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GLOBAL RESEARCH TREND IN WATER QUALITY: A BIBLIOMETRIC STUDY

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Abstract:

Water quality has become a critical universal concern due to increasing environmental pressures from industrial activities, urbanisation, agricultural practices and anthropogenic activities. As research in this field continues to expand, understanding the quantitative data- overview and emerging trends is essential. This bibliometric study presents a comprehensive analysis of scientific publications on water quality

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indexed in the Web of Science (WOS) database from 2000 to 2025. Bibliometric analysis was applied to explore the publication performance, language of document, document types, authorship, highly cited publication and well-known source titles. The science mapping on co-authorship between countries and keyword co-occurrence was conducted using VOSviewer, which helps to determine the influential country, major research theme and emerging topics. The result highlights a steady increase in water quality research over 25 years, which is due to the increasing concern about water quality, pollution and human health. Research articles constitute 82% of the document type, highlighting active scientific exploration and data production. The top research area in water quality is environmental science, with the Science of the Total Environment Journal demonstrating strong citation influence, indicating higher scholarly impact. Keyword analysis shows growth towards emerging trends such as advanced removal technologies, effective pollution detection, machine learning and data-driven approaches for water quality management. This bibliometric study provides a comprehensive overview of this field by examining its evolution, mapping the research structure, analysing publication trends, and identifying future research directions. It offers updated insights into collaboration networks and emerging data-driven approaches in the field. The findings of this study provide valuable insights for policymakers in supporting global initiatives such as the United Nations Sustainable Development Goal 6 (SDG 6), which aims to ensure clean water and sanitation for all.

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Keyword:

Bibliometric Analysis, Research trends, Science Mapping, Water Quality

Introduction

Water quality refers to the physical, chemical and biological characteristics of water to suit the specific usage of water for domestic, industrial and agriculture utilisation. The quality of water is critical to human health, the maintenance of the ecological balance, and the economic balance. Nevertheless, intensive urbanisation, industrial activities, and increased agricultural activities have played a critical role in the worsening of water quality, resulting in a massive change in chemical, physical, and biological properties of aquatic systems (Khanam et al., 2022). The industrial and municipal wastewater sources, the hospital effluents, the agricultural water runoff, the urban water runoff, the domestic water effluents, and the landfill leachates are major sources of water pollution (Morin-Crini et al., 2022). These sources introduce the following contaminants into the water systems such as suspended solids, toxic chemicals, organic and inorganic metals, and pharmaceutical residues. Water quality deterioration has therefore become one of the highest priorities in global environmental issues that has

implications for the risks to the health of the people and ecological harm. In the last two decades, the field of water pollution studies has also increased significantly due to the rise in awareness about new types of contaminants, including pharmaceuticals, endocrine-disrupting substances, heavy metals, nutrients and microplastics (Morin-Crini et al., 2022; J. Zhang et al., 2025). These contaminants disturb aquatic ecosystems by inducing bioaccumulation and biomagnification, causing destabilisation of food webs and reducing biodiversity. Other than this, endocrine-disrupting effects of the pollutants have also become a point of concern that has been linked to lowering male fertility and other negative health consequences (Bukhari et al., 2025; J. Zhang et al., 2025). The emergence of the new environmental monitoring technologies has enhanced detection and quantification of trace-level contaminants (Deivayanai et al., 2025; Nsibande & Forbes, 2025; Rashid & Rohit, 2025). Real-time monitoring and sensor-based systems, as well as remote sensing, are becoming significant to replace the previous approach to enhance surveillance and early warning systems. The modern technologies offer a greater competitive edge over the traditional approaches that are mainly time-consuming, labour-intensive, and the limited availability of real-time insights (Jain & Mitra, 2025). Remediation strategies have evolved from traditional treatment processes to advanced technologies such as membrane filtration, adsorption using engineered materials, advanced oxidation processes and nanotechnology-based solutions (Liu et al., 2024; Mishra et al., 2019; Ochando-Pulido et al., 2017). Because of the rapid growth of water quality research, there is an urgent need for a thorough assessment of knowledge structure and evolving trends.

Bibliometric analysis provides a larger and more quantitative method by mapping cumulative scientific knowledge and identifying evolutionary patterns within the subject area (Lazarides et al., 2025). It provides an in-depth overview of the research area, summing up the rising trend of publication and determining the seminal papers, authors and journals. Trends, pattern and the impact of research over time are revealed through the examination of academic literature in the field (Chen et al., 2023; Kumar, 2025). Despite the growing body of bibliometric studies on water quality and pollution, existing bibliometric analyses remains limited in terms of scope, methodological integration, and temporal coverage. A comprehensive and up-to-date bibliometric assessment is needed to provide a holistic understanding of the knowledge structure, research trends, and collaborative dynamics in water quality and pollution research. Therefore, this study addresses these gaps by offering comprehensive insight into research trend, collaboration network and emerging data driven direction in this field by providing an integrated analysis of publication performance, authorship influence, source titles, highly cited publications, and keyword-based thematic evolution, supported by science mapping techniques.

Literature Review

Water quality science is a highly important discipline that studies the physical, chemical, and biological properties of water to guarantee its safety and applicability to conditions for various uses such as drinking, industrial application, and ecosystems health (Ansell, 2004; Bozorg-Haddad et al., 2021). This research has expanded considerably over the past few decades in response to intensifying environmental pressures and public health concerns. The initial research efforts were mainly aimed at detecting and measuring traditional pollutants such as heavy metals, nutrients and organic contaminants, as well as development of analytical and monitoring methodologies which constituted the basis of environmental health risk assessment and regulatory standards. The role of water quality cannot be underestimated because it directly influences human health, environmental sustainability and economic development. With the

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intensification of the contaminant loads in the waters due to industrialization, rapid urbanization, and agricultural intensification research, focus has shifted to address more complex pollution patterns. Specifically, the new contaminants like pharmaceuticals, endocrine-disrupting compounds, personal care products and microplastics are now of great concern in terms of long-term ecological and human health effects (Alam et al., 2025) (Ravi et al., 2025). These substances pose significant challenges because they are persistent, have low-dose biologic effects and can be bioaccumulated and biomagnified (Murray, 2014; Negrete-Bolagay et al., 2021; Sinha et al., 2023).

