the Total Environment (7,226) is the most cited journal, followed by Ecological Engineering (6,656), Water Research (6,032), Bioresource Technology (5,282), and Critical Reviews in Environmental Science and Technology (4,669). The impact factors of ten journals are greater than 10, including Science of the Total Environment (10.94), Water Research (12.8), Bioresource Technology (11.4), Critical Reviews in Environmental Science and Technology (12.6), Journal of Hazardous Materials (13.6), Science (56.9), Nature (64.8), Environmental Pollution (56.9), Chemical Engineering Journal (16.74), and Global Change Biology (11.6).

3.4. Publishing Activity by Co-Cited Analysis

Co-citation analysis was introduced by Henry Small in 1973 as a means of identifying similar subjects. Co-citation coupling is an approach used to identify similar topics between two documents. The two documents are co-cited when they both appear in a third document's reference list[34]. The higher the co-citation coupling, the more likely the two documents are related. **Table 3** lists the top 20 co-cited references related to wetlands research.

There are two references that have been co-cited more than 1000 times, nine references that have been co-cited between 500 and 1000 times, and nine references that have been co-cited between 300 and 500 times. A total of nine papers were published in the top 20 journals (IF >10): Annual Review of Environment and Resources (16.4), Nature (64.8), Biotechnology Advances (16), Global Change Biology (11.6), Environment International (11.8), Bioresource Technology (11.4), Trends in Ecology and Evolution (16.8), Water Research (12.8), and Frontiers in Ecology and the Environment (10.3).

Table 1. Top 20 leading publishing journals in the wetland.

Ranking	Number of Publication	% of Total Publication	Journal			
			Name	Country/Region	Impact Factor (2022)	H-Index (2022)
1	97	4.062	Science of The Total Environment	Netherlands	10.94	317
2	70	2.931	Water	Switzerland	3.4	85
3	64	2.68	Journal of Environmental Management	United States	8.7	218
4	47	1.968	Environmental Science and Pollution Research	Germany	5.8	154
5	45	1.884	Critical Reviews in Environmental Science and Technology	United Kingdom	12.6	131
6	44	1.843	Sustainability	Switzerland	3.9	136
7	43	1.801	Wetlands	Netherlands	2	95
8	36	1.508	Ecological Engineering	Netherlands	3.8	150
9	28	1.173	Chemosphere	United Kingdom	8.8	288
10	28	1.173	Remote Sensing	Switzerland	5	81
11	27	1.131	Bioresource Technology	United Kingdom	11.4	341
12	27	2.131	Hydrobiologia	Netherlands	2.6	158
13	22	0.921	Environmental Reviews	Canada	5.7	81
14	22	0.921	Frontiers in Environmental Science	Switzerland	4.6	61
15	22	0.921	Water Environment Research	United States	3.1	81
16	22	0.921	Water Science and Technology	United Kingdom	2.7	153
17	20	0.838	Marine and Freshwater Research	Australia	1.8	97
18	19	0.796	Global Change Biology	United Kingdom	11.6	293
19	19	0.796	Water Research	United Kingdom	12.8	354
20	18	0.754	Frontiers in Ecology and the Environment	United States	10.3	186

Table 2. The top 20 co-cited journals related to wetlands.

Rank	Cited Number	Journal			
		Name	Country/Region	Impact Factor (2022)	H Index (2022)
1	7226	Science of The Total Environment	Netherlands	10.94	317
2	6656	Ecological Engineering	Netherlands	3.8	150
3	6032	Water Research	United Kingdom	12.8	354
4	5282	Bioresource Technology	United Kingdom	11.4	341
5	4669	Critical Reviews in Environmental Science and Technology	United Kingdom	12.6	131
6	4378	Chemosphere	United Kingdom	8.8	288
7	4088	Water Science and Technology	United Kingdom	2.7	153
8	2759	Journal Of Hazardous Materials	Netherlands	13.6	329
9	2681	Science	United States	56.9	1283
10	2630	Nature	United Kingdom	64.8	1331
11	2456	Wetlands	Netherlands	2	95
12	2433	Enviromental Pollution	United Kingdom	56.9	275
13	2386	Journal of Environmental Management	United States	8.7	218
14	1965	Environmental Science and Pollution Research	Germany	5.8	154
15	1912	Hydrobiologia	Netherlands	2.6	158
16	1827	Chemical Engineering Journal	Netherlands	16.74	280
17	1665	Applied Microbiology And Biotechnology	Germany	5.0	253
18	1589	Critical Reviews In Plant Sciences	United Kingdom	6.9	130
19	1570	Global Change Biology	United Kingdom	11.6	293
20	1567	Ecology	United States	4.8	322

During the middle and late 19th centuries, rapid population growth and economic development led to the conversion of wetlands into farmland. Overuse of resources and pollution have resulted in a significant reduction in wetland areas and species [35, 36]. To protect wetlands and their species, the 1971 Global Intergovernmental Convention on Wetland Conservation was established. Wetland research has only gained traction since the 1970s [37].

