

AI and Smart Water Treatment: A Bibliometric Perspective on Emerging Technologies in Water Purification

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ABSTRACT

Artificial Intelligence (AI) is redefining water treatment systems, enabling smarter, more efficient, and sustainable solutions. This work employs bibliometric approaches to explore trends, advancements, and future directions in the integration of AI technologies into water purification systems. By analyzing 350 articles from 2010 to March 2025 using VOSviewer software, the study highlights AI's role in optimizing processes such as contaminant detection, filtration efficiency, and predictive maintenance. Key challenges include cost, data availability, and scalability. The research identifies influential authors, institutions, and countries driving AI innovations in water treatment. Emerging themes like machine learning (ML), Internet of Things (IoT), and real-time monitoring are explored, with techniques such as neural networks and decision tree algorithms being applied to improve water treatment efficacy. Additionally, the study addresses gaps in interdisciplinary collaboration and the need for AI-driven models tailored to diverse water treatment scenarios. It emphasizes the importance of sustainable practices, the development of eco-friendly treatment methods, and the transformative potential of advanced computational techniques in addressing global water challenges. By providing a comprehensive overview of global research trends, this analysis serves as a valuable resource for researchers, engineers, and policymakers, underscoring the vital role of AI in fostering smarter, more resilient water purification systems.

1. Introduction

The growing demand for potable and safe water, motivated by quick urban expansion, industrialization, and climate change, has underscored the importance of innovative and efficient water treatment technologies[1]. Water purification is critical for addressing the global challenges of water scarcity and contamination, ensuring access to potable water for human consumption, agriculture, and industrial use[2], [3]. Traditional water treatment methods, while effective, often face limitations such as high operational costs, energy consumption, and difficulty in adapting to diverse water quality parameters[4]–[6]. In response, Artificial Intelligence (AI) has developed into a game-changing technology, enabling the development of smart, adaptive, and efficient water treatment systems[7]–[9]. By harnessing AI's capacity to analyse extensive datasets, recognize intricate patterns, and enhance processes, researchers and engineers are transforming water purification methods to attain sustainability, cost efficiency, and resilience.[4], [10], [11]

AI-enabled water treatment solutions utilize advanced computational strategies to address essential challenges in the water sector. From real-time monitoring of water quality parameters to predictive maintenance of treatment plants,

AI has demonstrated its ability to improve decision-making, enhance system efficiency, and reduce resource wastage[12], [13]. Key applications include contaminant detection, filtration process optimization, membrane fouling prediction, and chemical dosing control. Machine learning (ML), a subset of AI, plays a pivotal role in these advancements, with algorithms such as artificial neural networks (ANNs), support vector machines (SVMs), random forests, and deep learning models offering unparalleled capabilities in modelling complex processes and predicting outcomes[13]–[16]. These approaches reduce reliance on extensive physical experimentation, enabling faster and more accurate decision-making while addressing the variability and complexity of water treatment scenarios[1], [10], [17], [18].

Despite the significant impact AI could have, several challenges persist in its application to water purification. These include the need for high-quality, comprehensive datasets, the complexity of integrating AI models with existing water treatment infrastructure, and the scalability of AI-driven solutions across diverse geographic and socioeconomic contexts[19]–[23]. Additionally, the heterogeneity of water sources, contaminants, and treatment technologies requires AI models to be highly adaptive and robust, capable of providing reliable performance across varying conditions. Another critical issue is the lack of interdisciplinary collaboration between water science experts, AI researchers, and policymakers, which often hinders the development and adoption of practical AI-driven solutions in the water sector[24]–[28].

In addition to the transformative role of artificial intelligence, other emerging technologies such as the Internet of Things (IoT), cloud computing, and big data analytics significantly contribute to advancing smart water treatment systems by enabling continuous monitoring and improved resource management[7], [29]–[32]. The environmental and economic benefits of AI-driven water purification are notable, as these technologies reduce energy consumption and chemical usage, thus minimizing the environmental footprint while enhancing cost efficiency[33], [34]. However, the increased reliance on interconnected smart systems also raises critical challenges related to cybersecurity and data privacy, necessitating robust safeguards to ensure system reliability[35]–[38]. Furthermore, the growing impacts of climate change intensify pressure on water resources, making adaptable and resilient water treatment solutions essential. AI's capacity to analyze climate data and predict future demands equips systems to better respond to these challenges[39], [40]. Finally, the widespread adoption of AI in the water sector depends heavily on supportive policy frameworks and institutional backing, including regulations, funding, and capacity building, which collectively facilitate innovation and practical implementation of these advanced technologies.

To better understand the progress, trends, and future directions in this rapidly evolving field, bibliometric analysis offers a powerful tool for analysing the research landscape[41]–[43]. Bibliometric analysis enables a systematic evaluation of scholarly publications, identifying influential authors, institutions, and countries, as well as uncovering emerging research themes and knowledge gaps. By mapping the evolution of AI applications in water treatment, this research provides significant insights into the international research ecosystem and underscores the key players and collaborations that drive innovation in this sector[44]–[46].

This study conducts a bibliometric analysis of 1,200 scholarly articles published between 2010 and March 2025, focusing on the application of AI and smart technologies in water purification. Using data retrieved from the Scopus database, the analysis leverages VOSviewer software to visualize relationships among authors, institutions, keywords, and research themes. The findings reveal the growing adoption of AI in areas such as real-time water quality monitoring, predictive modelling, and process optimization. Furthermore, the analysis highlights the integration of emerging technologies like the Internet of Things (IoT), big data analytics, and blockchain with AI systems, offering new possibilities for creating holistic and sustainable water treatment solutions. By addressing research gaps and providing a comprehensive overview of global trends, this study aims to guide researchers, engineers, and policymakers in advancing smart water treatment systems. It emphasizes the importance of interdisciplinary collaboration and the adoption of AI-driven approaches to tackle the challenges of water scarcity and pollution. Ultimately, this bibliometric perspective highlights the transformative potential of AI in revolutionizing water purification practices and contributing to a sustainable and water-secure future.

2. Methodology

This study aims to analyse research on the application of artificial intelligence (AI) in smart water treatment systems through a bibliometric approach, highlighting key trends, existing research gaps, influential sources, leading institutions, notable authors, and contributing countries. Additionally, it seeks to provide strategic insights to guide future research directions and foster the development of innovative, AI-driven water purification technologies. The methodology is structured into three main stages: data collection and selection, identification of a suitable scientific mapping method, and application of bibliometric analysis techniques to uncover critical patterns and relationships within the research landscape. This review examines “AI and Smart Water Treatment: A Bibliometric Perspective on Emerging Technologies in Water Purification” from 2010 to 2025. The bibliometric analysis method was employed to achieve this objective. Bibliometric analysis involves tracking research publications on a specific theme and extracting insights by evaluating these studies across various parameters. To ensure a comprehensive and systematic selection of literature, the study adheres to the PRISMA framework[47], as illustrated in Fig. 1. The Scopus database was searched using multiple fields[48] including Title, Abstract, Author Keywords, and Keywords Plus to identify relevant publications. Fig. 1 presents the PRISMA flow diagram, detailing the selection process. Initially, 2052 records were identified through database searches. After removing duplicates, 2001 unique records remained for screening. During the screening stage, 1261 records were excluded for reasons such as irrelevance, non-English language, or publication type. Subsequently, 740 full-text articles were assessed for eligibility, with 62 excluded based on specific criteria such as lack of methodological rigor or focus. Ultimately, 678 studies met the inclusion criteria and were analyzed. This structured process ensures transparency and reproducibility in the literature selection methodology.