The concern in water quality issue has become complicated due to the increased rate at which society and economies rapidly develop, as well as the fluctuation in climate and the escalated exploitation of resources. Rather than being limited to contamination events, water issues today involve interconnected concerns such as ecosystem degradation, resource scarcity, public health risks, and sustainability transitions. Overuse and pollution of water resources harm the ecosystem and public health. Issues such as salinity, groundwater depletion, and waterborne diseases are prevalent, and poor water management can restrict economic growth and development (Alam et al., 2025; Kar & Samal, 2022). This complexity has driven the expansion of multidisciplinary research integrating environmental science, engineering, public health, and policy. Technological innovation has further reshaped the field. Advanced materials, membrane technologies, and oxidation processes have enhanced remediation capabilities, while digital transformation has introduced real-time monitoring, modelling, and predictive analytics into water management systems (Birmod et al., 2021; Cevallos-Mendoza et al., 2025; Khosravi & Ashkpour, 2024; Vinod et al., 2026). The application of machine learning and artificial intelligence reflects a movement toward data-informed and adaptive environmental governance. AI and machine learning improve the accuracy of contamination detection, optimize water distribution, and enhance treatment processes. These technologies also support predictive maintenance and anomaly detection, contributing to overall system reliability and efficiency (Haddout & Kurniawan, 2026; Singh et al., 2025). These developments signal a transition from reactive pollution control to proactive and intelligent water quality management. The research focus broadened from isolated pollutant analysis to system level understanding, including pollutant transport mechanisms, cumulative ecological impacts, and watershed scale management. This shift reflects growing recognition that water quality problems are not only chemical in nature but also socio environmental challenges. Despite the rapid expansion of research outputs across these domains, the intellectual structure and evolution of this field remain dispersed across disciplines and journals. Understanding how thematic priorities, influential contributors, and research paradigms have evolved requires systematic evaluation. Bibliometric analysis provides a structured approach to synthesize this growing body of literature, identify dominant research clusters, and reveal emerging directions.

Methodology

The bibliometric analysis of water quality was conducted based on the research published in the Web of Science (WOS) database. The study was conducted based on a three-phased methodology comprising search query formulation, data extraction and data analysis as presented in Figure 1. The selection of the WOS database as the primary database in this study was mainly due to its large database covering high-quality peer-reviewed journal articles and its suitability for bibliometric data extraction (Hossain et al., 2022). The inclusion criteria were designed to ensure both relevance and comprehensive coverage of the research field. The first phase involved the retrieval of the bibliometric data on 21st January 2026 using Boolean search

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terms related to water quality, as shown in Table 1. The Boolean search string used was ("water quality" OR "water quality monitoring") AND ("pollution detection" OR "contaminant detection" OR "water pollution") AND ("removal" OR "treatment" OR "remediation") This is to ensure the selection of only relevant research.

Publications were included if they were indexed in the Web of Science database, published between 2000 and 2025, and comprised various document types such as research articles, review papers, and conference proceedings, while only retracted publications were excluded. In phase 2 the retrieved records were exported in tab-delimited file format for bibliometric processing. To generate a visual representation of these connections, the VOSviewer (1.6.20 version) software is used. The extracted information included publication year, author names, subject categories, document types, source titles, keywords, affiliations, and countries. In the third phase, the dataset was analysed to perform performance analysis and science mapping, enabling the identification of major research themes and emerging trends within the field. Performance analysis is primarily used to assess the contributions of key research constituents, including authors' citation impact, publication output, and institutional affiliations, while also incorporating additional information such as country of origin, publication year, source titles, and funding data. In contrast, science mapping focuses on exploring the relationships among research elements through co-authorship, citation, and keyword co-occurrence networks. Figure 2 outlines the PRISMA flow diagram of complete literature search and screening process used to identify relevant studies on this field. The literature search and selection process is detailed in Figure 2. An initial search of the Web of Science database yielded 2,716 records based on our defined keywords and search strings. Following the screening phase, 207 records were removed (e.g., retracted publications) this resulted in a final total of 2,509 records included for the bibliometric analysis.

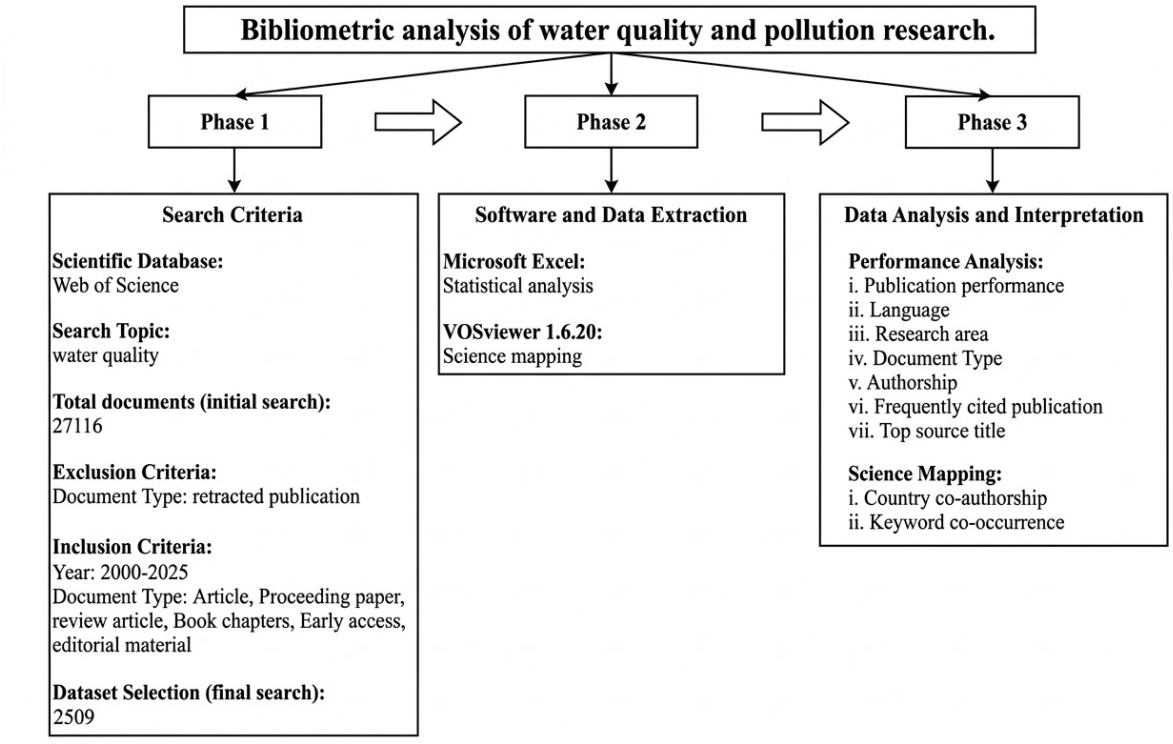

Figure 1: The Three-Phase Methodology

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Table 1: Search Query and Database Selection Criteria

Topic	Water Quality
Boolean search term	("water quality" OR "water quality monitoring") AND ("pollution detection" OR "contaminant detection" OR "water pollution") AND ("removal" OR "treatment" OR "remediation")
Timespan	2020 to 2025
Document types	Article, Proceeding paper, Review article, Book chapters, Early access, editorial material