The timeline view of the reference cited is shown in **Figure 5**. The reference network map has 1252 nodes and 4359 links. There are 10 clusters of references with active co-citations between them. According to available records, cluster #6 (present state) was first mentioned in WOS in 1997 [38]. It is noteworthy that the United Nations Frame-

work Convention on Climate Change (UNFCCC) adopted a climate change mitigation and adaptation plan in December 2015. According to the agreement, countries are required to incorporate nature-based solutions into their intended nationally determined contributions (NDCs) to address climate change, including wetland solutions. Wetland research and protection have gained more attention from government departments and academia [39]. Therefore, since 2016, scholars have paid more attention to the impact of gas emissions on the wetland environment, particularly methane emissions (cluster #2). Recently, there has been an increased focus on the study of new energy, materials, and technologies related to wetlands. These include microbial fuel cells (cluster #3) and antibiotic resistance genes (cluster #4). As a member of the Convention on Wetlands since 1992, the Chinese government has collaborated with the international community to address global challenges such as climate change and wetland degradation. In particular, China passed a Wetland Protection Law in 2021 to strengthen the protection and restoration of wetlands. Hence, there has been a significant interest in the study of wetland ecosystems (cluster #5) among Chinese scholars [40–42].

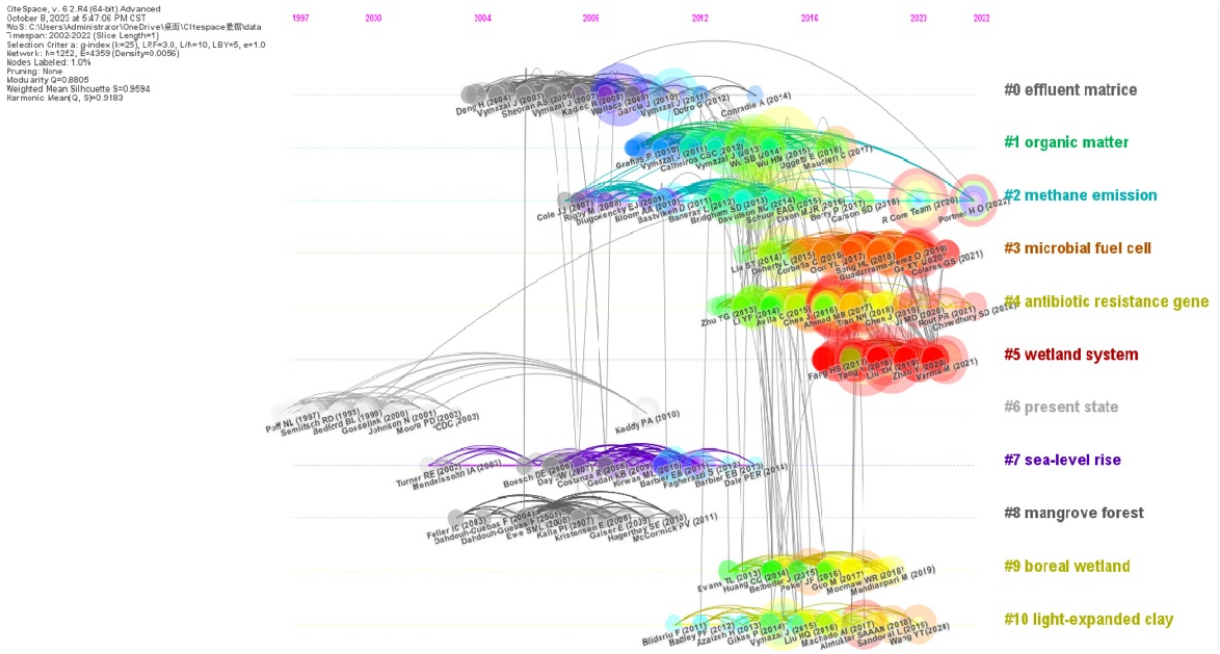

Figure 5. View of the reference timeline. Note(s): Lines of different colors show that two articles were co-cited in an article. The size of a node represents the total number of citations across all time slices. The color of the node indicates the number of citations from a single time slice. The lines between the nodes indicate co-citations. Q > 0.3 indicates convincing results, and S > 0.5 is considered reasonable for clustering.