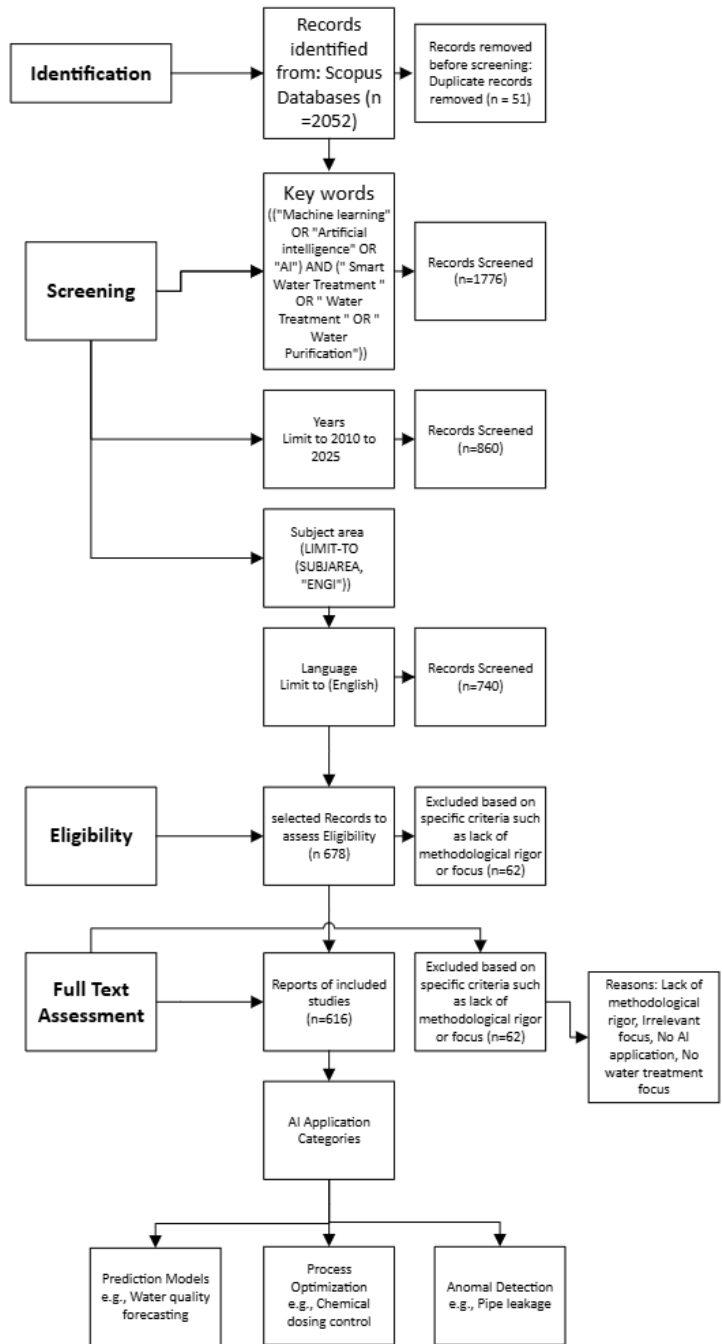


Fig. 1: PRISMA Framework for AI and Smart Water Treatment (Scopus search 27-3-2025)

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3. Results

Bibliometric analysis is a statistical approach used to quantify and evaluate the emerging trends within a particular field of study[49], [50]. Bibliometric analysis has been applied to evaluate academic outputs across multiple disciplines [51]. The search, conducted on the Scopus database from 2010 to 2025, utilized various search fields such as Author keywords, Title, Abstract, Author, and Keywords Plus. The search employed a combination of keywords using AND/OR logic, including terms like ("Machine learning" OR "Artificial intelligence" OR "AI") AND (" Smart Water Treatment " OR " Water Treatment " OR " Water Purification "). The results were assessed based on titles and abstracts to ensure coherence with the article's theme and core topic.

The analysis utilized Scopus analysis and VOS viewer for data visualization. Graphs were generated using Microsoft Excel. Various details were extracted for each document, including (1) the number of documents per year, (2) average citations of articles per year, (3) author keywords and frequently used words in titles, (4) journals of publication for each article, (5) science categories, (6) most cited articles, (7) authors and co-authors for each article, (8) H-index for top 10 authors, (9) affiliation details for authors and co-authors, (10) countries of the authors, and (11) H-index for top 30 journals. Bibliographic maps were generated using VOS viewer software, encompassing keywords co-occurrence, countries co-authorship maps, and bibliographic coupling for countries and affiliations.

2052 documents were initially identified, with 678 aligning with the study's theme. These documents were then categorized as follows: 397 research articles, 51 review papers, 177 conference papers, and 53 documents falling into other categories. The dataset comprises 98 sources and 577 keywords. The publications obtained showed an average growth rate of 34.07% per year. The most notable increase was observed between 2021 and 2024, reaching its peak with 176 publications in 2024, as shown in Fig. 2. The average annual citation was 40.66%, reported in 2024, as illustrated in Fig. 3. Only 3167 articles were cited for that particular year. Fig. 3 illustrates the fluctuation of journals over the years. Until 2024, the journal " Water Research " held the top position, but it was surpassed by the " Desalination," which accumulated a total of 2,082 articles. In terms of the Cite Score (2023) of journals, the " Water Research " led the rankings with a score of 20.8, followed by " Journal of Cleaner Production " and " Desalination " with scores of 20.4 and 14.6, respectively, as detailed in **Table 1**.

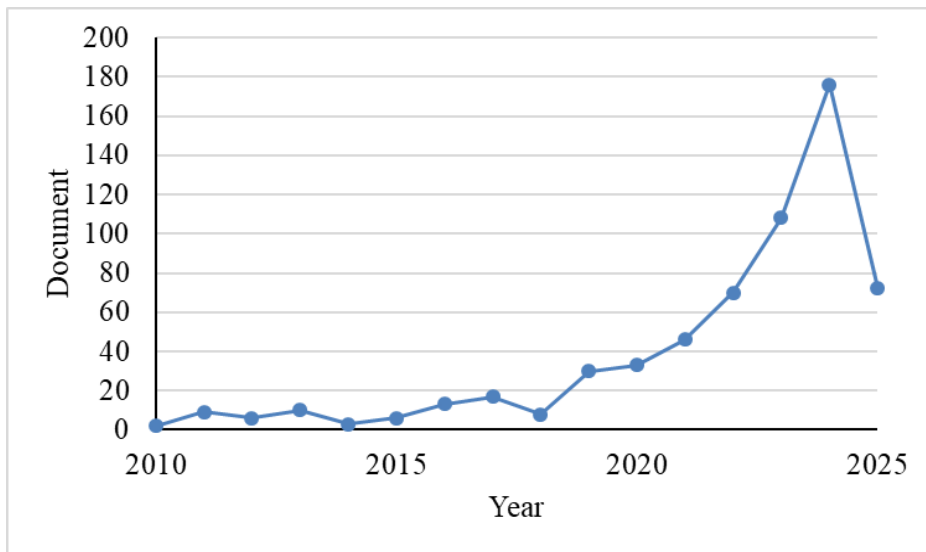


Fig.2. Annual Distribution of AI Applications in Smart Water Treatment and Emerging Technologies in Water Purification.