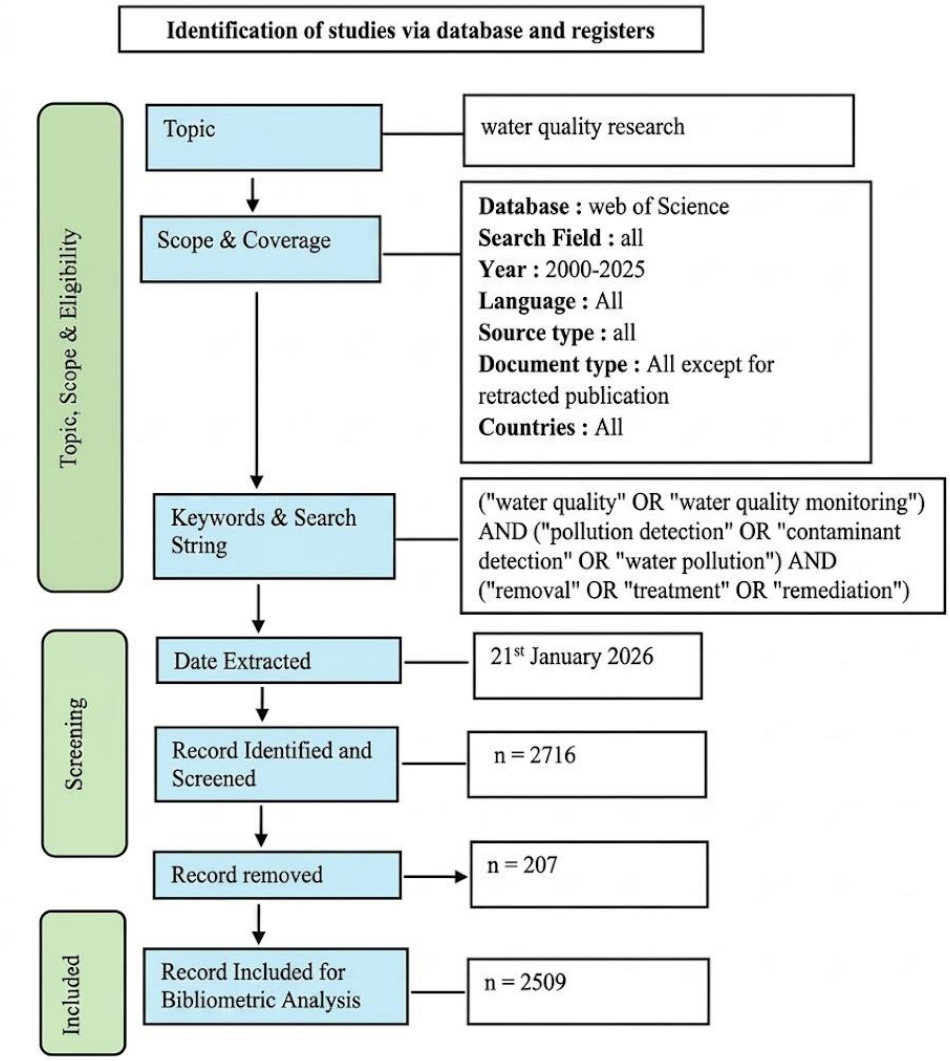

Figure 2: PRISMA Flow Diagram

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Result and Discussion

The result from the bibliometric analysis on the data retrieved from the Web of Science (WoS) database indicates the vast and diverse literature covering the area of water quality, pollution detection, removal strategies and ecological restoration. Based on the inclusion criteria, a total of 2509 relevant publications were retrieved as of 21st January 2026, comprising six types of documents reflecting the diverse forms of scientific communication in this research area as shown in Table 2. Almost all publications were published in the English language, covering 120 research area highlighting the multidisciplinary nature of the research domain. The research publication was published by 8417 authors worldwide, involving contributions from 113 countries. This research was funded by 2226 funding agencies, which indicates strong institutional and financial support. The publications have received over 61615 citations, indicating influential studies that shape research directions and contribute significantly to knowledge development in this field.

Table 2: Summary of Information from the Search of Water Quality Keyword in WOS

Item	Productivity
Total Documents	2509
Document types	6
Language	9
Research area	120
Countries	113
Authors	8417
Funding agencies	2226
Total overall citation	61615

Publication Performance

Figure 3 illustrates the number of publications output and citation performance in the field of water quality observed from 2000 to 2025. The trend in this research area shows an increasing trend in publication output and citation, indicating the increasing concern about water quality among researchers and society (Mingaleva et al., 2023). During year 2000 to 2008 less than 30 documents were published with minimal citation count, reflecting the new emergence of research in water quality with a limited study scope and low academic visibility. However, a steady increase was observed from 2009 onwards, with publication output rising from approximately 40 articles in 2010 to over 130 publications by 2015. This growth accelerated further after 2018, with publication output exceeding 200 articles annually and peaking at approximately 250–260 publications around 2021–2022. Overall, the number of publications increased more than threefold compared to the early years, indicating substantial expansion in research activity. This era is characterised by an exponential growth in research due to the increased awareness on environment and the tremendous advancements in sensor technologies, real-time monitoring systems, tighter environmental laws and the advent of new treatment and removal processes (Batra et al., 2025; Vedrtnam et al., 2025; Wu et al., 2024). The increasing integration of interdisciplinary approaches further contributed to this expansion, with citation count increasing significantly, suggesting that research published during these years attained high academic impact. The combined trends of increasing publication volume and rapidly rising citations indicate that research on water quality monitoring and pollution remediation

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has evolved into a mature and influential research field, making it well-suited for bibliometric analysis and further science mapping (Basu & Dasgupta, 2021).

The parallel growth in both publications and citations suggests not only an increase in research output but also an enhancement in research quality and influence. This trend reflects growing global awareness of water pollution issues, stricter environmental regulations, and increased research investment in sustainable water management and advanced monitoring technologies. The sharp rise in recent years also indicates the emergence of new research directions, particularly data-driven approaches and interdisciplinary solutions to address complex water quality challenge

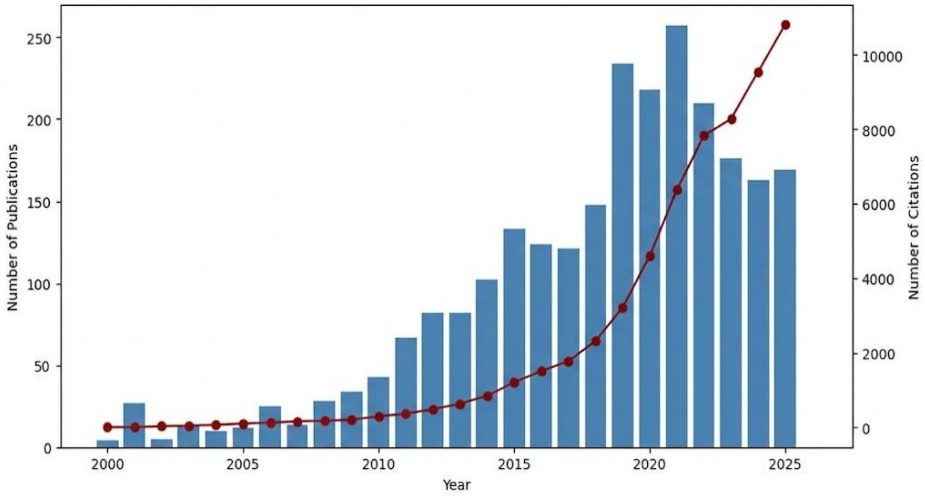

Figure 3: Yearly Distribution of Publication and Citation Related to Water Quality

