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Review Article

Integrating IoT and Water Quality: A Bibliometric Analysis

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***Abstract* - Water quality is a crucial aspect of environmental health, affecting ecosystems, human health, and economic activities. Integrating the Internet of Things (IoT) into water quality monitoring represents a significant advancement, providing real-time, continuous data on various water quality parameters. This paper presents a comprehensive bibliometric analysis of the literature on water quality and IoT from 2014 to July 2024, utilizing data from the Scopus database. Our analysis identifies key trends, influential studies, authors, sources, and geographic contributions. Results indicate a significant increase in publications and citations, reflecting growing interest and advancements in this field. The United States, China, and India are leading contributors, with notable research output and impact. Key themes include the development of IoT-based sensors, AI, and ML technologies for water quality monitoring, yet challenges in practical deployment and the need for more inclusive research persist. This analysis provides valuable insights into the evolution of research in water quality monitoring and highlights opportunities for future studies to address existing gaps and enhance global water management practices.*

***Keywords* - Water quality, Internet of Things (IoT), Bibliometric analysis, Sensor technology, Water management.*

1. Introduction

Water quality is a critical component of environmental health, affecting ecosystems, human health, and economic activities [1]. It encompasses various parameters, including chemical, physical, and biological characteristics that determine the suitability of water for specific uses such as drinking, agriculture, and industry [2]. Contaminants like heavy metals, pesticides, and microbial pathogens can degrade water quality, posing significant risks to both human and ecological health [3]. Effective monitoring and management of water quality are essential to ensure safe and sustainable water resources. Technology and policy advances continuously shape how we monitor, assess, and improve water quality on local, regional, and global scales [4]. The Internet of Things (IoT) refers to the interconnected network of physical devices embedded with sensors, software, and other technologies to collect and exchange data [5]. This network spans various applications, from smart homes and wearable devices to industrial automation and environmental monitoring [6]. IoT enables real-time data collection and analysis, providing insights and automation capabilities that were previously unattainable. IoT devices can track various parameters in environmental monitoring, offering granular and continuous data that can inform better decision-making processes [7]. The growth of IoT is driving significant advancements in numerous fields, enhancing efficiency, safety, and sustainability [8].

Incorporating IoT technology into water quality monitoring signifies a substantial advancement in environmental supervision [9]. IoT tools, such as intelligent sensors and automated sampling systems, offer continuous, real-time data on various water quality indicators, such as pH, turbidity, temperature, and levels of contaminants. This continual flow of information allows for the immediate identification of water quality issues and prompt responses to potential dangers [10]. Furthermore, IoT-powered quality monitoring water systems can encompass expansive geographic regions and difficult-to-access areas, delivering comprehensive and detailed understandings that conventional methods cannot equal. This amalgamation of IoT and water quality monitoring lays the groundwork for more efficient and proactive water management approaches [11].

Bibliometric analysis is a research method involving quantitative evaluation of academic literature [12]. It uses statistical and mathematical techniques to analyze publications, citations, and other aspects of written communication within a specific field. This type of analysis helps identify trends, patterns, and the impact of research activities over time [13]. By examining the volume of publications, citation networks, and authorship patterns, bibliometric analysis provides insights into the development and dissemination of knowledge [14]. In the context of water quality and IoT, bibliometric analysis can reveal how these fields have evolved, highlight influential research, and uncover emerging trends and collaborations. This method offers a valuable tool for researchers to understand the landscape of scientific inquiry and guide future research directions [15]. Bibliometric analysis offers significant benefits in understanding the intersection of water quality monitoring and IoT technologies. It enables the identification of key research trends, influential studies, and collaboration networks, thus providing a comprehensive overview of how these fields have developed and interacted over time [16]. This analysis can uncover the most impactful research, emerging areas of study, and the evolution of technological applications in water quality monitoring, helping to shape future research agendas and policy decisions [17].

Despite the advancements in IoT technologies for water quality monitoring, there remains a lack of comprehensive understanding of how these technologies are being integrated and utilized across various studies and applications. The current research does not sufficiently address the systematic evaluation of literature to identify gaps, trends, and the impact of IoT on water quality monitoring. This paper aims to fill this gap by providing a detailed bibliometric analysis to map the existing research landscape, highlight underexplored areas, and suggest directions for future research.

Finally, the literature review section of the paper reviews previous research in water quality monitoring and management, focusing on the use of IoT, AI, ML, and computer vision technologies and water quality. This section highlights significant advancements, trends, and themes in the field, examining the impact of these technologies on water management practices. By synthesizing and critiquing prior studies, the methods section provides valuable insights that contextualize the current research and lay the groundwork for the methodological approach detailed in subsequent sections. The results and discussions section emphasizes how these technologies have transformed water quality monitoring practices and identify research gaps and opportunities for future studies. Through a comprehensive review of scholarly contributions, this section elucidates the evolution, trends, and key themes shaping the water quality monitoring and management field. The limitations of the study section showcase the limitations of this research paper. Lastly, the conclusion section discusses the research paper's key findings and overall achievement.

2. Literature Review

The Related Work section provides a detailed review of previous research and key studies in water quality monitoring and management. This section highlights significant advancements, emerging trends, and central themes in the field by analysing a broad spectrum of academic contributions. It covers integrating advanced technologies such as IoT, AI, and ML in water quality monitoring and assesses their transformative impact on water management practices. This section synthesizes and critiques prior research, offering a comprehensive understanding that sets the stage for the methodological approach used in our bibliometric analysis.