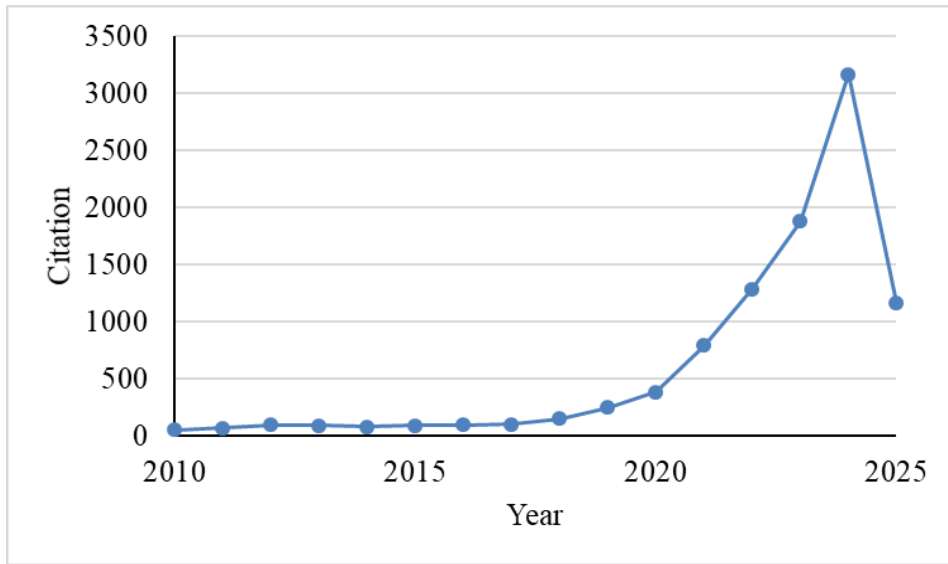


Fig.3. Average Citation Per Article on AI and Smart Water Treatment Each Year.

TABLE 1.
The Top 10 Highly Productive Journals in AI and Smart Water Treatment.

Journal	TP	TC	Cite Score (2023)	Most cited publication	Times Cited	Publisher
Water Research	4,826	100,330	20.8	.Li, Ning, et al (2023)	165	Elsevier
Desalination	2,082	30,471	14.6	.Zhang, Tong, et al (2023)	131	Elsevier
Chemical Engineering Journal	-	-	-	.Hikita, H., et al (1977)	405	Elsevier
Desalination and Water Treatment	4,385	9,714	2.2	.Xu, Peilong, et al (2023)	56	Elsevier
Journal of Water Process Engineering	3,477	37,357	10.7	Khan, Mohammad Danish, et .al (2023)	164	Elsevier
Journal of Cleaner Production	19,382	394,597	20.4	Mujtaba, Muhammad, et.al .(2023)	407	Elsevier
Process Safety and Environmental Protection	3,065	34,855	11.4	Aljohani, Meshari M., et.al .(2023)	169	Institution of Chemical Engineers
Lecture Notes in Networks and Systems	35,041	256,060	0.9	Bavkar, Dnyaneshwar, Ramgopal Kashyap, and Vaishali Khairmar (2023)	115	Springer Nature
Sensors	5,109	29,065	7.3	.Wang, Gang, et.al. (2023)	360	Multidisciplinary Digital Publishing Institute (MDPI)
IEEE Access	49,687	484,743	9.8	.Gupta, Maanak, et. al. (2023)	267	IEEE

TP= Total Publications, TC= Total Citation

Concerning scientific categories, 34.9% of total articles were categorized under Engineering, followed by Environmental Science and Computer Science with 14.8% and 11.6% of the total articles, respectively as illustrated in **Fig. 4**. The total number of authors across all articles amounted to 159. Notably, “Shon, H.K.” authored a superior number of articles, with 587 articles. Following by, “Chang, N.B.” contributed 442 articles, while “Kapelan, Z.” authored 346 articles as shown in **Fig. 5**. In terms of the authors' H-index, “Shon, H.K.” achieved the highest score of 80, followed by “Khayet, M.” with an H-index of 74, and “Chang, N.B.” attained an H-index of 56, as detailed in **Table 2**.