Language of Documents and Research Area

The English language was identified as the main language with 2483 (99%) documents published in English, as shown in Table 3. The dominance of the English language indicates that English was widely used to disseminate information and new knowledge on water quality among the international scientific community, particularly in interdisciplinary research areas such as water quality monitoring, pollution detection, and remediation strategies (Amano & Gonza, 2016). 8 publications were published in Spanish, 6 publications in Portuguese, 4 publications in Chinese and while the remaining languages in Polish, Russian, Turkish, Czech and Korean each contributed to only one or two documents. The dominance of the English language in journal publication is to optimise international visibility and impact (Huang et al., 2025).

Table 3: Language of Document

Language	Total Documents
English	2483
Spanish	8
Portuguese	6
Chinese	4
Polish	2
Russian	2

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Turkish	2
Czech	1
Korean	1

Table 4 demonstrate top 10 interdisciplinary research areas on water quality. Environmental Science and Technology, with 1567 publications leads the ranking, suggesting that environmental assessment and pollution control are the primary focus of this research area. The next research areas are the field of Engineering 814 publications and Water Resources 779 publications, pointing out the significance of the technological development, system design, and water management in solving water quality problems. The field is primarily driven by environmental and engineering perspectives, and its dominance reflects the critical role of environmental monitoring, pollution control, and technological solutions in addressing water quality issues. Science, Technology and Other Topics (188), Marine Freshwater Biology (119), Geology (110) and Chemistry (108) contribute to a smaller but meaningful share, revealing the contributions from ecosystem studies, geochemical processes, pollutants behaviour and analytical methods. The link between water quality and human health was covered in Public, Environmental and Occupational Health with 76 publications. Material Science and Agriculture (25) highlight concerns related to the issues of agricultural pollution and the development of materials that will facilitate the elimination of the pollutants. The distribution of the research area proves that the study of water quality has a multidisciplinary nature and combines the environmental, engineering, chemical, and health-related approaches to solving complex tasks related to water pollution (Gowri et al., 2024; Locke, 2025; Muniz & Oliveira-Filho, 2023). The cumulative count of publications across research areas exceeds the total number of documents, as individual publications may be assigned to multiple subject categories within the Web of Science database. This reflects the interdisciplinary nature of the research landscape which spans multiple fields such as environmental science, engineering, and water resources.

Table 4: Top 10 Research Areas on Water Quality

Research Area	Total Documents
Environmental Sciences	1576
Engineering	814
Water Resources	779
Science Technology Other Topics	188
Marine Freshwater Biology	119
Geology	110
Chemistry	108
Public Environment Occupational Health	76
Material Science	25
Agriculture	25

Document Type

Table 5 summarised the document types published in the water quality area. Research articles account for most of the publications with 2158 publications (82.28%), followed by proceeding paper with 265 publications (10.17%), review articles with 145 publications (5.56%), book chapters with 20 publications (0.77%), early access with 10 publications (0.38%) and editorial

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material with 7 publications (0.27%). The predominance of research article demonstrate that the field is largely driven by original empirical studies with new findings and contributions to the water quality area. Proceeding papers usually represent preliminary research findings that are disseminated through academic conferences where researchers share innovative ideas and provide opportunities for future collaboration (Sharpe, 2024). Review articles at publications 5.56%, indicates a relatively smaller proportion of synthesis studies, which highlights the need for more comprehensive reviews to consolidate existing knowledge and guide future research. There is a clear need to publish more high-quality and comprehensive review papers in this area, given the rapid expansion, technological diversity and interdisciplinary nature of this field. The review paper will allow researchers to find significant findings, research gap and provide clear directions for future research. A small proportion of the document was published as book chapters, early access paper and editorial materials emphasising journal articles to facilitate knowledge transfer within this field.

Table 5: Document Type Distribution

Document Types	Total Documents	% (N=2605)
Article	2158	82.28
Proceeding Paper	265	10.17
Review Article	145	5.56
Book Chapters	20	0.77
Early Acess	10	0.38
Editorial Material	7	0.27

Authorship

Table 6 presents the most prolific authors in the field, where it is measured by the number of publications. Yang Min leads the list with 17 publications, followed by Zhang Tuqiau, Zheng Binghui, An Shuqing, Wang Hua and Wang Shenrui with 16 publications. Table 7 shows the most influential authors in the field of water quality, where it is measured using citation counts obtained from WOS. Yang Min emerges as the most influential author with 894 citations, followed by Wu Zaoshi with 724 citations, Gao Junfeng with 686 citations and Cai Yonjiu with 683 citations. Yang Min appears as the most prolific and influential authors revealing high productivity and influence among the research community. Weng Shengrui and Gao Junfeng demonstrate the same pattern as Yang Min, which suggests that these authors contribute as the key role in shaping the development of research in this area. The analysis revealed that these authors are primarily affiliated with leading Chinese research institutions, highlighting China's dominant contribution to this research area (Yuan et al., 2022). It is stated that some of the authors are only observed in the prolific list, whereas others are observed in the influential list, indicating that the scholarly influence is not just dependent on the volume of publications but also highly dependent on the importance, novelty, and relevance of individual research outputs (Aksnes et al., 2019; Pérez-Campdesuñer et al., 2025).