3.5. Publishing Activity by Author and Affiliation Institution

3.5.1. Publishing Activity by Author

Of the 58,612 papers published by global researchers, the top 15 authors (i.e., those with 15 or more publications) published 3,505 papers, which constitutes 5.98% of the total publications. This implies that the concentration of authors is low. **Table 4** shows seven total citations exceeding 10,000, with Ngo from the University of Technology Sydney having the highest number (29,853). Second place is Guo, affiliated with the University of Technology Sydney, with 25,674 citations. In third place is Rinklebe, affiliated with the University of Wuppertal (25,190 citations).

3.5.2. Publishing Activity by Institutions

In total, 58,612 papers were published in 200 research institutions around the world, which indicates that wetland researchers are scattered around the world. **Figure 6** shows that 30 institutions have published >400 wetland research publications. They published 18,515 publications, representing 31.59% of all publications published by research institutions.

Table 3. The top 20 cited articles related to wetland.

Rank	Cited Number	The Title of Article	Year	Journal			
				Source	Country	Impact Factor (2022)	H-Index (2022)
1	1288	Wetland resources: Status, trends, ecosystem services, and restorability	2005	Annual Review of Environment and Resources	United States	16.4	135
2	1113	Tidal wetland stability in the face of human impacts and sea-level rise	2013	Nature	United Kingdom	64.8	1331
3	781	Effects of plants and microorganisms in constructed wetlands for wastewater treatment	2003	Biotechnology Advances	United States	16	226
4	704	Methane emissions from wetlands: biogeochemical, microbial, and modeling perspectives from local to global scales	2013	Global Change Biology	United Kingdom	11.6	293
5	693	Metal uptake, transport and release by wetland plants: implications for phytoremediation and restoration	2004	Enviroment International	United Kingdom	11.8	227
6	628	A review on nitrogen and organics removal mechanisms in subsurface flow constructed wetlands: Dependency on environmental parameters, operating conditions and supporting media	2012	Journal of Environmental Management	United States	8.7	218
7	623	A review on the sustainability of constructed wetlands for wastewater treatment: Design and operation	2015	Bioresource Technilogy	United Kingdom	11.4	341
8	623	The carbon balance of North American wetlands	2006	Wetlands	Netherlands	2	95
9	605	Causes and consequences of invasive plants in wetlands: Opportunities, opportunists, and outcomes	2004	Critical Reviews In Plant Sciences	United Kingdom	6.9	130
10	570	Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles	2003	Conservation Biology	United Kingdom	6.3	241
11	524	Regional and global concerns over wetlands and water quality	2006	Trends in Ecology and Evolution	United Kingdom	16.8	370
12	498	Heavy metal removal mechanism of acid mine drainage in wetlands: A critical review	2006	Minerals Engineering	United Kingdom	4.8	125
13	467	Biogeochemistry of methane exchange between natural wetlands and the atmosphere	2005	Enviroment Engineering Science	United States	1.8	71
14	426	Plants used in constructed wetlands with horizontal subsurface flow: a review	2011	Hydrobiologia	Netherlands	2.6	158
15	405	A review on removing pharmaceutical contaminants from wastewater by constructed wetlands: Design, performance and mechanism	2014	Science Of The Total Enviroment	Netherlands	9.8	317
16	402	The use constructed wetlands with horizontal sub-surface flow for various types of wastewater	2009	Ecological Engineering	Netherlands	3.8	150
17	398	Development of constructed wetlands in performance intensifications for wastewater treatment: A nitrogen and organic matter targeted review	2014	Water Research	United Kingdom	12.8	354
18	395	Wetlands at your service: reducing impacts of agriculture at the watershed scale	2003	Frontiers in Ecology and the Environment	United States	10.3	186
19	388	Artificial drainage of peatlands: hydrological and hydrochemical process and wetland restoration	2004	Progress in Physical Geography-Earth And Enviroment	United Kingdom	3.9	113
20	387	Constructed Wetlands for Wastewater Treatment	2010	Water	Switzerland	3.4	85

Table 4. The most productive authors in the field of wetlands.