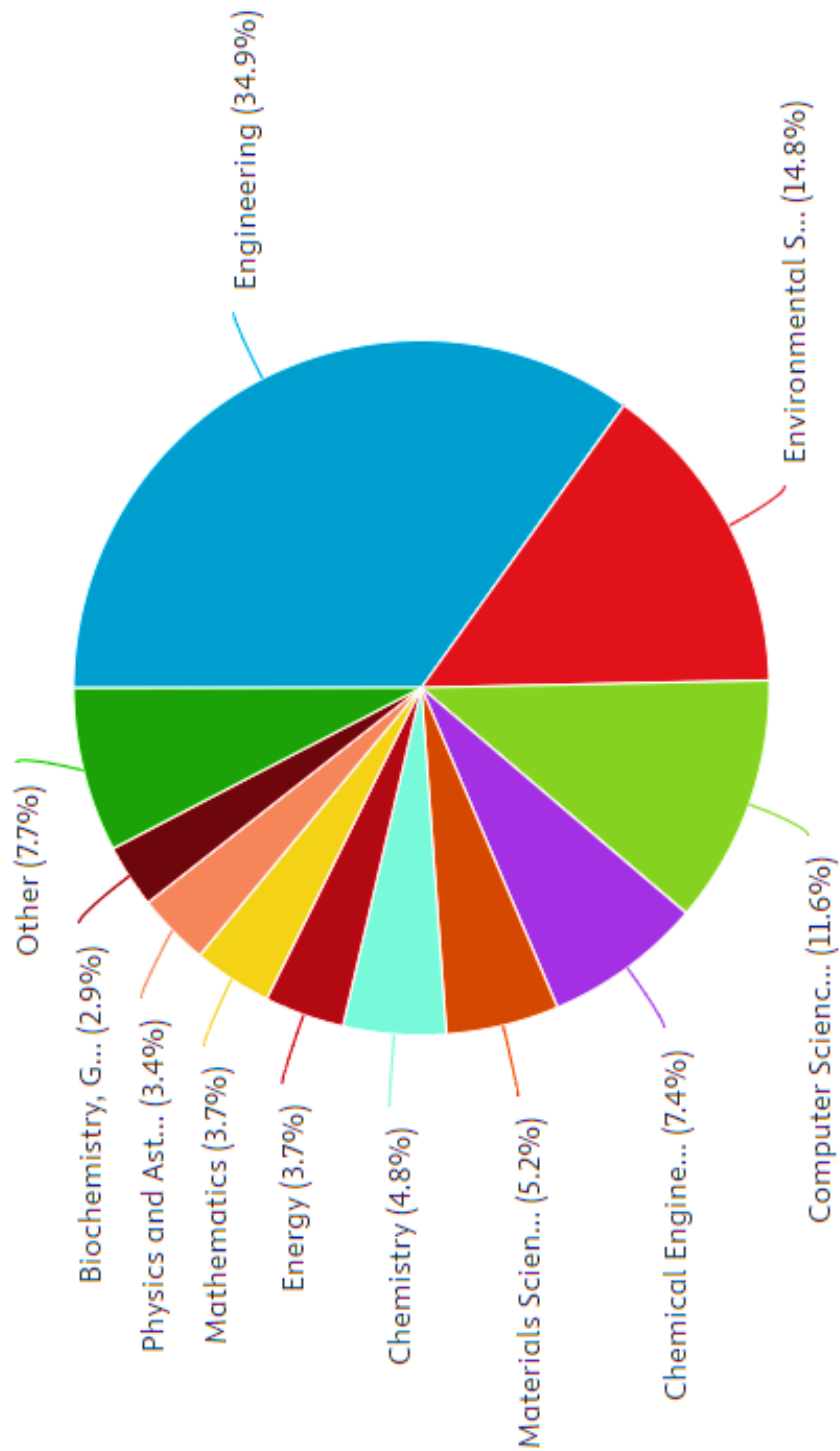


Fig.4. Publication Distribution by Research Field in AI and Smart Water Treatment.

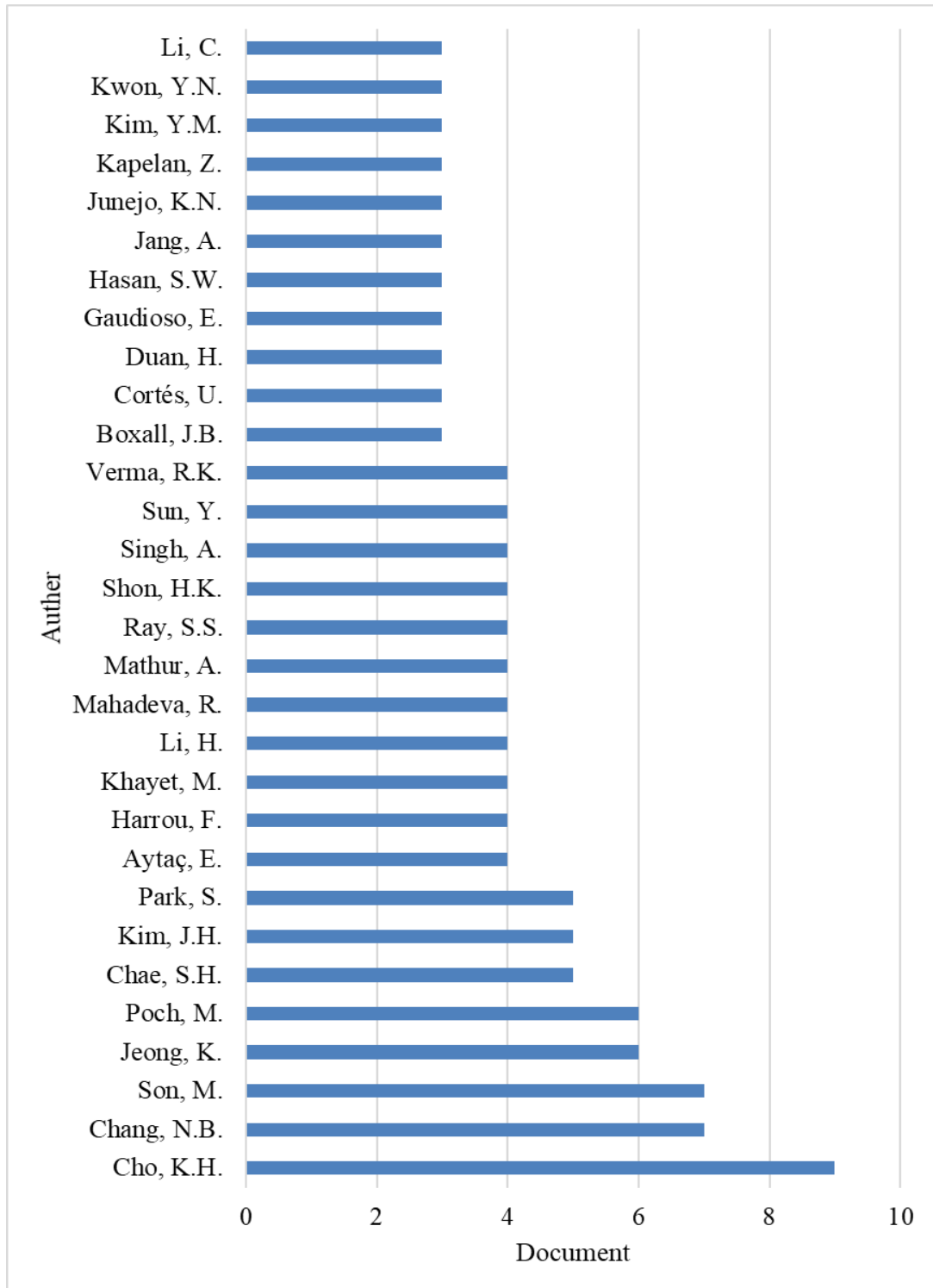


Fig.5. Top 30 Authors Ranked by Number of Articles in AI and Smart Water Treatment.

TABLE 2.
List of the 30 Most Prolific Authors in AI and Smart Water Treatment.

No	author	TP*	h-index	Current affiliation	Country
1.	Cho, K.H.	222	46	Korea UniversityThe institution will open in a new tab, Seoul, South Korea	South Korea
2.	Chang, N.B.	442	56	University of Central FloridaThe institution will open in a new tab, Orlando, United States	, United States
3.	Son, M.	70	25	University of Science and Technology (UST)The institution will open in a new tab, Daejeon, South Korea	, South Korea
4.	Jeong, K.	30	14	Chosun UniversityThe institution will open in a new tab, Gwangju, South Korea	South Korea
5.	Poch, M.	159	39	Universitat de GironaThe institution will open in a new tab, Girona, Spain	Spain
6.	Chae, S.H.	128	8	Korea Institute of Science and TechnologyThe institution will open in a new tab, Seoul, South Korea	South Korea
7.	Kim, J.H.	168	43	Gwangju Institute of Science and TechnologyThe institution will open in a new tab, Gwangju, South Korea	South Korea
8.	Park, S.	42	19	Pukyong National UniversityThe institution will open in a new tab, Busan, South Korea	South Korea
9.	Aytaç, E.	16	8	Universidad Complutense de MadridThe institution will open in a new tab, Madrid, Spain	Spain
10.	Harrou, F.	211	41	King Abdullah University of Science and TechnologyThe institution will open in a new tab, Thuwal, Saudi Arabia	Saudi Arabia
11.	Khayet, M.	227	74	Universidad Complutense de MadridThe institution will open in a new tab, Madrid, Spain	Spain
12.	Li, H.	21	8	Tickle College of EngineeringThe institution will open in a new tab, Knoxville, United States	United States
13.	Mahadeva, R.	67	16	Manipal Academy of Higher EducationThe institution will open in a new tab, Manipal, India	India
14.	Mathur, A.	187	40	Singapore University of Technology and DesignThe institution will open in a new tab, Singapore City, Singapore	Singapore
15.	Ray, S.S.	63	26	School of Engineering and Sciences, India	India