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Table 6: Most Prolific Authors

Authors	Affiliations	Document
Yang Min	University of Chinese Academy of Sciences	17
Zhang Tuqiao	Zhejiang University	16
Zheng Binghui	Chinese Research Academy of Environmental Science	16
An Shuqing	Nanjing University	16
Wang Hua	Hohai University	16
Wang Shengrui	Beijing Normal University	16
Pang yong	Chinese Academy of Forestry	15
Yu Jianwei	Chinese Academy of Science	14
Gao Junfeng	Chinese Academy of Sciences	13
Meng Wei	Ocean University of China	12
Wu Zhenbin	Chinese Academy of Science	12
Giesy John	University of Saskatchewan	12

Table 7: Most Prolific Authors

Authors	Affiliations	Citations
Yang Min	University of Chinese Academy of Sciences	894
Wu Zaoshi	Chinese Academy of Science	724
Gao Junfeng	Chinese Academy of Sciences	686
Cai Yongjiu	Chinese Academy of Science	683
Zhang Yuan	Chinese Research Academy of Environmental Sciences	680
Wang Shengrui	Beijing Normal University	629
Deng Jianchai	Chinese Academy of Sciences	627
Shi Baoyou	Chinese Academy of Science	552
Meng Wei	Ocean University of China	548
Qu Jiuhui	Chinese Academy of Science	547

The Most Cited Publication

The top 10 most cited publication is highlighted in Table 8. The most cited publications measure the impact or influence of a publication, which indicates that this work is widely recognised and frequently referenced by the scientific community. The most cited publication is Global Water Pollution and Human Health by (Schwarzenbach et al., 2010), which indicates the strong influence due to its interdisciplinary nature and focused research area on water pollution and its association with human health. Most of the highly cited articles in Table 8 discuss pollutants identification and management and the development of efficient removal technologies, particularly for heavy metals and common contaminants in water systems (Khaligh & Johan, 2018; Vidu et al., 2020). A review paper, such as “Effects of Water Pollution on Human Health and Disease Heterogeneity: A Review”, shows a high citation count as it is often cited by researchers due to its comprehensive discussion on types of pollutants, their environmental behaviour, associated risks, and available removal technologies. The analysis of the top 10 most cited publications reveals an emerging trend from traditional conventional methods towards high technology and modern approaches such as the application of nanotechnology and machine learning. The implementation of high technology improves

pollution detection and effective removal technologies to address the global water challenge as a collaborative effort among researchers (Altuner et al., 2025; Kumar & Goyal, 2025). The technological advancement needs to be prioritised in line with the rapid progress of technology to address the critical research area on water technology, highlighting the growing emphasis on sustainable and innovative solutions for water pollution control. The identified research trends and emerging themes can support policy development aligned with global frameworks such as the United Nations Sustainable Development Goal 6 (SDG 6) and Guidelines for Drinking Water Quality established by the World Health Organization, in improving monitoring, pollution control, and sustainable water management strategies.

Table 8: Most Cited Publication

Authors	Article Title	Affiliations	Citation	Average Citation Per Year
(Schwarzenbach, Rene P. et al., 2010)	Global Water Pollution and Human Health	Institute of Biogeochemistry and Pollutants Dynamics	1492	87.76
(Yu Chaoqing et al., 2019)	Managing nitrogen to restore water quality in China	Tsinghua University	927	115.88
(Zamora Ledezma et al.,2021)	Heavy metal water pollution: A fresh look about hazards, novel and conventional remediation methods	UCAM Catholic University of Mucia	842	140.33
(Saravanan A et al., 2021)	Effective water/wastewater treatment methodologies for toxic pollutants removal: Processes and applications towards sustainable development	Sri Sivasubramaniya Nadar College of Engineering	838	139.67
(Xu Xiaochang et al., 2022)	Effects of Water Pollution on Human Health and Disease Heterogeneity: A Review	Huzhou University	674	134.80
Qu Xiaolei et al.,2013	Nanotechnology for a Safe and Sustainable Water Supply: Enabling Integrated Water Treatment and Reuse	Rice University	523	37.76
(Rathi. B. Senthil et al., 2021)	Critical review on hazardous pollutants in water environment:	St Joseph's College of Engineering	510	85.00

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	Occurrence, monitoring, fate, removal technologies and risk assessment			
(Saleh. Iman A. et al., 2020)	Removal of pesticides from water and wastewater: Chemical, physical and biological treatment approaches	Qatar University	507	72.43
(Wu, Zhaoshi etal., 2018)	Assessing river water quality using water quality index in Lake Taihu Basin, China	Chinese Academy of Sciences	476	52.89
(Zhu Mengyuan et al., 2022)	A review of the application of machine learning in water quality evaluation	Nanjing University	384	76.80

Publication by Source Title

Table 9 summarises the publication output by source title on water quality and pollution study. The result shows that the research was published in a high impact interdisciplinary journals focusing on water quality monitoring, pollution and its management. Water with 122 publications leads reflecting its broad scope covering water science and technology, including the ecology and management of water resources. Science of the Total Environment followed closely with 121 publications and demonstrates a significantly higher citation impact of 5640 citations, revealing its high impact, integrative and multi-disciplinary studies on the total environment. The open access format for selected articles allows free and immediate online access, to readers that enhances research visibility and dissemination. The list is followed by Desalination and Water Treatment with 116 publications and Environmental Science and Pollution Research with 111 publications. The study published in the journal listed in Table 9 gives greater attention to environmental monitoring, analytical method development, and pollution risk assessment related to new contaminants with novel remediation technologies. The journals emphasise pollutants in water and its management through pollution control by designing and implementing monitoring systems and risk assessment methods.

The journal with high citations includes Environmental Science and Pollution Research with 2179 citations, Water Research with 2123 citations and Environmental Pollution with 2006 citations, mainly related to its scope of addressing water quality, pollution and environmental stressors with emphasis on their impacts on the ecosystem and human health. 116 documents were published in Desalination and Water Treatment, which received 920 citations mainly focused on desalination technology, water reuse, integrated water management, wastewater and energy considerations. The highly cited journals depict changing trends in the remediation method, applying superior engineering procedures to address and improve the water quality challenges.

At the same time, Desalination and Water Treatment and Water Science and Technology emphasise the significance of remediation and treatment technologies, in terms of wastewater treatment, desalination, adsorption systems, and resource recovery. The journal Water

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Research, Environmental Pollution, and Ecological Engineering exhibits fewer publications but higher citation reflecting a certain inclination to innovation-based research with a focus on mechanistic insight, sophisticated utilisation of advancements in AI, IoT, nanotechnology, and hybrid systems (Altuner et al., 2025; Kumar & Goyal, 2025).