The study by Olatinwo and Joubert, titled "A Bibliometric Analysis and Review of Resource Management in Internet of Water Things: The Use of Game Theory" [18], provides a comprehensive bibliometric analysis of research from 2012 to 2022 on resource management in IoT-based water quality monitoring. The analysis used keywords such as "IoT for water quality monitoring," "resource management in IoT," and "game theory." Data was collected from major scientific databases like Scopus, ScienceDirect, and IEEE Xplore. Tools such as VOSviewer were utilized for keyword density, cluster, and timeline analysis. The dataset comprised various studies that revealed key trends in publication and citation patterns, highlighting contributions from leading countries and core research topics. Central themes included power optimization, bandwidth management, and time resource management, with game theory methods emerging as a significant focus. The keyword analysis identified the most frequent terms and conceptual relationships, providing insights into developing and disseminating knowledge in this field. Overall, the bibliometric analysis offers valuable insights into the evolution and trends in resource management for IoT-based water quality monitoring, emphasizing the role of game theory in addressing resource constraints and enhancing system performance.

Similarly, the study by Nasture et al., titled "Water Quality Carbon Nanotube-Based Sensors: Technological Barriers and Late Research Trends - A Bibliometric Analysis" [19], provides a bibliometric analysis of research from 2015 to 2021 on water quality sensors utilizing carbon nanotubes. Keywords included "water quality," "carbon nanotube," and "sensor," excluding gas sensors and IoT. Tools such as VoS Viewer, Bibliometrix, and Excel were used for analysis. The dataset comprised 73 articles, 2 book chapters, 18 reviews, and 7 proceedings papers. Key trends in publication and citation patterns highlighted contributions from countries like China, Brazil, Canada, the USA, and Egypt. Central themes included "sensitivity," "detection limit," and "selectivity." VOSviewer mapping revealed interconnected research themes, emphasizing the physical characterization of carbon nanotubes and sensor performance metrics. Overall, the bibliometric analysis offers insights into developing and disseminating knowledge in carbon nanotube-based water quality sensors, highlighting key trends and future research directions.

Furthermore, the study by Pérez-Beltrán et al., titled "Artificial Intelligence and Water Quality: From Drinking Water to Wastewater" [20], provides a bibliometric analysis of AI and machine learning applications in water quality assessment and treatment from 2010 to 2020. The analysis used keywords such as "AI," "machine learning," and "water quality" across multiple databases, employing VOSviewer for keyword density, cluster, and timeline analysis. The study highlights significant research trends and technological impacts, revealing the growing importance of AI and ML in water quality monitoring and treatment. Neural networks are particularly noted for their efficiency in analyzing and predicting water quality parameters. The analysis emphasizes the need for large and diverse datasets to optimize AI applications and calls for open databases to support AI in water quality control. Overall, the bibliometric analysis offers valuable insights into the development and dissemination of AI technologies in water quality, identifying key trends, technological advancements, and future research directions. This work underscores the potential of AI to enhance water management practices globally.

In addition, Iqbal et al. [21] conducted a bibliometric analysis on the application of computer vision technologies in water resource management, covering literature from 2000 to 2022. The analysis was performed in four steps: (a) selection of keywords and source database, (b) definition of inclusion/exclusion criteria, (c) retrieval and cleaning of bibliographic records, and (d) bibliometric analysis and visualizations. Keywords related to computer vision and water resource management were used to query the Web of Science (WoS) core collection database, resulting in 1059 bibliographic records. The analysis employed software tools such as Microsoft Excel, CiteSpace, and VOSviewer to generate performance analysis and scientific mapping visualizations. Performance analysis highlighted trends in publications, citations, top journals, institutions, and countries, while scientific mapping included co-citations, co-occurrences, co-authorships, and bursts.

Despite the significant advancements in integrating IoT, AI, and ML for water quality monitoring and management, several research gaps persist. The analysis reveals a lack of comprehensive frameworks for real-time, large-scale water quality monitoring systems that leverage IoT and AI technologies. Existing studies often focus on isolated applications or case studies, leaving a gap in understanding the scalability and interoperability of these technologies across different water bodies and geographical regions. Moreover, there is a need for more research on the long-term sustainability and cost-effectiveness of deploying such advanced monitoring systems, especially in developing countries where resources may be limited.

Additionally, the literature indicates a shortage of studies addressing the integration of predictive analytics with IoT-based water quality monitoring systems. While AI and ML have shown promise in predicting water quality parameters, there is a gap in deploying these predictive models in real-world IoT networks. Furthermore, widespread IoT deployment's ethical and privacy implications in water quality monitoring are underexplored. Ensuring data security and user privacy while maximizing the benefits of advanced technologies remains critical for future research. Addressing these gaps will be crucial for developing and effectively implementing IoT, AI, and ML in water quality management.

3. Methods

The methodology for this bibliometric analysis involved a systematic approach to data collection, screening, preprocessing, and analysis. By leveraging the Scopus database, we aimed to capture relevant literature on water quality comprehensively and the Internet of Things (IoT) published between 2014 and July 10, 2024. Our methodology encompasses detailed search strategies, rigorous data screening processes, and extensive data analysis using advanced bibliometric tools and software. The following subsections outline each step of our methodology in detail.

3.1. Data Collection and Search Strategy

The data for this bibliometric analysis was sourced from the Scopus database, covering the period from 2014 to July 10, 2024. The data retrieval was performed on July 10, 2024. The document types included in the search were articles, conference papers, conference reviews, reviews, book chapters, and books, with the search being restricted to English-language publications. To identify relevant literature, a specific search string was utilized:

(TITLE-ABS-KEY (water AND quality) AND TITLE-ABS-KEY (internet AND of AND things) OR TITLE-ABS-KEY (iot)) AND PUBYEAR > 2013 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE, "cp") OR LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "ch") OR LIMIT-TO (DOCTYPE, "cr") OR LIMIT-TO (DOCTYPE, "re") OR LIMIT-TO (DOCTYPE, "bk")) AND (LIMIT-TO (LANGUAGE, "English"))

This search strategy ensured a comprehensive collection of relevant documents, initially yielding a total of 2,582 records.

3.2. Data Screening and Preprocessing

The data underwent a two-stage screening process to ensure its quality and relevance. In the first screening, the initial dataset of 2,582 records was examined to remove any entries with missing or incomplete information. This step reduced the dataset to 2,434 records. Subsequently, the refined dataset was checked for duplicate entries in the second screening, resulting in a final dataset of 2,430 unique records. This rigorous screening process ensured the dataset was clean and suitable for subsequent bibliometric analysis. Figure 1 shows the search and data screening strategy.