16.	Shon, H.K.	587	80	University of Technology SydneyThe institution will open in a new tab, Sydney, Australia	Australia
17.	Singh, A.	185	22	Shiv Nadar Institution of Eminence deemed to be UniversityThe institution will open in a new tab, Greater Noida, India	India
18.	Sun, Y.	276	43	King Abdullah University of Science and TechnologyThe institution will open in a new tab, Thuwal, Saudi Arabia	Saudi Arabia
19.	Verma, R.K.	7	5	Shiv Nadar Institution of Eminence deemed to be UniversityThe institution will open in a new tab, Greater Noida, India	India
20.	Boxall, J.B.	216	41	The University of SheffieldThe institution will open in a new tab, Sheffield, United Kingdom	United Kingdom
21.	Cortés, U.	202	29	Centro Nacional de SupercomputaciónThe institution will open in a new tab, Barcelona, Spain	Spain
22.	Duan, H.	16	10	Harbin Institute of TechnologyThe institution will open in a new tab, Harbin, China	China
23.	Gaudioso, E.	39	12	Universidad Nacional de Educacion a DistanciaThe institution will open in a new tab, Madrid, Spain	Spain
24.	Hasan, S.W.	255	50	Khalifa University of Science and TechnologyThe institution will open in a new tab, Abu Dhabi, United Arab Emirates	United Arab Emirates
25.	Jang, A.	237	45	Sungkyunkwan UniversityThe institution will open in a new tab, Seoul, South Korea	South Korea
26.	Junejo, K.N.	24	11	DNNae Inc., Islamabad, Pakistan	Pakistan
27.	Kapelan, Z.	346	55	Department of Water Management, TU DelftThe institution will open in a new tab, Delft, Netherlands	Netherlands
28.	Kim, Y.M.	126	40	Hanyang UniversityThe institution will open in a new tab, Seoul, South Korea	South Korea
29.	Kwon, Y.N.	96	37	Ulsan National Institute of Science and TechnologyThe institution will open in a new tab, Ulsan, South Korea	South Korea
30.	Li, C.	113	33	Harbin Institute of TechnologyThe institution will open in a new tab, Harbin, China	China

*TP= Total Publications.

The total number of keywords used in the articles was 577. "Machine Learning" emerged as the most frequently utilized keyword, appearing 285 times, as depicted in **Fig. 6**. This was followed by "Water Treatment" observed 273 times, and "Wastewater Treatment" documented 189 times. As shown in **Table 3**, The frequently occurring keywords in the articles on "AI and Smart Water Treatment: A Bibliometric Perspective on Emerging Technologies in Water Purification" are grouped into five primary subject areas: AI and ML applications in water treatment,

Wastewater to Energy, Seawater Treatment and Desalination Processes, Sustainable and Quality Control, and Other topics. These classifications emphasize the integration of intelligent technologies with traditional methods to drive innovation in water purification and management.

Table 3
Classification of frequently occurring terms in articles according to their research domains.

ID	Keywords	Subject Areas	Occurrences
1.	Machine Learning	AI and ML applications in water treatment	285
2.	Artificial Intelligence		186
3.	Machine-learning		165
4.	Learning Systems		94
5.	Forecasting		92
6.	Prediction		62
7.	Neural Networks		60
8.	Learning Algorithms		52
9.	Deep Learning		51
10.	Artificial Neural Network		49
11.	Support Vector Machines		36
12.	Decision Making		36
13.	Random Forest		34
14.	Decision Trees		34
15.	Decision Support Systems		33
16.	Machine Learning Models		32
17.	Energy Utilization	Wastewater to Energy	31
18.	Energy Efficiency		28
19.	Water Treatment		273
20.	Wastewater Treatment		189
21.	Water Quality		123
22.	Water Purification		73
23.	Wastewater		58
24.	Industrial Water Treatment		20
25.	Water Treatment		273
26.	Wastewater Treatment		189
27.	Desalination	Seawater Treatment and Desalination Processes	49
28.	Potable Water		47
29.	Drinking Water		32
30.	Water		29
31.	Sustainable Development	Sustainable and Quality Control	29
32.	Control Systems		24
33.	Quality Control		24
34.	Environmental Monitoring		13
35.	Water Management	Other topics	69
36.	Optimization		46
37.	Water Conservation		25

place, India contributed 106 publications, followed by United States ranked third with 90 publications, as detailed in **Table 4**.