Table 9: Top 10 Publications by Source Title

Journal Title	Number of Publications	Citation	Subject Category of The Journal
Water	122	1687	Water science and technology and management of water resources and ecology
Science of the Total Environment	121	5640	Environmental chemistry, pollution, waste management disposal and environmental engineering,
Desalination and Water Treatment	116	920	Desalination technology, environment, integrated water management, water reuse, wastewater and energy considerations,
Environmental Science and Pollution Research	111	2179	Environmental science and related subjects with emphasis on chemical and environmental stressors
Environmental Monitoring and Assessment	63	1109	Design and implementation of monitoring systems and pollution risk assessment methods.
Water Science and Technology	56	796	Wastewater management, treatment, and resource recovery.
Environmental Pollution	44	2006	Pollution in the environment and its effects on ecosystems and human health.
Journal of Environmental Management	44	1618	Advancing the understanding and application of environmental management practices
Ecological Engineering	43	1720	Designing, monitoring, or restoring ecosystems, and serves as a bridge between the fields of ecology and engineering
Water Research	42	2123	Science and technology of the anthropogenic water cycle, water quality, and its management

Co-Authorship Between Countries

VOSviewer is an essential tool for a visual representation of the publication landscape within the scientific landscape of water studies. The mapping techniques in bibliometric analysis facilitate the identification of collaboration patterns, research clusters, and temporal publication trends (Li & Wei, 2022). The co-authorship analysis between countries was conducted to explore and identify the leading contributors, international research collaborations and emerging participants in this area. The network and overlay visualisation mapping offer valuable insight into scientific collaborations and the development of research fields over time (Indriati et al., 2024; Purwanto et al., 2025). The analysis of co-authorship between countries

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was conducted with a minimum threshold of 5 documents per country, and the result revealed 67 countries in the science mapping. Figure 4 illustrates the co-authorship network visualisation which reveals the global collaboration between countries. The size of the node indicates the number of publications, while the connecting line thickness reflects the strength of the collaboration. The colour cluster demonstrates closer collaborative relationships between countries. The network visualisation shows that China occupies a dominant and central position in the network, with the largest node size and the highest number of collaborative links. This indicates that China emerges as a leading contributor and serves as a major hub of international collaboration, highlighting its extensive global research partnerships with countries like India, Australia, South Korea, Germany and Malaysia. China's central position suggests that it serves as a link between Western Asia and developing countries. Its dominant position reflects its recent strategic globalisation plans and expanding research capabilities. The USA and England stand out as influential secondary hubs. The USA exhibits strong linkages with Asian, European and Middle Eastern countries, bridging the knowledge and research expertise between these countries. The USA has been recognised as a major hub for water quality research domain due to its longstanding research capacity and institutional influence in environmental science and water pollution studies. England exhibits a strong collaboration with European countries, forming a cluster with Germany, Italy, France, and the Netherlands, while also maintaining strong research collaboration with countries from other continents. India emerged rapidly as one of the main contributors to in this field with increasing collaborative strength. Its strong connection with countries like China and the USA implies a growing role in international collaboration and research knowledge in water quality.

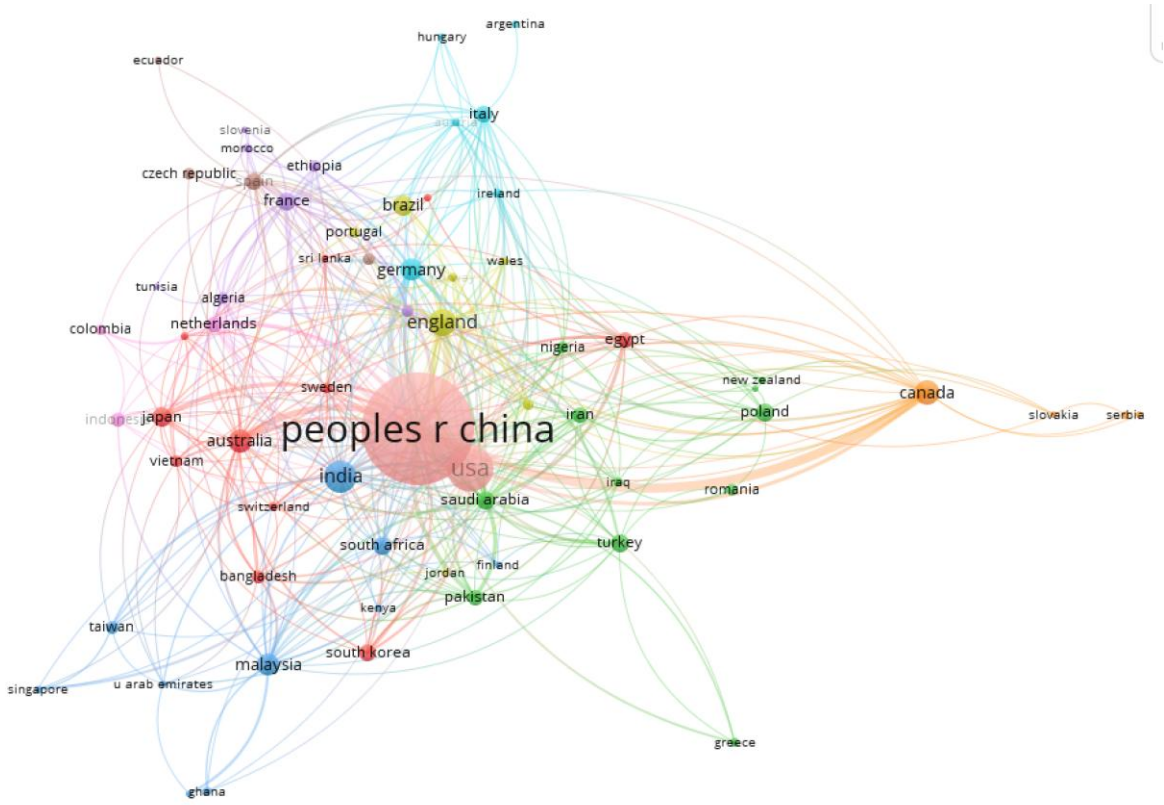

Figure 4: Network Visualisation of the Co-authorship Between Countries.

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Figure 5 provides an overview of the overlay visualisation on co-authorship between countries that provides insight into the temporal evolution network by mapping average publication years of each country. The temporal progression was represented by node colour, where earlier contributions (2016-2018) were represented by blue-green tones and yellow tones for recent research activities (2021-2022). The overlay visualisation allows better analysis and identification of pioneers, emerging contributors and shifts in global research participation (R. Zhang & Wang, 2025). Early research activity was largely focused among established scientific nations, including the USA, China, England, Italy, Canada, and several Western European countries, suggesting their foundational role during the early development of this research area. The countries' involvement in the initial stage of research development is further strengthened by their well-established environmental monitoring frameworks, strong funding and advanced research infrastructure. The lighter yellow tones depict the emergence of developing countries such as India, Malaysia, Pakistan and Saudi Arabia in this area. In recent years, these countries have increased their research publication rate, which indicates that it has improved their research capacity, allocated more funding and established a stronger international scientific network. China maintains its central position as evidenced by its relatively recent publication year, which suggests active international collaboration and productivity. China's dual position as an early contributor and primary driver of present research output is shown by its persistent presence across the temporal gradient.