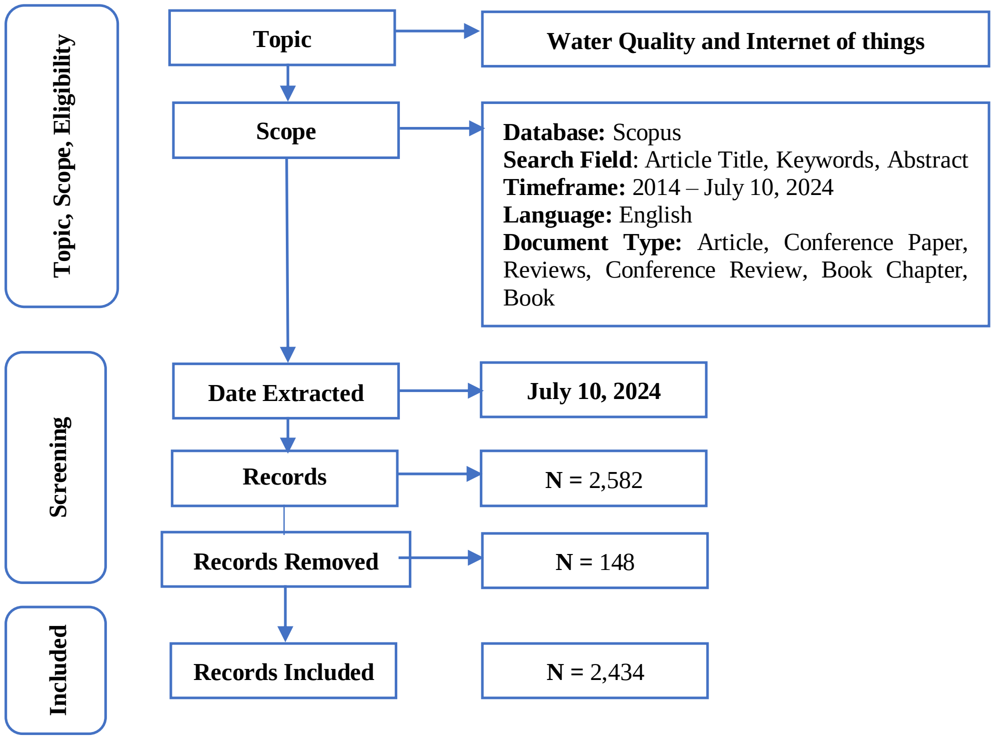

Fig. 1 Search and data screening strategy

3.3. Data Analysis

The cleaned dataset was subjected to detailed bibliometric analysis using various productivity, impact, and collaborative metrics. The analysis was conducted using Excel Spreadsheet, VOSviewer, and the Bibliometrix package in R specifically designed for bibliometric analysis [22]. Key areas of analysis included publication and citation trends, document types, contributing countries, influential authors, influential sources, keyword co-occurrence networks, and influential affiliations. Using the aforementioned tools, we analyzed various aspects, including publication and citation trends, document types, contributing countries, influential authors, influential sources, keyword co-occurrence networks, and influential affiliations. These analytical steps ensured a comprehensive examination of the bibliometric data, providing valuable insights into research trends, influential contributions, and collaborative patterns in the field of water quality and the Internet of Things.

4. Results and Discussion

4.1. Document Types

The analysis of document types reveals a diverse range of publication formats contributing to the body of research on Water Quality and IoT. The majority of the documents are Conference Papers, totaling 1323, which underscores the active discussion and dissemination of research findings in professional gatherings and symposia. Articles form the second largest category with 829 documents, reflecting the substantial amount of research being published in peer-reviewed journals. Reviews, which provide comprehensive overviews of existing research, account for 88 documents, indicating efforts to synthesize and evaluate this field's current state of knowledge. Book Chapters contribute 177 documents, suggesting that the topic is also being explored in the context of broader academic volumes and compilations. Books, although a smaller category with 13 documents highlight in-depth and expansive treatments of the subject matter. Notably, no documents are categorized as Conference Reviews, typically summaries or evaluations of conference proceedings. Figure 2 shows the document type included in the analysis.

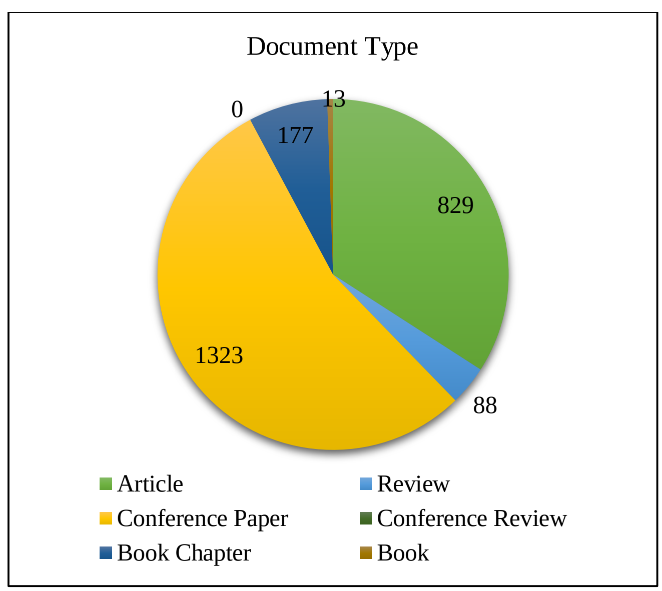

Fig. 2 Document type

4.2. Publications and Citations Trends

The bibliometric analysis of research articles related to Water Quality and the Internet of Things (IoT) from 2014 to 2024 reveals notable trends in the number of publications and citations over the years. From 2014 to 2024, there was a significant increase in the number of documents published on the topic. Starting with just 13 documents in 2014, the number of publications has steadily increased each year, reaching a peak of 577 documents in 2023. The upward trend indicates growing interest and research activity in the intersection of Water Quality and IoT.