Author's Name	Affiliation	TP	NCP	TC	C/P	C/CP	h-Index
Ngo, Hao H	University of Technology Sydney	513	549	29,853	58.19	54.38	84
Rinklebe, Joerg	University of Wuppertal	486	454	25,190	51.83	55.48	82
Guo, Wenshan	University of Technology Sydney	425	449	25,674	60.41	57.18	77
Zhang, Jian	Shandong University	377	353	13,532	35.89	38.33	59
Day, John	Louisiana State University	291	228	12,248	42.09	53.72	57
Colmer, Timothy D	University of Western Australia	258	252	17,533	67.96	69.58	68
Zhao, Yaqian	Xi'an University of Technology	189	181	7,478	39.57	41.31	46
Vymazal, Jan	Czech University of Life Sciences	180	170	12,320	68.44	72.47	53
Finlayson,Colin Maxwell	University of New South Wales Sydney	163	146	4,938	30.29	33.82	41
Gupta, Ashok Kuma	Indian Institute of Technology (IIT) - Kharagpur	154	134	2,895	18.80	21.60	29
Twilley, R.	Louisiana State University	143	137	9,253	64.71	67.54	52
Kuschk, Peter	Helmholtz Center for Environmental Research (UFZ)	125	118	5,350	42.80	45.34	39
Brisco, Brian	Canada Centre for Mapping & Earth Observation (CCMEO)	124	113	3,792	30.58	33.56	35
Masi, Fabio	Iridra Srl	61	57	1,561	25.59	27.39	21
Ilyas, Huma	Universite Paris Cite	16	16	415	25.94	25.94	11

Note (s): Publications on the Web of Science. TP = Total number of publications, NCP = Number of cited publications, TC = Total citations, C/P = Average citations per publication, C/CP = Average citations per cited publication.

Global ranking refers to a measure of an institution's influence on a global level. This includes graduate performance and academic reputation [43]. In terms of institutional ranking, the United States has five institutes in the global top 10. These institutes are highly regarded worldwide, including the State University System of Florida, established in 1905. The US leads the world in scientific research. The Chinese Academy of Science and the Centre National de la Recherche Scientifique (French) are also among the top 10 institutions. Chinese institutions have shown remarkable growth in recent years, with four research institutions in the top 10, second only to the United States. This indicates that Chinese scholars have a keen interest in wetland research. It also reflects the Chinese government's strong emphasis on wetland protection and development since joining the Convention on Wetlands.

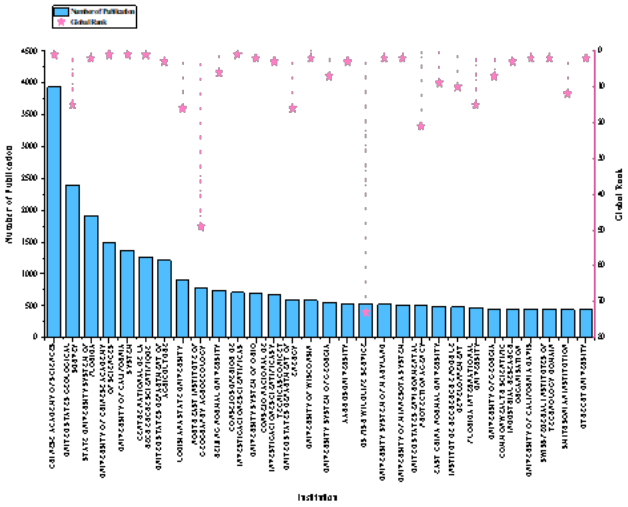

Figure 6. The top 30 institutions producing at least four hundred wetland research publications. Note(s): The x-axis of the graph represents institutions, while the left y-axis shows the number of publications. The right y-axis represents global institutional ranking.

3.5.3. Publishing Activity by Authors' Collaboration

Figure 7 illustrates how the study conducted a co-authorship analysis of interactions among scholars in wetland research using VOSviewer software. Most wetland papers have at least two or more authors. The trend of authors toward group joint research is gradually emerging with the development of the subject. This is due to the application of various modern methods and the cross-penetration of the subject. Wetland research relies even more on group strength to overcome some major topics. Therefore, the number of co-authored papers is increasing.

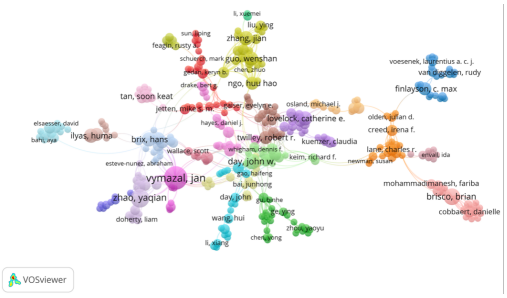

Figure 7. Co-authorship network visualization using fractional counting based on the number of citations the author has that have a minimum number of citations equal to 3. Note(s): The different colors, size of circles, font size, and viscidity of linking lines represent the potency of the relationship among the authors; the same color represents connected authors usually involved in wetland tourism research.

3.6. Research Topic

3.6.1. Keywords Analysis

To answer question 2 (Q2) "Which topics have received the most attention in wetland tourism research?", a keyword co-occurrence analysis was conducted. **Figure 8** shows the nodes' size, which indicates keyword occurrence frequency. Thus, seven main research themes were identified, including wetlands (255), constructed wetlands (240), climate change (106), wastewater treatment (102), phytoremediation (73), restoration (49), and hydrology (43). These themes accounted for 36.35% of all publications, with 2,388 review articles published. Wetlands and constructed wetlands accounted for 20.73% of these articles, indicating that these topics have been extensively researched.