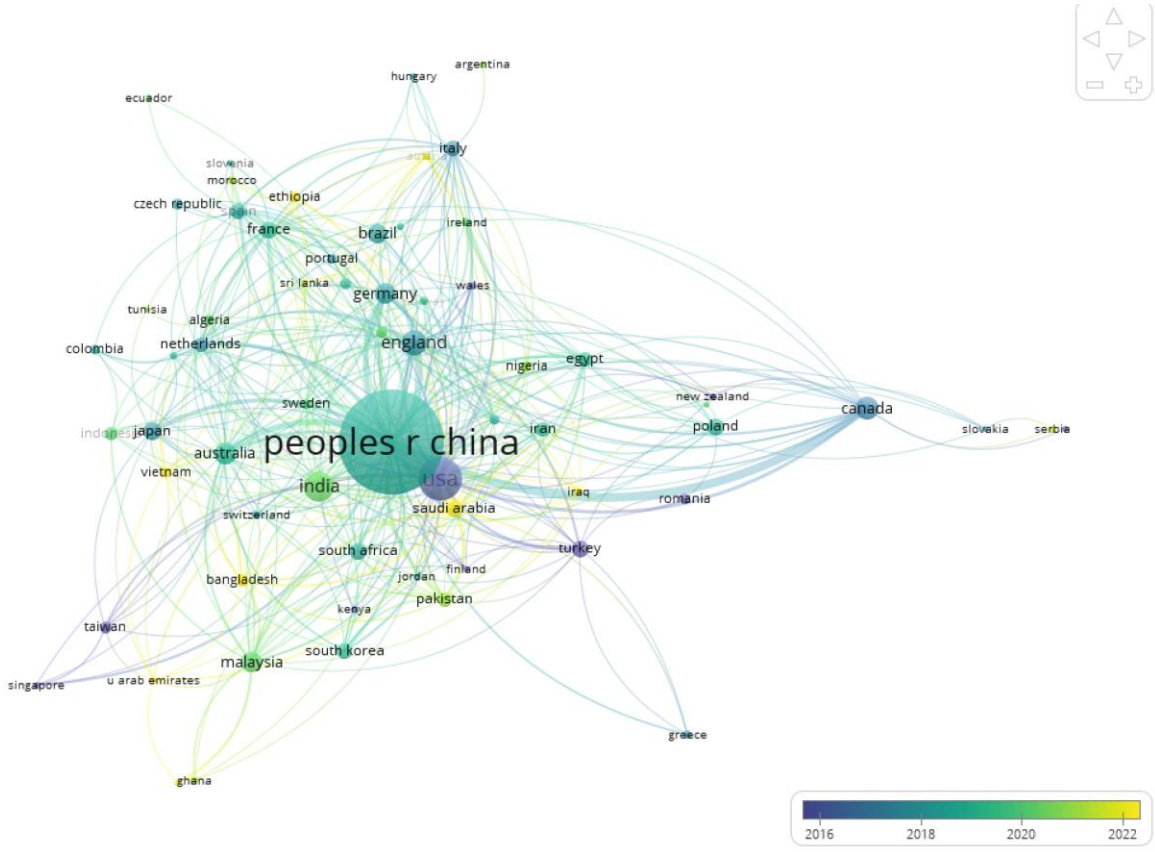

Figure 5: Overlay Visualisation the Co-authorship Between Countries.

Analysing Co-occurrence of Keywords

Author keyword co-occurrence analysis was conducted to identify the core themes that reflect the primary focus of the published articles (Molina-Collado et al., 2021). In the network

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visualisation, each node and its corresponding label represent a specific keyword. The size of the node indicates the frequency of occurrence, whereas the colour denotes the cluster or thematic grouping to which the keyword belongs (Duvvuru et al., 2012; Salma & Prakasan, 2025). Spatial distance between nodes reflects the strength of their relationship, with shorter distances indicating stronger co-occurrence and thematic similarity. Keywords with higher frequencies appear as larger nodes within the network (Yan & Kui, 2023). Based on the minimum occurrence threshold, 296 keywords were included in the network mapping. The network visualization in Figure 6 reveals a dense and highly interconnected thematic structure, indicating strong conceptual integration across pollution assessment, treatment technologies, nutrient dynamics, and environmental management. As shown in Table 10 "water quality" is the most frequently occurring keyword (416 occurrences), confirming its role as the central research focus. Its high total link strength (TLS = 66) reflects strong interconnections with multiple thematic areas, reinforcing its position as the conceptual core of the field.

Interestingly, "water pollution" demonstrates the second-highest occurrence (352) but exhibits the highest total link strength (TLS = 579). This suggests that while "water quality" represents the central theme, "water pollution" functions as the primary operational focus, strongly linked with other specific research topics such as eutrophication, heavy metals, and wastewater treatment. The high TLS indicates that pollution-related studies form the structural backbone of the research network. Among specific environmental concerns, "eutrophication" (91 occurrences, TLS = 185) and nutrient-related keywords including "phosphorus" (49, TLS = 121) and "nitrogen" (44, TLS = 110) demonstrate substantial prominence. Their strong linkages indicate sustained scientific attention toward nutrient enrichment and its ecological consequences. This reflects the persistent global challenge of nutrient driven water quality degradation, particularly in freshwater and coastal ecosystems. Similarly, "heavy metals" (62 occurrences, TLS = 122) remains a major contaminant-focused theme. Its strong connections with health risk assessment and contamination-related terms in the network visualization suggest continued concern regarding toxic metal exposure and environmental risk.

Table 10: Top 10 Authors Keyword

Keywords	Occurrence	Total link strength
Water quality	416	66
Water pollution	352	579
Eutrophication	91	185
Heavy metals	62	122
Wastewater treatment	58	104
Nutrients	56	122
Drinking water	55	75
Wastewater	51	111
Phosphorus	49	121
Nitrogen	44	110

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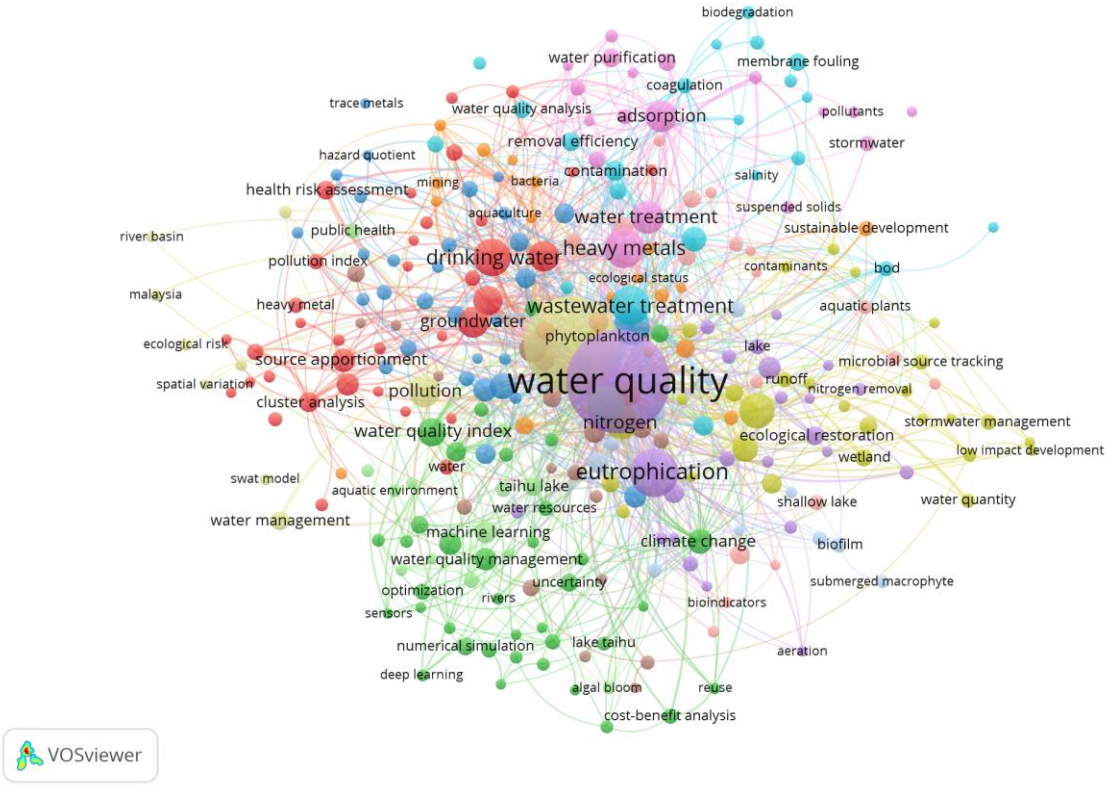