In 2014, the field saw the publication of 13 documents. A slight decline was observed in 2015 with 11 documents. From 2016 onwards, there was a marked increase in publications: 39 in 2016, 76 in 2017, and 146 in 2018. The number of documents more than doubled in 2019, reaching 219. The upward trend continued through 2020 (282 documents) and 2021 (371 documents). A significant surge in publications was noted in 2022, with 442 documents. The highest number of publications was recorded in 2023, with 577 documents. Although 2024 is still in progress, it has already seen 254 documents published.

The citation analysis shows a similar upward trajectory, reflecting the increasing impact and recognition of research in this domain. The number of citations per year has generally increased, though there are some fluctuations. In 2014, the 13 documents received 250 citations.

Despite a decrease in the number of documents in 2015, citations increased to 371. There was a significant rise in citations from 2016 (1281 citations) to 2017 (2366 citations). The citations continued to grow in 2018 (2735 citations) and 2019 (3291 citations). The highest number of citations was observed in 2020, with 5167 citations, coinciding with a substantial increase in publications.

In 2021, citations slightly decreased to 3921 despite continued publication growth. Citations dropped to 2879 in 2022, even with an increase in the number of documents. A notable decline in citations occurred in 2023, with 1354 citations suggesting either a saturation point or a shift in research focus. For 2024, up to the current date, the documents have received 197 citations. Figure 3 shows the publications and citation trends.

4.3. Contributing Countries

The analysis of contributing countries highlights the geographical diversity and the global nature of research on Water Quality and the Internet of Things (IoT). The data reveals significant contributions from a wide range of countries, each varying in the number of documents, citations, and other bibliometric measures. Among the leading contributors, India stands out with the highest number of documents (906) and citations (7683). The country's average normalized citations score is also notable, reflecting its research's high impact and relevance in this field. The United States follows with 149 documents and 2488 citations, showcasing its substantial contribution and influence in the domain. China, with 225 documents and 1962 citations, is another major contributor. The country's average publication year is 2021, indicating that a significant portion of its contributions is relatively recent. Australia's research output is also noteworthy, with 56 documents and 1333 citations, and it shows a strong average citation rate, indicating high-quality research.

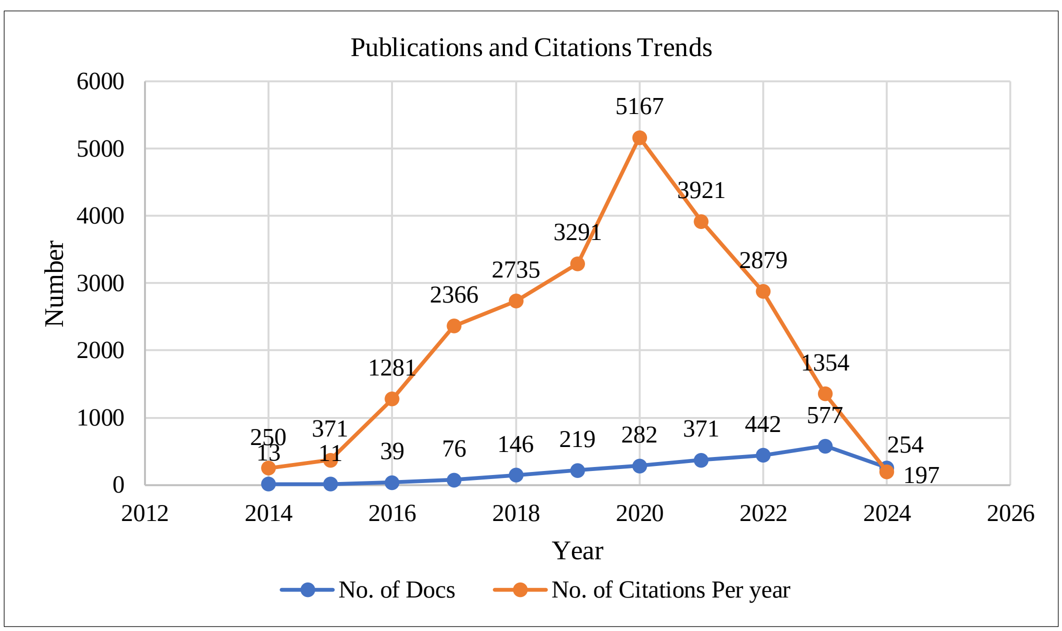

Fig. 3 Publications and citations trends

European countries such as the United Kingdom, Germany, and France also contribute significantly. The United Kingdom has 59 documents and 1653 citations, while Germany and France have 24 and 24 documents, respectively, with notable citation counts. The research outputs from these countries are well-regarded, as indicated by their average citations per document.

Smaller countries also make important contributions. For instance, Austria has 8 documents with a high average citation rate, reflecting impactful research despite the smaller number of publications. Similar trends are observed in countries like Denmark and Switzerland. Countries from different regions, such as Brazil, Egypt, and Malaysia, also contribute significantly. Brazil has 33 documents with 358 citations, while Egypt has 31 documents and 341 citations. Malaysia's contribution includes 164 documents with 1633 citations, indicating a strong presence in the research landscape.

The data also reveals emerging contributors like Algeria, Bahrain, and Jordan, which, although having fewer documents, show promising citation counts and normalized citation scores. Figure 4 shows the countries contributing to this field.