3.6.2. Keywords with Citation Bursts

Keywords with citation bursts indicate more citations during a given period. It can provide insight into whether a particular research area has been hot over the past few years and spotlight emerging topics. It can also be used to identify trends in research, such as the emergence of new topics and the decline of existing topics. This can help researchers understand the current state of research in each field and develop strategies for further study [44]. In **Figure 9**, blue and red bars indicate the frequency of keyword citations within a certain period of time. The first value represents strength, and the second value represents time span. Through the

analysis of keywords such as restoration (7.51; 2013–2018), bioelectricity generation (6.32; 2020–2022), electricity generation (5.52; 2020–2022), treatment plants (5.5; 2019-2022), domestic sewage (4.77; 2020–2022), and emerging organic contaminants (4.45; 2019–2020), treatment of constructed wetland wastewater [45–47] and wetland restoration [48–50] have gained significant attention over the past decade. These keywords have demonstrated varying significance and temporal relevance levels within the specified timeframes. Moreover, research into wetlands and surrounding environments, such as vulnerability assessment and management planning for the ecological environment [51], is particularly significant.

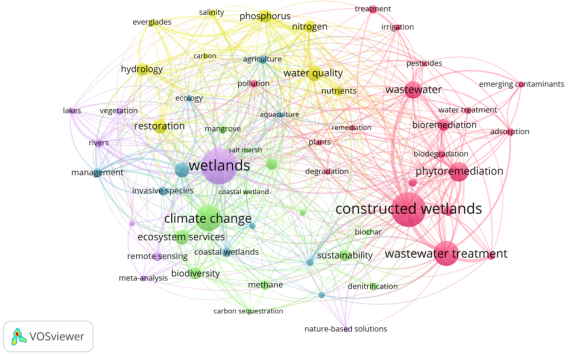

Figure 8. Network visualization of keyword co-occurrences using fractional counting with a minimum of 15 citations. Note(s): Each node in a network represents an entity (e.g., a keyword). "Keywords" (1) indicate the frequency of occurrence; (2) indicate co-occurrence (i.e., keywords that occur together); (3) the thickness of a link indicates how often keywords co-occur. Each color represents a thematic cluster; by using nodes and links, you can explain how a theme (cluster) covers topics (nodes) and how they relate to one another.

Top 30 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	2002 - 2022
restoration	2002	7.51	2013	2018	
phragmites australis	2003	7.35	2008	2016	
wetland restoration	2004	7.32	2004	2010	
carbon dioxide	2003	7.01	2003	2013	
united states	2003	6.88	2003	2009	
bioelectricity generation	2020	6.32	2020	2022	
climate	2008	5.92	2008	2015	
invasive species	2005	5.83	2005	2014	
flow	2014	5.75	2014	2017	
electricity generation	2020	5.52	2020	2022	
treatment plants	2019	5.5	2019	2022	
dissolved organic carbon	2007	4.9	2007	2013	
removal efficiency	2012	4.88	2019	2020	
waste water	2003	4.82	2017	2018	
domestic sewage	2020	4.77	2020	2022	
trends	2017	4.73	2017	2020	
wetland plants	2003	4.73	2003	2013	
risk assessment	2020	4.51	2020	2022	
emerging organic contaminants	2019	4.45	2019	2020	
china	2015	4.43	2015	2017	
natural wetlands	2009	4.39	2009	2015	
fresh water	2002	4.37	2010	2014	
soils	2009	4.25	2009	2011	
removal mechanisms	2020	4.25	2020	2022	
land use	2002	4.22	2010	2013	
life history	2002	4.14	2002	2013	
river	2002	4.11	2002	2006	
trace elements	2003	4.03	2003	2011	
growth	2004	3.94	2004	2006	
developing country	2017	3.9	2017	2019	

Figure 9. Top 30 keywords with the strongest citation bursts. Note(s): In parentheses, the first value represents strength, and the second value represents time span.

3.6.3. Research Direction

Figure 10 shows that most research articles on wetlands are devoted to the following two topics: Environmental Science and Ecology, with Environmental Science occupying 45.186% of the articles and Ecology occupying 21.762%. More than half of the articles come from these two subject areas. Environment Science research topics include conservation interventions, climate change, constructed wetlands, hydrology, and carbon storage. Ecology includes carbon storage, wetland restoration, carbon, and nutrient allocations, etc. As a result, the construction of wetlands, carbon storage and emissions, climate change, and wetland restoration are the most popular research topics.

