A Decadal Bibliometric Analysis of Research Trends in Sensor and IoT-based Water Quality Remote Monitoring Systems

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Abstract: - Water quality monitoring is critical for environmental protection, public health, and the maintenance of aquatic ecosystems. Recent advancements in sensor technology and the Internet of Things (IoT) have significantly enhanced water quality monitoring. This study conducts a review and bibliometric analysis of research trends in water quality monitoring using sensors and IoT systems from the past decade. Searches of the Scopus and Web of Science (WoS) databases identified 501 relevant English-language publications after duplicates were removed. Key findings include the average citation count of 12.19 per document and an average document age of 3.18 years, indicating a focus on recent research. The number of publications has grown steadily, from one in 2015 to 34 in 2022, with an annual growth rate of 5.5%. Notably, India, China, Malaysia, and the United States are the leading contributors. Bibliometric analysis using ScitoPy, Biblioshiny, VOSviewer, and descriptive statistics revealed emerging trends, collaboration patterns, and conceptual themes. Review and implementation papers are highly cited, underscoring their importance in consolidating knowledge and driving practical applications. A shift from foundational research to applied engineering innovations for water monitoring is evident. Current priorities emphasize demonstrating the environmental value and practical viability of sensor technologies. This comprehensive analysis identifies knowledge gaps and developmental trends, providing insights to guide future research and decision-making in water quality monitoring. The study aims to stimulate strategic research initiatives, foster collaborations, and advance sensor technology applications in environmental monitoring.

Key-Words: - Water quality, Sensors, Internet of Things, Monitoring, Bibliometric analysis.

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1 Introduction

Monitoring water quality is vital for protecting human and environmental health. Advances in sensor technologies and the Internet of Things (IoT) have enabled remote, real-time surveillance, fundamentally transforming approaches to water research and management. Despite these innovations, the knowledge structure, research evolution, and future directions of this field remain insufficiently understood.

Bibliometric techniques provide valuable tools for mapping research landscapes by revealing publication trends, collaboration networks, thematic structures, and emerging priorities. This study applies bibliometric analysis to comprehensively examine the intellectual and scientific development of sensor-based water quality monitoring systems.

The analysis identifies influential authors, institutions, and journals, while also uncovering patterns of international collaboration and disciplinary integration. Network mapping and overlay visualization further illustrate conceptual clusters, highlight emerging research themes, and indicate areas of growing scholarly attention. Together, these approaches provide a data-driven understanding of how the field has developed and where it is heading.

The findings contribute to a deeper understanding of high-impact studies, effective collaboration practices, and core thematic areas that underpin sensor-based water quality monitoring. In addition, the study highlights key publication outlets and best practices for maximizing scholarly visibility and impact.

Overall, this paper evaluates the current state and trajectory of research on sensor-based water quality monitoring. By clarifying the knowledge landscape through bibliometric insights, it offers strategic guidance for future research activities, academic collaboration, and investment, thereby accelerating progress and innovation in this critical domain.

2 Literature Review

Water quality monitoring relies on a wide range of sensors and technologies to measure parameters critical for assessing the health and safety of aquatic environments. Optical sensors exploit light properties to quantify turbidity, dissolved organic matter, and chlorophyll concentration [1]. Electrochemical sensors detect electrical signals from chemical reactions, enabling measurement of pH, conductivity, dissolved oxygen, and redox potential [2]. Physical sensors, including temperature probes and level detectors, directly capture parameters such as temperature, water level, and flow rate [3]. Chemical sensors, based on selective membranes or specific reactions, target ions and compounds such as ammonia, nitrate, phosphate, and heavy metals [4]. Each sensor category presents distinct advantages and constraints that determine its suitability for particular monitoring applications, influenced by accuracy, sensitivity, response time, operational stability, and cost.

Recent advances in sensor technologies are driving innovation in water quality monitoring, emphasizing enhanced performance, miniaturization, and integration with Internet of Things (IoT) platforms to improve data acquisition and analysis. Growing demand for real-time, actionable information has intensified research aimed at addressing persistent challenges in sensor deployment, calibration, long-term maintenance, and data interpretation. These developments are paving the way for more reliable, efficient, and sustainable approaches to water quality management.

2.1 Integration of Sensors with IoT Platforms

The integration of sensors with Internet of Things (IoT) platforms has become a cornerstone of modern water quality monitoring. Leveraging IoT technologies enables the collection, transmission, and real-time analysis of sensor data, thereby supporting continuous surveillance of water bodies with high efficiency and accuracy. This integration allows remote access to water quality information across diverse locations, empowering stakeholders to make timely and informed decisions on pollution control, resource allocation, and environmental conservation. Furthermore, IoT platforms facilitate the aggregation of heterogeneous sensor data, ensuring comprehensive spatial and temporal coverage. When coupled with advanced analytics and machine learning algorithms, IoT-enabled systems enhance data interpretation through predictive modelling, anomaly detection, and early-warning mechanisms for environmental hazards [5]. Collectively, the integration of sensors with IoT platforms represents a transformative shift in water quality monitoring, delivering scalable, cost-effective, and actionable insights that promote sustainable water resource management.

Equally critical to this transformation are data acquisition and transmission systems, which underpin the functionality of IoT-enabled monitoring. Advances in sensor and communication technologies have made data collection more efficient, cost-effective, and suitable for real-time applications [6]. Deployed sensors capture water quality parameters at regular intervals and transmit them via wireless communication networks to centralized databases or cloud-based platforms, enabling rapid detection of changes and swift responses to pollution incidents. In addition, data logging functions preserve historical datasets, facilitating trend analysis, model development, and long-term environmental assessments [7]. Robust and inclusive data acquisition and transmission frameworks therefore, form the backbone of modern water quality monitoring, ensuring evidence-based decision-making and supporting sustainable management of aquatic ecosystems.