4.4. Influential Authors

The analysis of influential authors in the field of water quality and the Internet of Things reveals notable contributions from various researchers. Among these, WANG Y stands out with an h-index of 8, a g-index of 13, and an m-index of 0.727. Since 2014, WANG Y has published 21 papers that have garnered 187 citations. Similarly, LIU Y, with an h-index of 5 and a g-index of 6, has achieved an m-index of 0.625. Since 2017, LIU Y has contributed 18 publications that have received 52 citations. SINGH R is another key contributor, having an h-index of 6, a g-index of 13, and an m-index of 0.667. Since 2016, SINGH R's 15 publications have been cited 172 times. KUMAR A, with an h-index of 3 and a g-index of 7, has an m-index of 0.429. KUMAR A's work, beginning in 2018, includes 14 publications that have received 62 citations. KUMAR R is notable for his high impact with an h-index of 6, a g-index of 13, and a significant m-index of 0.857. His 13 publications since 2018 have accumulated 203 citations.

Despite having a lower h-index of 2, ZHANG Y has a g-index of 10 and an m-index of 0.286. Since 2018, ZHANG Y's 13 publications have been cited 115 times. CHEN Y, with an h-index of 6, a g-index of 12, and an m-index of 0.857, has had 12 publications cited 267 times since 2018. LI Z, who began publishing in 2020, has an h-index of 3, a g-index of 12, and an m-index of 0.6. LI Z's 12 publications have received 189 citations.

KUMAR S, with an h-index of 3 and a g-index of 5, has an m-index of 0.429. Since 2018, KUMAR S's 10 publications have garnered 35 citations. Finally, MUKHOPADHYAY SC has made significant contributions with an h-index of 6, a g-index of 9, and an m-index of 0.667. Since 2016, MUKHOPADHYAY SC's 9 publications have received the highest number of citations among the authors, totaling 298. Table 1 shows the top ten most influential authors.

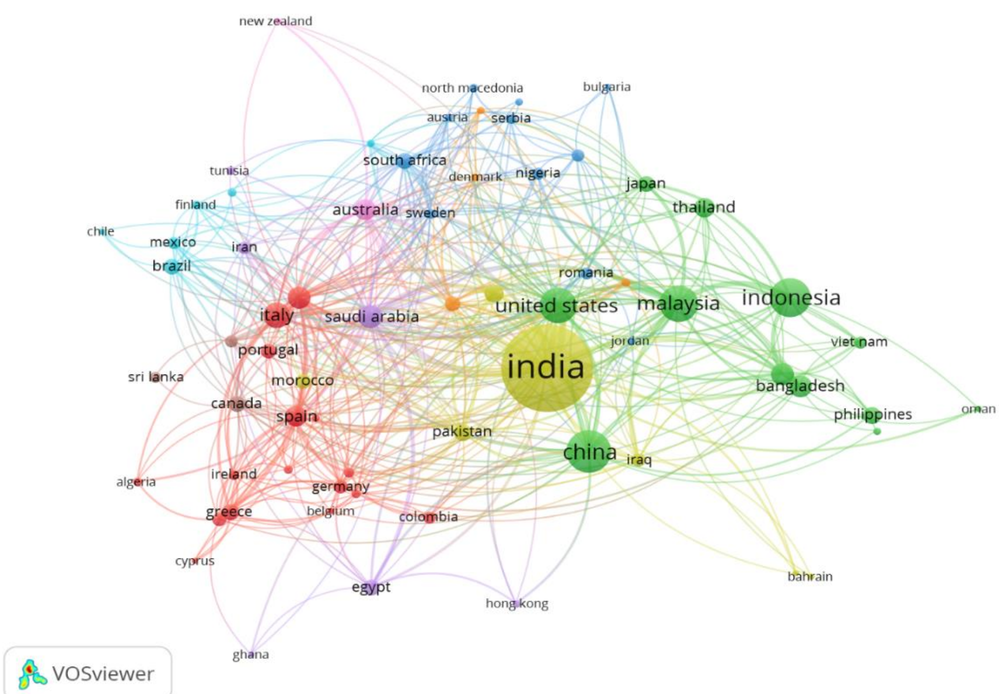

Fig. 4 Contributing countries

Table 1. Top ten most influential authors

Element	h_index	g_index	m_index	TC	NP	PY_start
WANG Y	8	13	0.727	187	21	2014
LIU Y	5	6	0.625	52	18	2017
SINGH R	6	13	0.667	172	15	2016
KUMAR A	3	7	0.429	62	14	2018
KUMAR R	6	13	0.857	203	13	2018
ZHANG Y	2	10	0.286	115	13	2018
CHEN Y	6	12	0.857	267	12	2018
LI Z	3	12	0.6	189	12	2020
KUMAR S	3	5	0.429	35	10	2018
MUKHOPADHYAY SC	6	9	0.667	298	9	2016

4.5. Influential Sources

The analysis of influential sources in the field of water quality and the Internet of Things highlights several key journals and conference proceedings that have made significant contributions.

"IEEE ACCESS" is identified as a major source with an h-index of 14, a g-index of 27, and an m-index of 1.75. Since 2017, it has published 27 articles that have accumulated 745 citations. "SENSORS" stands out with a high h-index of 14, a g-index of 20, and an impressive m-index of 3.5. Since 2021, SENSORS has published 37 articles cited 435 times.

"SENSORS (SWITZERLAND)" shows substantial impact with an h-index of 14, a g-index of 15, and an m-index of 1.556. Since 2016, it has published 15 articles, which have received a remarkable 1322 citations. "IEEE INTERNET OF THINGS JOURNAL" also has a strong presence with an h-index of 11, a g-index of 21, and an m-index of 2.2. Since 2020, it has published 21 articles with 503 citations.

"WATER (SWITZERLAND)" has an h-index of 9, a g-index of 19, and an m-index of 1.125. Since 2017, it has published 19 articles that have garnered 462 citations. "SUSTAINABILITY (SWITZERLAND)" has an h-index of 8, a g-index of 12, and an m-index of 1.333. Since 2019, it has published 12 articles that have received 442 citations.

"ADVANCES IN INTELLIGENT SYSTEMS AND COMPUTING" has an h-index of 7, a g-index of 12, and an m-index of 0.778. Since 2016, it has published 25 articles with 152 citations. "APPLIED SCIENCES (SWITZERLAND)" also has an h-index of 7, a g-index of 11, and an m-index of 1.4. Since 2020, it has published 11 articles with 142 citations.