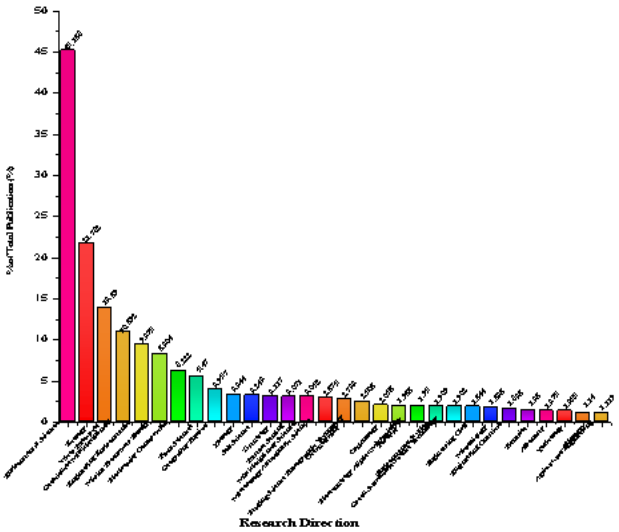

Figure 10. The top 30 categories in wetland research were published by scholars worldwide in 2002–2022.

3.7. Research Hotspots

The more relevant research papers in a region, the more likely it is that the region is a research hotspot [52]. Using research hotspots, scholars can determine the countries and regions where they are most interested in studying a particular field. In this study, using the density view, significant fields and levels of knowledge and research in a particular area can be quickly identified. **Figure 11** illustrates the top 10 countries with the most frequent wetland research papers. As can be seen, the United States, the People's Republic of China, Australia, Canada, and India are among the countries with a high concentration of research hotspots.

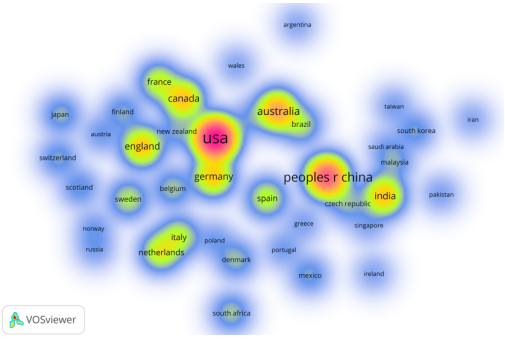

Figure 11. Top 10 countries with the most frequent occurrence of wetlands research papers from 2002 to 2022. Note(s): Visualization of bibliographic coupling density based on fractional counting of ten minimum documents and five minimum citations. Each point is assigned a color based on the density of elements surrounding it. As the density increases, it gets closer to red, and vice versa.

3.8. Funding Sponsors

Despite the publication of 2,388 papers, only 1,008 papers had clear funding sponsors, accounting for 45.56% of all papers. **Table 5** shows that the National Natural Science Foundation of China is the largest provider of grants to Chinese scholars in wetland research. The next highest funding sponsor is the National Science Foundation, followed by the European Union. Interestingly, three of the top 10 funding sponsors are from China. This indicates that the Chinese government has shown strong support and provided significant assistance to the domestic academic community in wetland research. Moreover, scholars in North America and Europe also receive financial support from their respective governments or affiliated organizations. As a result, wetland research has become a global concern.

Table 5. Top 10 funding sponsors in the world for publishing research papers on wetland.

Documents by Funding Sponsors	Total Publications	Percentage (%)
National Natural Science Foundation Of China	235	9.84%
National Science Foundation	122	5.11%
European Union	74	3.10%
Uk Research Innovation	62	2.60%
Natural Environment Research Council	47	1.97%
Natural Sciences And Engineering Research Council Of Canada	42	1.76%
National Key Research And Development Program Of China	34	1.42%
Fundamental Research Funds For The Central Universities	33	1.38%
Spanish Government	33	1.38%
Conselho Nacional De Desenvolvimento Cientifico E Tecnologico	31	1.30%

3.9. Citation Analysis

3.9.1. Research the Citations of Articles

A timeline view of the VOS viewer software is shown in **Figure 12**, which illustrates bibliographic coupling with source analysis. The picture shows numerous journals publishing wetland articles in blue and purple. This means researchers have discovered and cited more journals in recent years. Additionally, it shows that more journals are interested in publishing wetland-related articles, which is a sign of increasing research in the field.

3.9.2. Research the Frequency of Paper Citations

According to the **Table 6**, out of 2,388 publications, 2,329 were referenced, which is 97.08% of the total publications. The research used "Publish and Perish" software to analyze article statistics in the Web of Science database. **Table 6** shows that these 2,388 publications were cited 196,035 times over 20 years, with an average annual citation of 9,801.75. On average, each article received 82.09 citations. Additionally, each author was cited approximately 11.94 times per article.