Figure 6: Network Visualisation of The Co-occurrence of Keywords.

The temporal evolution of the research theme based on the authors' keywords is shown in the overlay visualisation map in Figure 7. The earlier research theme was more focused on the sources of pollution and pollutant detection; however, recent contributions significantly shift towards integrated and sustainability-focused research themes, including advanced treatment processes, ecosystem restoration approaches and machine learning applications. The emergence of modelling and artificial intelligence tools (e.g., machine learning, numerical simulation) in the broader network reflects methodological modernisation and high technology application within the field.

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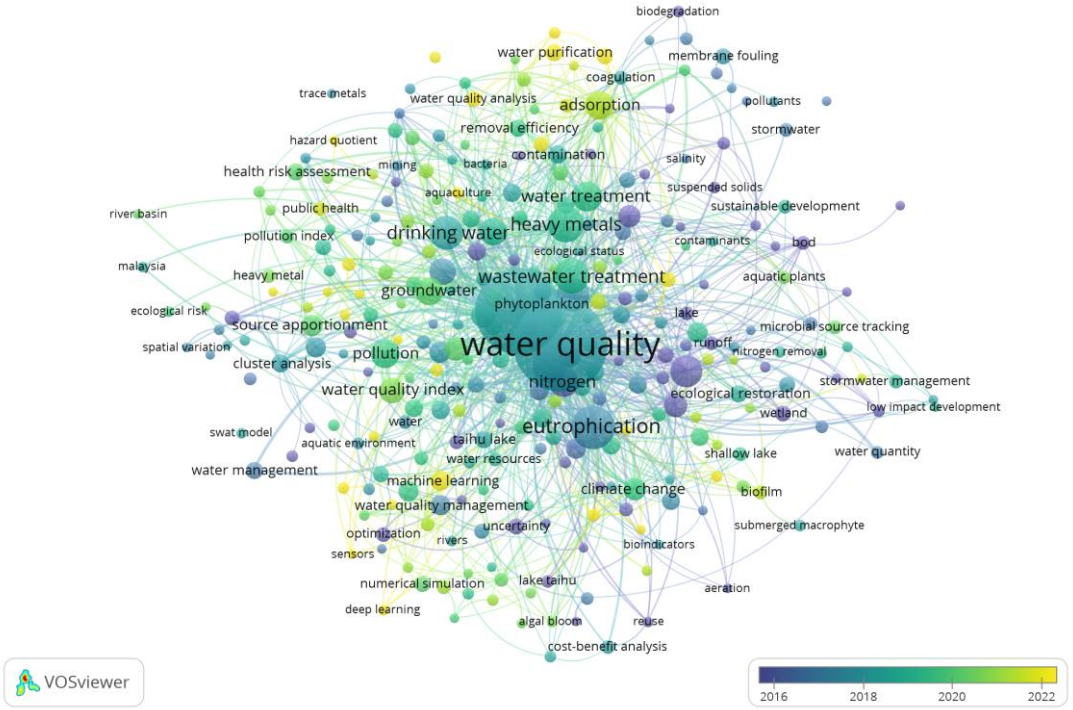

Figure 7: Overlay Visualisation of The Co-occurrence of Keywords.

Conclusion

This study contributes to the literature by providing an up-to-date bibliometric analysis, integrating science mapping techniques, and highlighting emerging trends such as data-driven approaches and global collaboration pattern. It offers an organised overview of publication performance, language, document type, authorship patterns, influential journals and highly cited publications. The co-authorship and keyword occurrence were analysed using science mapping in VOSviewer. Findings reveal a steady growth in scientific publication output from 2000 to 2025. This reflects an increasing global awareness on the topic of water quality, covering water pollution, water remediation, environmental protection and human health. Most of the publication type is research article which highlight the empirical and experimental nature of the research area. The authorship analysis reveals several authors with high productivity and high citation impact, which emphasise the collaborative and interdisciplinary nature of the field. The analysis of highly cited articles revealed that "Global Water Pollution" stands out as a foundational pillar with 1492 citations. The source title analysis highlights a discrepancy between productivity and actual research impact. While Water maintains the highest publication output, Science of the Environment indicate a greater impact when measured by citation count. Water Research and Environmental Pollution exhibit a high citation count, which implies that the research scope and depth may contribute to greater scholarly impact. China appears to be one of the main contributors in this area as it occupies a dominant and central position in the network. Strong linkage with countries like Australia, India and South Korea demonstrates knowledge sharing and knowledge transfer between researchers. A clear shift from conventional monitoring towards more advanced theme was observed based on the keyword analysis. While research on water quality mainly focused on detecting pollutants, recent studies focused more on removal technology, ecological restoration and safety of human health. The direction of water quality studies has been fundamentally shaped by technological

advancement using high technology applications. The emergence of machine learning has opened a new area defined by automated detection and complex data synthesis. This bibliometric study indicates that this study area is important and has evolved significantly with the current digital age and technological innovation. The insight provided by mapping the knowledge structure and identifying emerging research directions provides a strategic path for frontliners on water quality and support policy development aligned with global initiatives of SDG 6 and WHO guidelines. Future research is expected to embrace the advanced analytical tools alongside sustainable remediation to ensure long term sustainability and continued safety of public health.

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Ethics Statement: This study did not involve any human participants, animals, or sensitive data requiring ethical approval. The authors confirm that the research was conducted in accordance with accepted academic integrity and ethical publishing standards.

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