"IEEE SENSORS JOURNAL" has an h-index of 7, a g-index of 10, and an m-index of 0.636. Since 2014, it has published 10 articles that have received 317 citations. "PROCEDIA COMPUTER SCIENCE" has an h-index of 7, a g-index of 14, and an m-index of 0.778. Since 2016, it has published 14 articles, garnered 531 citations. Table 2 shows the top ten most influential sources in the field.

Table 2. Top ten most influential sources

Element	h_index	g_index	m_index	TC	NP	PY_start
IEEE ACCESS	14	27	1.75	745	27	2017
SENSORS	14	20	3.5	435	37	2021
SENSORS (SWITZERLAND)	14	15	1.556	1322	15	2016
IEEE INTERNET OF THINGS JOURNAL	11	21	2.2	503	21	2020
WATER (SWITZERLAND)	9	19	1.125	462	19	2017
SUSTAINABILITY (SWITZERLAND)	8	12	1.333	442	12	2019
ADVANCES IN INTELLIGENT SYSTEMS AND COMPUTING	7	12	0.778	152	25	2016
APPLIED SCIENCES (SWITZERLAND)	7	11	1.4	142	11	2020
IEEE SENSORS JOURNAL	7	10	0.636	317	10	2014
PROCEDIA COMPUTER SCIENCE	7	14	0.778	531	14	2016

4.6. Keyword Co-Occurrence

The keyword co-occurrence network analysis reveals the most significant terms related to water quality and the Internet of Things (IoT), highlighting their interconnections and prominence in the research field.

The top keyword, "Internet of Things (IoT)," appears 1,622 times with a total link strength of 18,907, underscoring its central role in the research landscape. This keyword emphasizes IoT technologies' widespread application and importance in water quality research. Similarly, the keyword "water quality" has 1,131 occurrences and a total link strength of 13,992, reflecting its critical importance in the domain. Both these keywords belong to clusters 1, 3, 5, and 8, indicating their extensive interconnectedness with other key terms.

The term "IoT," a variant of the Internet of Things, appears 615 times with a total link strength of 6,213, further emphasizing the technological focus in this research area (cluster 2). The keyword "monitoring," with 331 occurrences and a total link strength of 4,365, highlights the importance of continuous and systematic water quality assessment, making it a significant aspect of the research (cluster 8).

"Water quality monitoring" appears 322 times with a total link strength of 4,118, signifying dedicated efforts to monitor water quality (cluster 8) specifically. Another variant, "Internet of Things (IoT)," has 342 occurrences and a total link strength of 3,887, indicating substantial research attention (cluster 3). The term "water pollution," with 277 occurrences and a total link strength of 3,793, points to the critical issue of water contamination that needs to be addressed (cluster 2).

"Quality control," occurring 252 times with a total link strength of 3,539, reflects the emphasis on maintaining water standards (cluster 5). The integration of advanced computational techniques in water quality research is highlighted by the term "machine learning," which has 229 occurrences and a total link strength of 3,098 (cluster 5). Lastly, "water management" appears 205 times with a total link strength of 2,792, highlighting the strategic efforts to manage water resources (cluster 2) effectively.

These top ten keywords provide a comprehensive overview of the primary research focus areas within the field, emphasizing the integration of IoT technologies, systematic monitoring and control, and advanced computational methods to address water quality and pollution issues.