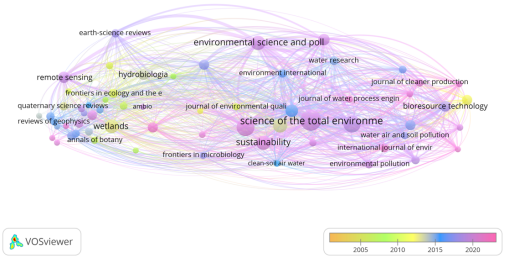

Figure 12. The color display of published journals varies from yellow (2005) to red (2020). Note(s): Bibliographic coupling uses a timeline view with sources represented based on influential sources with three minimum numbers of documents and six minimum numbers of citations, which are determined by fractional counting.

Table 6. Citation metrics for wetland research in the Web of Science database from 2002 to 2022.

Metric	Data
Publication years	2002–2022
Citation years	20
Paper	2,388
Citations	196,035
Cites/year	9,801.75
Cites/paper	82.09
Authors/paper	11.94
h-index	208

3.9.3. Research the Highly Cited Publications

There were 196,035 citations recorded among 2,388 publications. Out of these, 1490 publications were cited between 1–49 times, while 404 publications were cited between 50–99 times. Moreover, 184 publications were cited 100–149 times, 89 publications were cited 150–199 times, and finally, 220 publications were cited 200 times or more. Based on **Table 7**, the most frequently cited single article is the article titled "Wetland resources: Status, trends, ecosystem services, and restorability[53]."

Among published publications, **Table 7** shows the top ten most frequently cited publications. The most cited time is 1,292, and the least cited time is 243. For all 2,388 publications, the majority were published between 2016 and 2022. Researchers around the world have paid more attention to wetlands from multiple perspectives in recent years and contributed to wetland research. Those research outcomes provide valuable references for policymakers and scholars in the field of wetlands.

4. Discussion

Based on Section 3.1, we found that global wetland research publications have increased from double-digit to three-digit since 2016. This shows a clear upward trend overall, with clear stages of development. Specifically, from 2016 to 2022, the number of publications was 4.02 times and 2.61 times that of the first and second stages, respectively. This indicates that global wetland research is gaining momentum and increase in momentum. This trend is expected to continue in the future, as increasing awareness of the importance of wetlands causes scholars worldwide to become more and more interested in researching wetlands[54].

Based on Sections 3.2 and 3.4, our study discloses that among the 194 countries, the United States has contributed 32.51% of the published wetland articles, and their articles exert a more substantial influence. This is attributed to the fact that the United States possesses one of the most extensive wetlands worldwide. Wetlands are of vital significance for economic development. As ecological pressures and other factors escalate, wetlands in the United States are drawing enhanced attention from researchers. Additionally, wetland research in the United States was initiated earlier. Numerous globally ranked and prestigious universities or institutions are engaged in wetland research, which renders their articles highly influential and impact[55–57].

For wetland research, countries collaborate significantly. Sections 3.3 and 3.4 corroborate this. This collaboration highlights the importance of wetland restoration and protection as a global challenge. It's worth noting that the majority of publications on this topic are published in developed countries. This could be attributed to both objective and subjective factors. Objectively, developed countries dedicate more funding to scientific research, including on wetlands. Subjectively, developed countries tend to place higher value on the protection and management of wetland ecological environments. This makes wetland research an active research topic.

In addition, many journals included in the global wetland literature have low-impact factors, and most wetland publications are cited less frequently. There is a clear distinction between articles that are cited more frequently and those that are cited less frequently. Considering this finding, researchers should strengthen their research efforts in this field and explore it in depth. This could lead to breakthroughs in the field and attract more attention and funding. When comparing journal analysis with co-citation analysis, it is evident that the top co-citation journals have experienced a surge in citations. This suggests that the studies published in those journals are fundamental or have a strong theoretical basis. Additionally, these journals are also valuable sources of information and can serve as references for other journals.

It is interesting to note that wetland research is most concentrated in the United States, the People's Republic of China, Australia, Canada, and India, as depicted in Sections 3.5 and 3.7. While most of these institutions are universities, government departments also play a significant role in wetland research. For example, the US Fish and Wildlife Service.

Table 7. The top 10 publications with the most citations between 2002 and 2022.