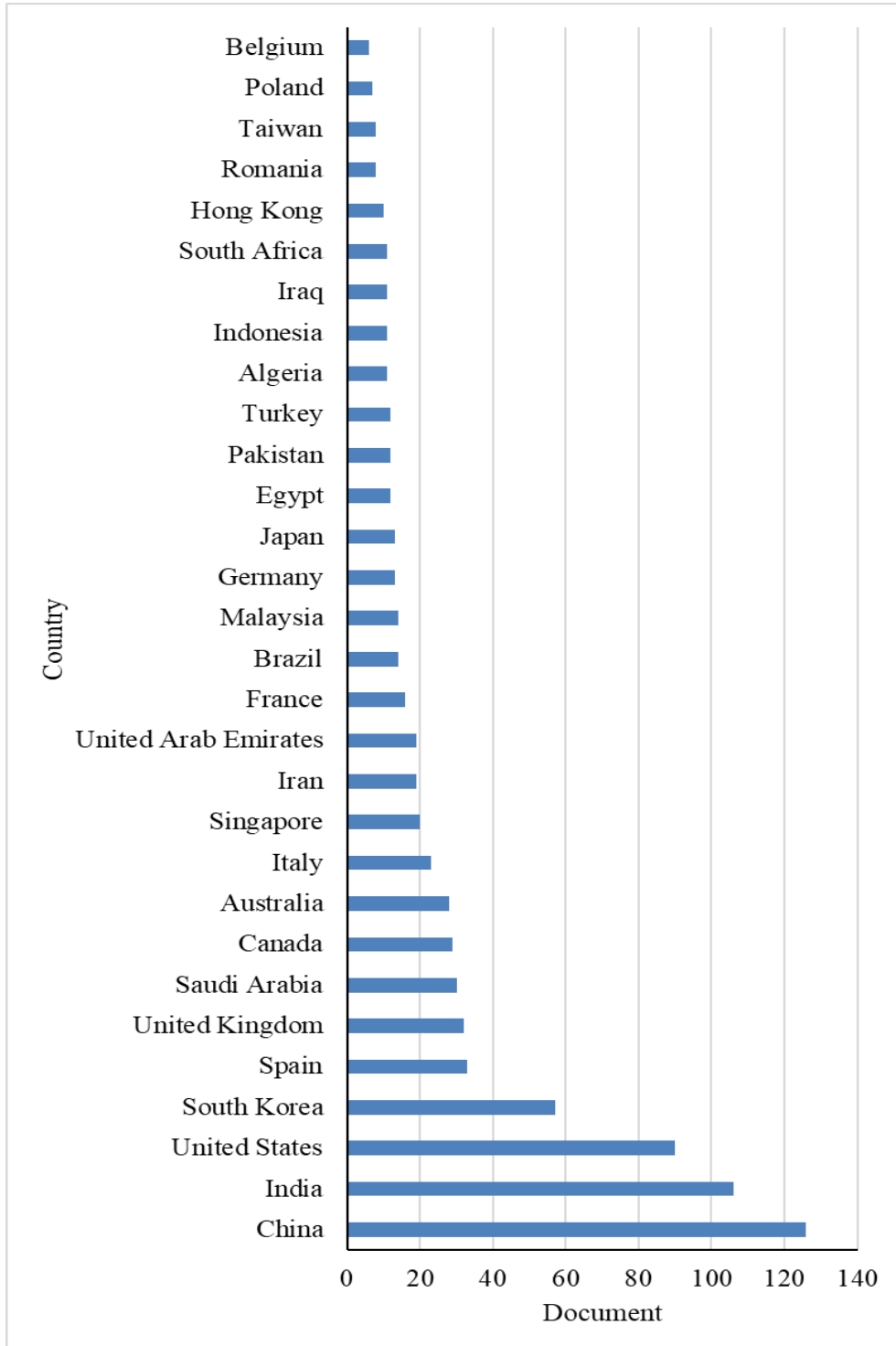


Fig.7. List of the Most Productive Countries in AI and Smart Water Treatment Research.

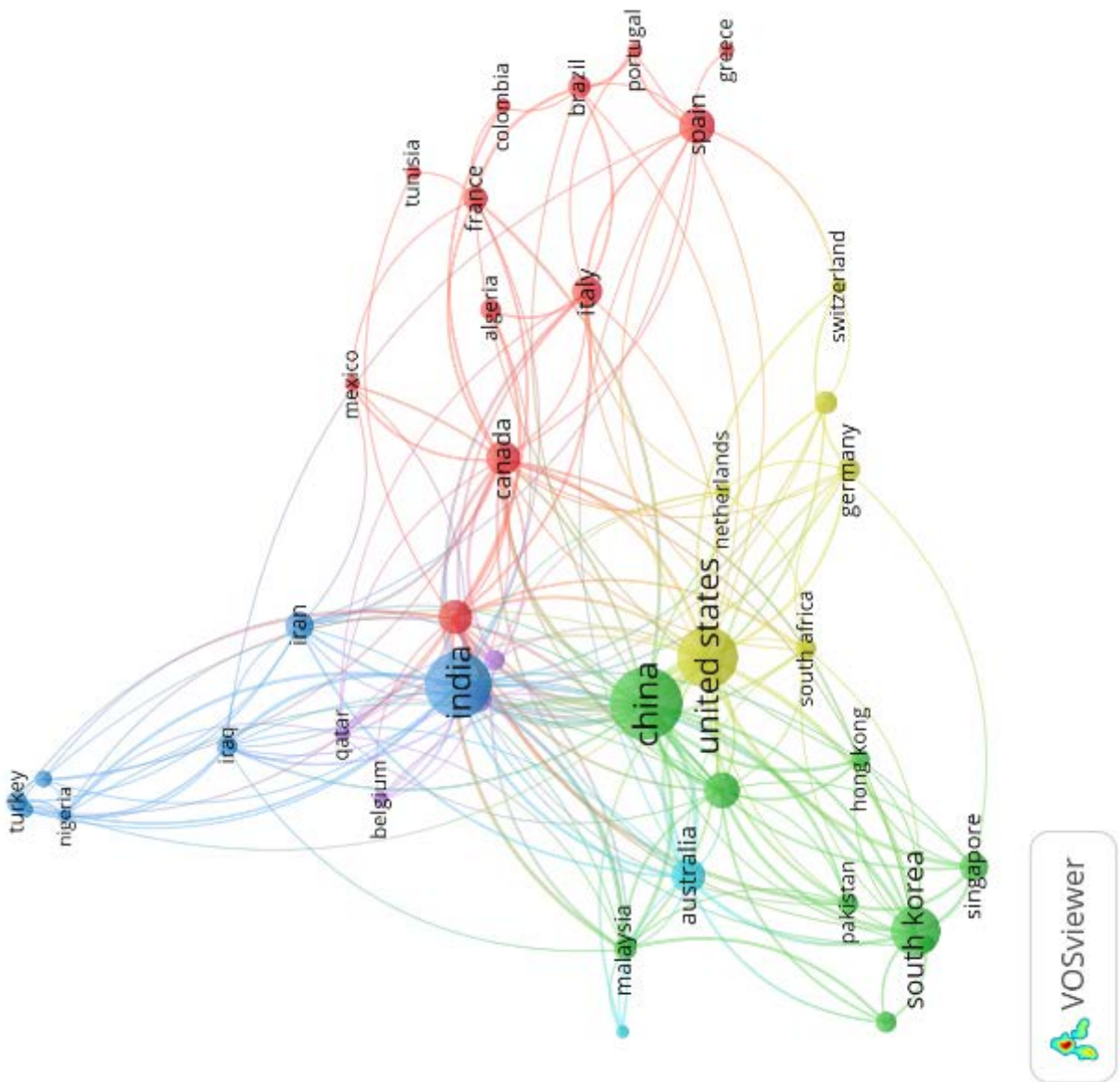


Fig.8. Co-Authorship Network Map of Countries in AI and Smart Water Treatment Research.

TABLE 4.
The Most Productive Countries in AI and Smart Water Treatment Research.

COUNTRY	No of articles
China	126
India	106
United States	90
South Korea	57
Spain	33
United Kingdom	32
Saudi Arabia	30
Canada	29
Australia	28
Italy	23
Singapore	20
Iran	19
United Arab Emirates	19
France	16
Brazil	14
Malaysia	14
Germany	13
Japan	13
Egypt	12
Pakistan	12
Turkey	12
Algeria	11
Indonesia	11
Iraq	11
South Africa	11
Hong Kong	10
Romania	8
Taiwan	8
Poland	7
Belgium	6

The most productive affiliation was “Harbin Institute of Technology” with 17 articles, followed by “Singapore University of Technology and Design” with 13 articles and “Tongji University” with 12 articles as shown in **Fig. 9**.