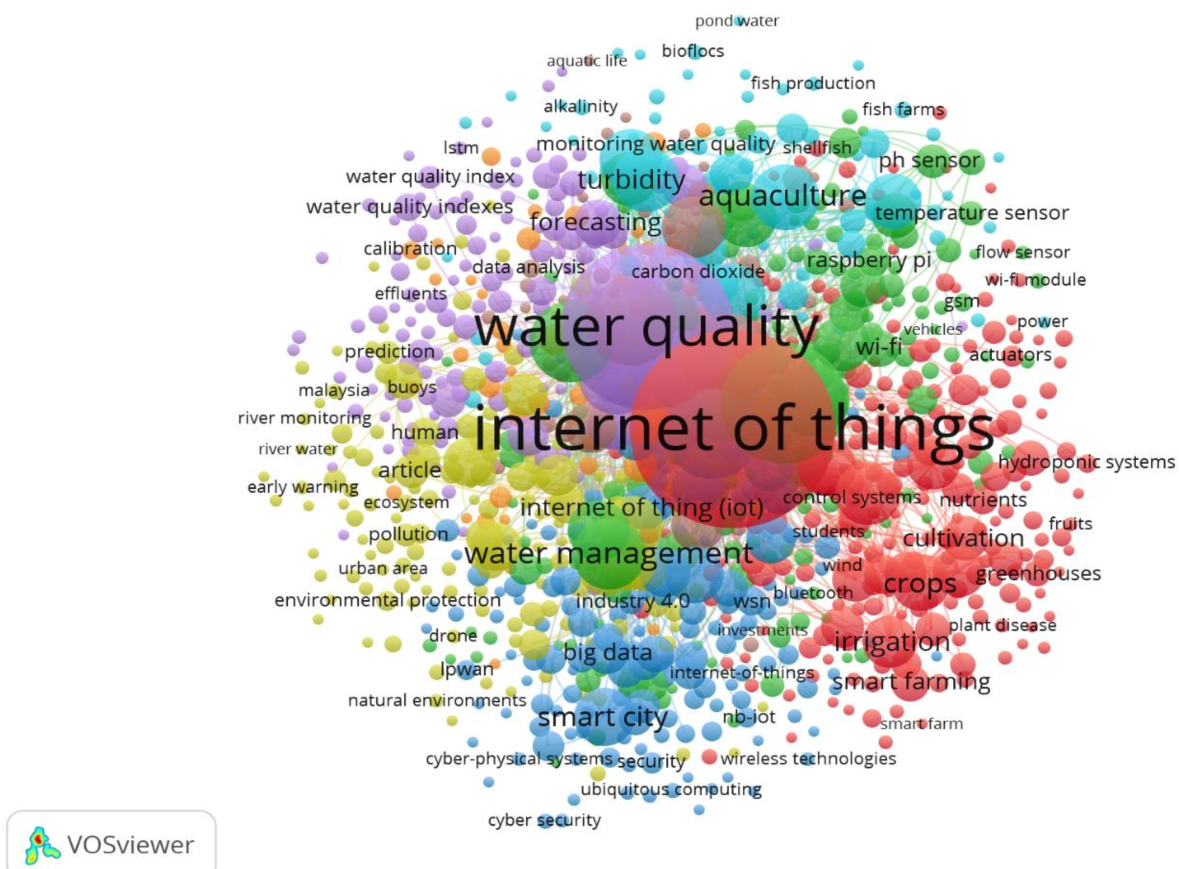

Fig. 5 Keyword co-occurrence network

4.7. Influential Affiliations

The analysis of influential affiliations in the field of water quality and the Internet of Things identifies several institutions that have made significant contributions through their research outputs.

"Universiti Teknologi Malaysia" leads the field with a total of 44 articles. Close behind is "Telkom University", which has published 43 articles. The "School of Information Engineering" also stands out, contributing 39 articles to the literature.

"Kongu Engineering College" and "Tunghai University" have both published 31 articles each, marking their significant presence in this research area. "SRM Institute of Science and Technology" and "Universiti Kuala Lumpur" have each contributed 29 articles, showcasing their active involvement in the field.

"National Taiwan Ocean University" has published 28 articles, further emphasizing its role in advancing research on water quality and the Internet of Things. Finally, "Sri Sairam Engineering College" has produced 27 articles, rounding out the list of top contributing affiliations.

These institutions represent the leading academic and research bodies driving forward the study and application of IoT in water quality management, highlighting their pivotal roles in this interdisciplinary domain. Figure 6 shows the most influential affiliations.

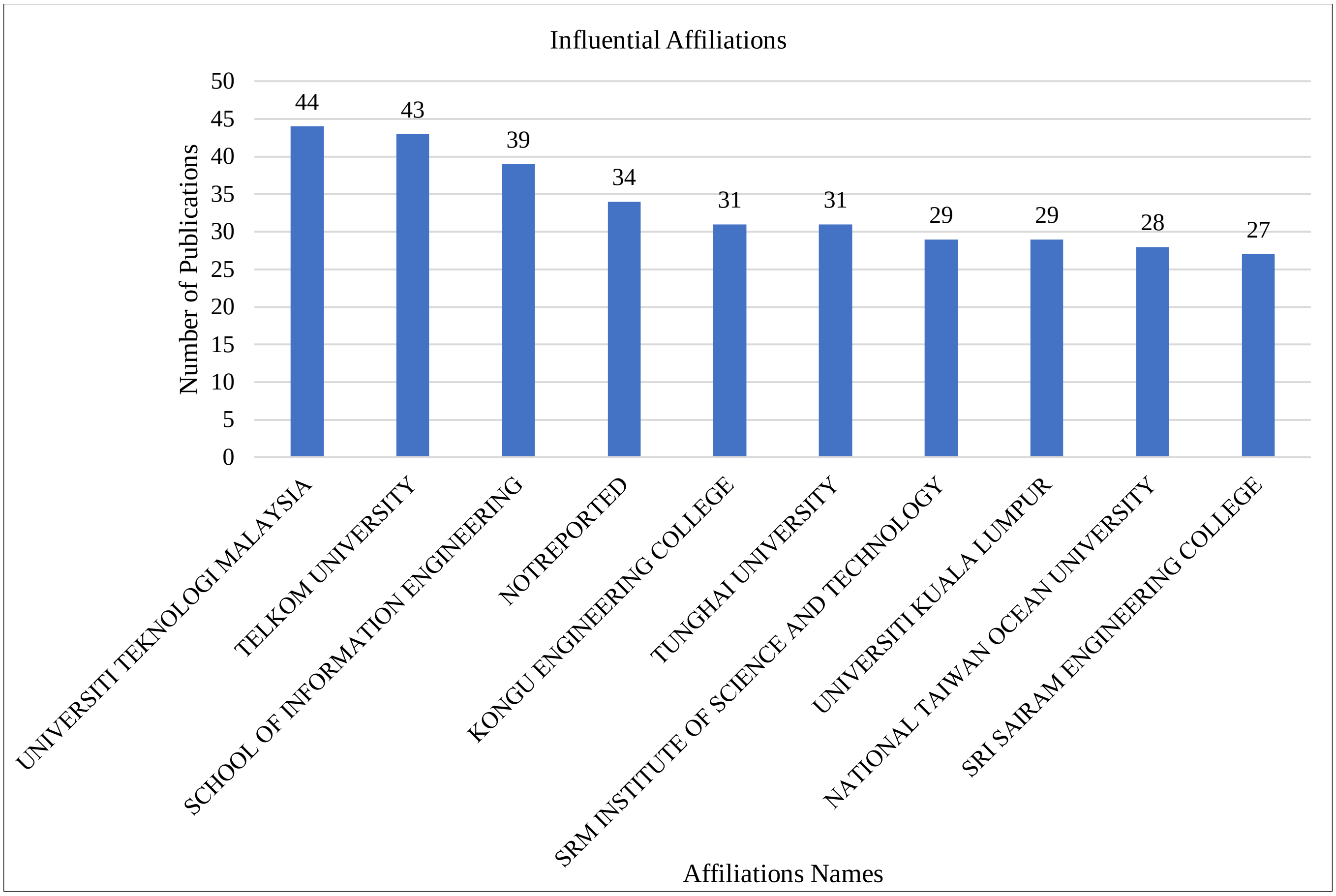

Fig. 6 Influential affiliations

The integration of IoT, AI, and ML technologies in water quality monitoring has shown promising advancements, as demonstrated by the findings from our bibliometric analysis. The increased publication trends observed from 2014 to 2024 reflect a growing interest and investment in this interdisciplinary field. The results align with the broader global focus on sustainable water management and the pursuit of smart solutions to environmental challenges.