No.	Author	Title	Cites	Cites per Year
1	Zedler, JB & Kercher, S (2005)	Wetland resources: Status, trends, ecosystem services, and restorability	1,292	68
2	Kirwan, ML & Megonigal, JP (2013)	Tidal wetland stability in the face of human impacts and sea-level rise	1,116	101.45
3	Bridgham et al. (2013)	Methane emissions from wetlands: biogeochemical, microbial, and modeling perspectives from local to global scales	706	64.18
4	Wu et al. (2015)	A review on the sustainability of constructed wetlands for wastewater treatment: Design and operation	626	69.56
5	Bridgham et al. (2006)	The carbon balance of North American wetlands	625	34.72
6	Zedler, JB & Kercher, S (2004)	Causes and consequences of invasive plants in wetlands: Opportunities, opportunists, and outcomes	605	30.25
7	Vymazal, J (2010)	Constructed Wetlands for Wastewater Treatment	387	27.64
8	Kayranli et al. (2010)	Carbon Storage and Fluxes within Freshwater Wetlands: a Critical Review	385	27.5
9	Vymazal, J (2014)	Constructed wetlands for treatment of industrial wastewaters: A review	348	34.8
10	Guo et al. (2017)	A Review of Wetland Remote Sensing	243	34.71

Additionally, most wetland research papers have at least two or more authors, reflecting scientific research's increasing complexity and interdisciplinarity. These days, collaborative networks between researchers in the same discipline or across disciplines are gradually emerging and forming around the world.

Section 3.9 discloses that highly cited articles in wetland research predominantly focus on fundamental themes such as ecosystem services, carbon storage balance, and wetland restoration, thereby establishing essential references for the domain. These subjects not only act as theoretical and practical cornerstones for wetland research but also align with broader environmental science and ecological disciplines, where citation analysis typically identifies such influential and foundational literature. Furthermore, as emphasized in Section 3.6, wetland research encompasses a diverse range of topics—from wetland establishment and carbon dynamics to climate change impacts and ecosystem rehabilitation—reflecting key domains and urgent issues within environmental science. The emphasis on wetland construction and restoration conforms to global climate action goals, highlighting the significance of wetland research in addressing crucial ecological challenges and promoting environmental sustainability.

According to Section 3.8, it is evident that funding support in wetland research is mainly concentrated in the U.S. and China, where governments and research institutions offer substantial grants to advance studies on wetland conservation and ecological restoration. The United States attaches significant importance to wetland studies. It has obvious advantages in the deployment of research forces and research funding support. China followed suit, with the Chinese government attaching increasing importance to wetland conservation and restoration since its accession to the Convention on Wetlands in 1992. It is evident that the government strongly supports wetland conservation and increases scientific research funding. Therefore, China has developed rapidly in wetland research. Moreover, scholars in North America and Europe also receive financial support from their respective governments or affiliated organizations. As a result, wetland research has become a global concern.

5. Limitations

This paper only used the Web of Science Core Collection database to collect wetlands research from 2002 to 2022. Since the literature was only obtained from the WOS, some were not retrieved and counted. Furthermore, the latest publication date was chosen as 2022. It should be noted that the data has limitations. Hopefully, future researchers will

be able to build upon this work and improve their findings.

6. Conclusions

This research paper conducts an analysis of the SCI-E database literature spanning from 2002 to 2022 through the utilization of CiteSpace, VOS viewer, and Origin software to delve into publishing institutions, co-citations, research hotspots, thematic directions, and the publishing activities of countries and institutions engaged in wetland research. The study discloses a pronounced concentration of research outputs among developed nations, especially the United States, propelled by considerable research capacity, funding, and well-established theoretical frameworks. Key institutions within these countries have considerably molded the methodologies and frameworks that steer global wetland research.

Furthermore, our analysis pinpoints major research hotspots and evolving themes within the domain, accentuating the adaptability of wetland studies in addressing emerging environmental and ecological challenges. Recently, there has been a notable escalation in wetland research interest among developing countries, most conspicuously in China, which mirrors a strategic governmental emphasis on wetland conservation and restoration. As these nations fortify their research capabilities and align with global environmental goals, the dynamics of wetland research are anticipated to diversify, creating opportunities for enhanced international collaboration and knowledge exchange. This study accentuates the necessity for sustained global cooperation to support and advance wetland preservation endeavors worldwide efficaciously.

Author contributions

J.C. carried out the research and wrote and revised the article. S.H.M.A. provided the theoretical framework, and reviewed, revised, and approved the article submission. N.K.A./L.M. provided feedback and ideas for improving the article.

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Informed Consent Statement

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Data Availability Statement

The datasets generated during and/ or analyzed during the current study are available from the corresponding author upon reasonable request.

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Conflict of interest

The authors agree that this research was conducted without any self-benefits or commercial or financial conflicts and declare the absence of conflicting interests with the funder.

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