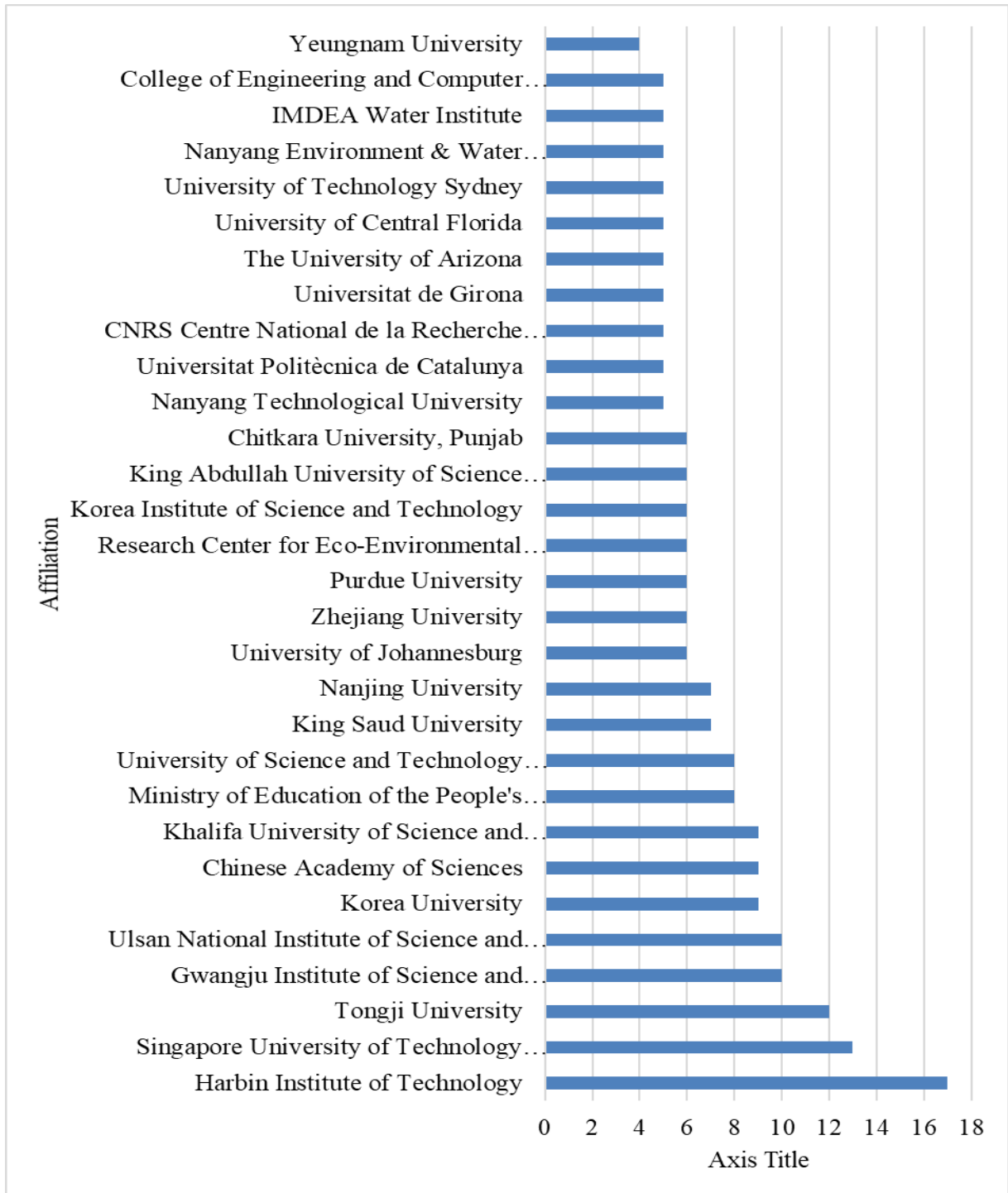


Fig.9. List of the Top 30 Affiliations Ranked by Number of Documents in AI and Smart Water Treatment Research.

4. Discussion

Artificial intelligence (AI) has emerged as a transformative force in addressing global water challenges, enabling the development of advanced, efficient, and sustainable water treatment systems[10], [52], [53]. The integration of AI into water purification processes is revolutionizing the field by enhancing contaminant detection, optimizing filtration efficiency, improving resource management, and predicting system maintenance needs[54]–[56]. These capabilities are particularly vital in a world facing increasing water scarcity, pollution, and rising demand for clean water[1], [57], [58]. Understanding the role of AI-driven technologies in water treatment requires a thorough examination of their applications, methodologies, and outcomes to identify critical trends, opportunities, and challenges[59]–[64].

AI-driven water treatment systems utilize machine learning (ML) techniques, such as artificial neural networks (ANN), support vector machines (SVM), decision trees (DT), and gradient boosting regression (GBR), to model and predict complex water purification processes[65]–[69]. These methods are employed for tasks such as identifying contamination patterns, forecasting water quality, and optimizing operational parameters. The interaction between AI models and the variables influencing water treatment such as chemical composition, contaminant levels, flow rates, and environmental conditions enables researchers and engineers to design smarter and more adaptable solutions[70]–[73]. Despite these advancements, several challenges persist, including the heterogeneity of water sources, data quality issues, and the difficulty of integrating AI models into traditional water treatment infrastructure[70], [74]–[77].

4.1. Research Gaps and Future Directions

The bibliometric analysis reveals several critical gaps in the current research landscape concerning the application of artificial intelligence (AI) in smart water treatment systems. One major gap is the limited integration of AI with real-time monitoring and control mechanisms, which are essential for adaptive, responsive water quality management in practical settings. Additionally, the absence of standardized datasets and benchmarking protocols hinders the reproducibility and comparability of AI models across studies. Much of the existing research relies on localized or proprietary data, limiting the scalability and generalizability of proposed solutions. Moreover, interdisciplinary collaboration remains insufficient, with many studies focusing solely on computational or environmental perspectives without incorporating domain-specific expertise from fields such as environmental engineering, microbiology, or systems science. To address these issues, future research should prioritize the development of hybrid AI models that combine data-driven and physics-based approaches, the creation of open-access datasets to support collaborative innovation, and the advancement of real-time, edge-AI solutions for on-site water quality assessment. It is also essential to evaluate the environmental and energy impacts of AI implementations and to foster stronger partnerships between academia and industry to bridge the gap between theoretical advancements and real-world applications. These directions will support the evolution of intelligent, sustainable, and scalable water treatment technologies in response to global water management challenges.

4.2. Limitations of the Bibliometric Approach

Despite the strengths of the bibliometric approach in mapping research trends and identifying influential contributions, it is important to acknowledge its inherent limitations. First, this study relies exclusively on the Scopus database, which, although comprehensive, may not capture all relevant publications indexed in other databases such as Web of Science, IEEE Xplore, or Google Scholar. This creates a potential database bias that may influence the representativeness of the results. Second, the accuracy of the analysis is highly dependent on the selection of search keywords. The use of limited or inconsistent terminology across publications may result in the omission of relevant studies or the inclusion of unrelated ones. Moreover, bibliometric analysis primarily focuses on quantitative aspects such as publication counts, citation metrics, and co-authorship patterns, without evaluating the methodological rigor or contextual quality of individual studies. Therefore, while bibliometric tools provide valuable insights into the structure and development of a research field, their findings should be interpreted alongside qualitative assessments to ensure a more comprehensive understanding.

4.3. Integration of AI and Water Engineering Perspectives

To deepen the discussion, this study integrates domain knowledge from both artificial intelligence and water engineering. In the context of AI, advanced techniques such as machine learning, deep learning, and predictive analytics play a crucial role in optimizing water treatment processes by enabling accurate forecasting, anomaly detection, and adaptive control. From the water engineering perspective, factors such as system design, sensor deployment, data acquisition challenges, and regulatory standards are critical to the successful implementation of AI-driven solutions. This interdisciplinary integration allows for a more comprehensive understanding of the technical opportunities and practical constraints involved in applying AI to smart water treatment systems, ensuring that proposed models are not only innovative but also feasible and aligned with industry requirements.