Our analysis highlighted a few key trends and gaps. In the publication output, the dominance of certain countries, particularly the United States and China, underscores the uneven global research distribution. This concentration suggests that while some regions are pioneering advancements in water quality monitoring through IoT and AI, other regions, particularly developing countries, might lag. The underrepresentation of these regions in the literature suggests a need for more inclusive and diverse research efforts that address regional water quality challenges and resource constraints.

The methods employed in the analysed studies reveal a strong focus on developing and implementing IoT-based sensors and AI algorithms for water quality monitoring. However, there appears to be a limited exploration of these technologies' practical deployment and maintenance challenges in real-world settings. Many studies remain at the prototype or pilot stage, with few transitioning to large-scale implementation. This gap indicates the need for more applied research that bridges the gap between theoretical advancements and practical applications.

Another significant finding from our results is the underdeveloped area of predictive analytics within IoT-based water quality monitoring systems. While AI and ML models have demonstrated the potential to predict water quality parameters, there is a lack of integration of these predictive models into operational IoT networks. Future research should focus on developing robust, real-time predictive models that can be seamlessly integrated into existing IoT frameworks to provide proactive water quality management solutions.

Ethical considerations, including data privacy and security, are also areas that require more attention. With the increasing deployment of IoT devices, the potential for data breaches and misuse of information becomes a significant concern. Our analysis found limited discussion on these aspects within the current literature, indicating a need for comprehensive studies addressing IoT's ethical and legal implications in water quality monitoring.

Overall, while the field has made substantial progress, there are clear areas that require further exploration to ensure the effective and sustainable use of IoT, AI, and ML technologies in water quality monitoring. Addressing the identified gaps will be essential for advancing this field and achieving more equitable and efficient water management practices globally.

5. Limitations of the Study

The results and discussion may be presented separately or in one combined section and may optionally be divided into headed subsections. Despite the comprehensive approach employed in this bibliometric analysis, several limitations should be acknowledged. Firstly, the study exclusively utilized the Scopus database for data collection. While Scopus is a reputable and extensive database, it may not cover all relevant publications in the field, potentially omitting important research indexed in other databases such as Web of Science, PubMed, or Google Scholar. This limitation could affect the comprehensiveness and generalizability of the findings.

Secondly, the analysis was restricted to publications in English, which may introduce language bias and exclude significant research published in other languages. This restriction could particularly impact the representation of studies from non-English-speaking regions, potentially skewing the results towards predominantly English-speaking countries and institutions.

The search strategy, while detailed, may not capture all relevant literature due to variations in terminology and indexing practices. The specific search string used (TITLE-ABS-KEY (water AND quality) AND TITLE-ABS-KEY (internet AND of AND things) OR TITLE-ABS-KEY (iot)) may miss relevant articles that do not explicitly use these keywords in their titles, abstracts, or keywords.

During the data screening process, a significant number of records were removed due to incomplete information and duplication. Although necessary for data quality, this reduction in dataset size (from 2,582 to 2,430 records) could potentially exclude some relevant studies, affecting the overall analysis. Furthermore, the analysis relied on bibliometric tools such as Excel, VOSviewer, and the Bibliometrix package in R, which, while powerful, have inherent limitations. For instance, the accuracy of author name disambiguation, affiliation matching, and keyword co-occurrence analysis may be compromised by variations in data entry and indexing practices.

Finally, the study's timeframe (2014 to July 10, 2024) excludes recent publications that may not yet have accumulated citations or significant impact. This could lead to underestimating the influence of newer research and emerging trends within the field. These limitations highlight the need for cautious interpretation of the results and suggest that future studies could benefit from incorporating multiple databases, broader language inclusion, and ongoing updates to capture the evolving landscape of research on water quality and the Internet of Things.

6. Conclusion and Research Directions

This bibliometric analysis provides valuable insights into the growing research interest and evolving landscape of water quality and the Internet of Things (IoT) from 2014 to July 10, 2024. The study reveals a significant increase in both publications and citations over the years, indicative of escalating interest and impact in this interdisciplinary field. Document analysis shows that conference papers and articles are predominant, highlighting active dissemination and peer-reviewed research output in professional forums. Geographically, contributions are diverse, with significant outputs from countries like India, the United States, China, and various European nations, underscoring global collaboration in addressing challenges related to water quality monitoring and IoT applications. Key authors and influential sources identified through the analysis underscore the pivotal role of technological advancements and interdisciplinary approaches in tackling water quality issues through IoT solutions.

Future research in this field should consider several avenues based on the findings of this bibliometric analysis. Firstly, integrating emerging technologies such as artificial intelligence, blockchain, and edge computing could enhance the efficiency and real-time capabilities of water quality monitoring and management systems. Secondly, fostering multidisciplinary collaborations among water quality experts, IoT technologists, data scientists, and environmental engineers can stimulate innovative solutions to complex challenges at the intersection of water quality and IoT. Thirdly, future studies should expand beyond English-language publications to encompass research in other languages and databases to mitigate language bias and improve global representation. Longitudinal studies beyond 2024 would capture emerging trends and technological advancements, ensuring ongoing relevance and applicability of research findings. Additionally, exploring the impact of research on policy formulation and implementation strategies can bridge the gap between academic findings and practical applications, promoting sustainable water management practices worldwide. Further investigation into quality assurance protocols, standardization of IoT devices, and validation methodologies could enhance the reliability and accuracy of IoT-driven water quality monitoring systems.

Lastly, assessing the direct public health implications of improved water quality facilitated by IoT technologies would provide compelling evidence for policymakers and stakeholders, guiding future interventions and investments in this growing field of research.

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