4.4. Emerging AI Technologies and Their Influence on Water Purification

Emerging technologies such as Large Language Models (LLMs) and edge artificial intelligence (edge AI) are expected to play a pivotal role in the evolution of water purification systems. LLMs, with their advanced natural language processing capabilities, can analyze and synthesize large volumes of technical documents, operational data, and sensor information to support decision-making and predictive maintenance in water treatment processes. Meanwhile, edge AI enables real-time data processing directly at the sensor or treatment site, reducing latency and dependence on cloud infrastructure. This allows for immediate anomaly detection, adaptive control, and localized optimization of purification processes. The integration of these technologies promises enhanced system responsiveness, improved accuracy in contaminant detection, and more efficient resource utilization. Consequently, their adoption is likely to drive the development of smarter, more autonomous, and resilient water purification systems that can better address the increasing complexity and variability of water quality challenges.

4.5. Contribution to Sustainable Development Goals

This study aligns closely with the United Nations Sustainable Development Goals, particularly SDG 6 (Clean Water and Sanitation) and SDG 9 (Industry, Innovation, and Infrastructure)[78]–[81]. By analyzing the application of artificial intelligence in smart water treatment systems, our findings demonstrate how emerging technologies can enhance the efficiency, reliability, and accessibility of water purification processes, directly contributing to SDG 6's objective of ensuring availability and sustainable management of water for all. Moreover, the adoption of AI-driven innovations fosters the development of resilient infrastructure and promotes sustainable industrial advancements, which are core aims of SDG 9. Through improved monitoring, predictive maintenance, and adaptive control, these technologies support the creation of smarter water treatment facilities that can better meet environmental challenges while driving innovation in the water sector. Thus, the insights provided in this study not only advance academic understanding but also support global efforts toward sustainable water and infrastructure development.

5. Conclusion

This study presents a bibliometric analysis of AI and machine learning applications in smart water treatment, addressing global challenges in water management and sustainability. It explores AI's role in optimizing processes such as contaminant removal, desalination, and energy recovery from wastewater while evaluating various AI modeling approaches like neural networks and deep learning. The analysis highlights global research trends, key contributors, and interdisciplinary strategies, offering insights into sustainable practices and technological innovation. Ultimately, it emphasizes the transformative potential of AI in advancing intelligent water treatment systems and achieving sustainable water resource management.

6. Study Contributions

This study conducts an in-depth bibliometric review of the intersection between artificial intelligence (AI) and smart water treatment technologies, categorizing research into six primary domains: AI-driven optimization of water purification processes, advancements in sensor and monitoring systems, predictive modeling for contaminant removal, integration of IoT and automation in water treatment, sustainability and energy efficiency assessments, and real-time decision-making frameworks. These classifications shed light on key research priorities and prevailing methodologies utilized in the study of AI-enabled water purification. Research activity in this domain has shown a consistent upward trend since 2010, peaking in 2024, with indications of sustained growth in 2025 and beyond.

Major contributors to this field include China, India, the United States, South Korea, Spain, and United Kingdom, reflecting their commitment to advancing water treatment technologies, promoting sustainable resource management, and addressing global water scarcity challenges. Prominent researchers, such as Cho, K.H. and Chang, N.B., have significantly contributed to the literature with highly cited works, showcasing their influence on advancing the understanding of AI applications in water treatment. Notable institutions like Harbin Institute of Technology and Singapore University of Technology and Design have emerged as leaders in this field, driving innovation in smart water treatment solutions. Journals such as *Water Research* and *Desalination* serve as pivotal platforms for publishing advancements in this interdisciplinary domain.

The study also highlights the expanding application of machine learning (ML) and deep learning (DL) techniques in optimizing water purification processes due to their efficiency in analyzing complex datasets. Techniques such as artificial neural networks (ANN), convolutional neural networks (CNN), support vector machines (SVM), random forests (RF), and gradient boosting algorithms have been employed to predict contaminant levels, optimize filtration systems, and enhance operational efficiency. More sophisticated approaches, such as reinforcement learning (RL) and hybrid models combining ML with physics-based simulations, are particularly effective in handling nonlinear data and improving system adaptability. However, challenges such as data quality, algorithm interpretability, and scalability persist, requiring further research and refinement.

This bibliometric review provides a comprehensive overview of emerging trends in AI and smart water treatment technologies, identifies influential contributors, and underscores the growing role of advanced computational tools in advancing the field. By addressing existing challenges and leveraging new technologies, the study aims to guide future research efforts toward sustainable, efficient, and intelligent water purification systems, ultimately contributing to global water security and environmental sustainability.

7. Suggestions for Academia and Industry Practice

This study is expected to contribute significantly to advancements in environmental engineering, water treatment technologies, and smart water purification systems by highlighting the pivotal role of artificial intelligence (AI) and machine learning (ML) in optimizing and predicting the performance of emerging water treatment solutions. Based on the findings, the following recommendations are proposed to drive both academic research and practical industry applications:

- **Enhanced Predictive Modeling:** AI and ML models should serve as the cornerstone for developing more precise and reliable techniques for predicting contaminant removal efficiency, energy consumption, and system performance in smart water treatment processes.
- **Model Optimization:** Continuous improvement of these models is essential to enhance their accuracy, robustness, and adaptability to diverse water quality conditions and operational scenarios.
- **Support for Sustainable Practices:** The study promotes the integration of eco-friendly materials and renewable energy sources in water treatment systems, fostering sustainable resource management and reducing environmental impact.

- **Advancements in Real-Time Monitoring:** AI-driven approaches will complement advanced sensor technologies, enabling real-time monitoring and adaptive control of water purification processes.
- **Digital Simulations and Process Optimization:** AI-powered digital simulations should be leveraged to optimize the design, operation, and scalability of smart water treatment systems, ensuring cost-effectiveness and efficiency.
- **Time-Dependent Analysis:** Future research should focus on developing time-dependent modeling techniques to analyze the long-term performance and reliability of water treatment technologies under varying environmental and operational conditions.
- **Expanded Datasets:** The diversification and expansion of datasets are critical, particularly in regions with limited data availability, to enhance model training and predictive accuracy for global applicability.
- **Integration of IoT and Automation:** The combination of IoT-enabled devices and automated systems in water treatment will likely lead to the development of innovative hybrid models for process optimization and decision-making.
- **Insights into Contaminant Behavior:** AI models should improve interpretability, offering deeper insights into the factors influencing contaminant behavior, treatment efficiency, and system resilience.
- **Focus on Sustainability and Energy Efficiency:** Future studies should emphasize sustainable approaches to minimize the environmental footprint of water treatment systems while enhancing their energy efficiency and performance.
- **Quality Control and Safety Standards:** AI-driven solutions will play a vital role in advancing quality control measures and safety standards in water treatment, ensuring compliance with regulatory requirements and public health protection.
- **Hybrid Modeling Techniques:** Novel algorithms and hybrid AI models should be developed to address the complex relationships between water quality parameters, treatment processes, and system performance metrics.

By addressing these recommendations, this study sets a comprehensive framework for future research and innovation in the field of AI-enabled smart water treatment technologies. These efforts will ensure the development of sustainable, efficient, and intelligent water purification systems, ultimately contributing to global water security and environmental sustainability..

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