3 Methodology

A multi-dimensional bibliometric approach was employed, combining performance analysis, science mapping, and network analysis. Performance analysis examined publication trends and growth rates over time, providing insights into research productivity. Science mapping, conducted in VOSviewer, generated spatial visualisations of bibliometric networks, highlighting relationships among contributing countries, authors, and research topics. Network analysis further examined collaboration patterns and identified influential studies through citation linkages.

Specifically, Biblioshiny was applied to assess temporal trends in publication output and growth dynamics. VOSviewer enabled the construction of co-authorship and bibliographic coupling networks, facilitating visualisation of the intellectual and collaborative structure of the field. Additionally, keyword co-occurrence analysis in VOSviewer revealed thematic clusters and emerging research topics. Collectively, this multi-tool bibliometric strategy provided both quantitative performance metrics and qualitative visual analytics, offering a comprehensive overview of the sensor-based water quality monitoring systems research landscape.

In this stage, the bibliometric review was based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Review (PRISMA-ScR) guidelines [8]. There are five (5) approaches that were applied as outlined below:

3.1 Stage 1: Research Questions

The overall research objective was to comprehensively review the existing literature on related studies on sensor-based water quality monitoring systems. Hence, the current review sought to answer the following questions:

i) What are the publication trends, most influential authors, and seminal studies?

ii) What collaboration networks exist based on co-authorships and co-occurrence of authors' keywords?

iii) What are the implications for future research, policy, and practice based on the thematic mapping?

3.2 Stage 2: Identifying Relevant Studies

A systematic search of Web of Science (WoS) and Scopus databases was performed using the search strategy detailed below. English language articles and reviews published during 2011-2024 will be included.

Web of Science	water (All Fields) and quality (All Fields) and control* (All Fields) and "internet of thing" or "iot" (All Fields) and "sensor*" (All Fields) and 2024 or 2023 or 2022 or 2021 or 2020 or 2019 or 2018 or 2017 or 2016 or 2015 or 2013 or 2012 or 2011 (Publication Years) and Article or Review Article (Document Types) and English (Languages)
Scopus	(TITLE-ABS-KEY (water) AND TITLE-ABS-KEY (quality) AND TITLE-ABS-KEY (monitor*) AND TITLE-ABS-KEY ("internet of thing" OR "iot") AND TITLE-ABS-KEY ("sensor*")) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re"))

3.3 Stage 3: Study Selection

Two independent reviewers will screen retrieved titles/abstracts against eligibility criteria. Full texts will then be assessed for inclusion. Quality appraisal will be undertaken using tools like the Newcastle-Ottawa Scale. Any disagreements will be resolved through discussion.

3.4 Stage 4: Extracting and Charting Data

Initial search results yielded 563 articles, with 120 from WoS and 443 from Scopus. Deduplication will be performed to remove duplicate articles that exist across both databases. ScientoPy identified 62 duplicate articles, all originating from Scopus. After duplicate removal, the dataset comprised 501 unique articles - 120 from WoS and 381 from Scopus.

3.5 Stage 5: Analyzing, Reporting and Visualizing Results

In this last stage of review, the relevant findings according to research questions were presented in the form of frequency and percentage to describe key characteristics of included publications. Figure 1 indicates the flow diagram for this bibliometric analysis.

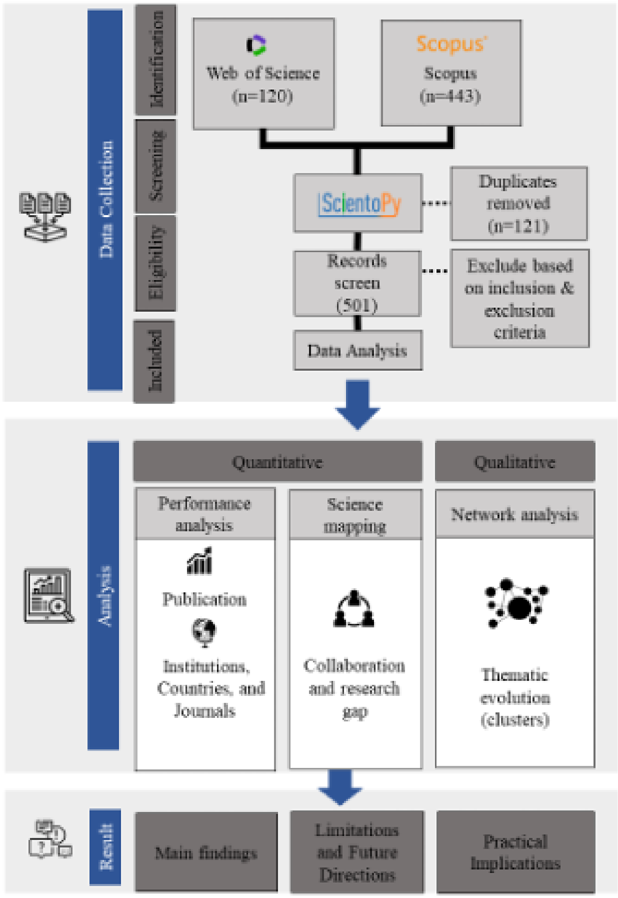

Fig. 1: The study flowchart.

4 Result and Discussion

4.1 Main Information

Table 1 presents the main bibliometric information on sensor-based water quality monitoring systems. The retrieved literature spanned 2011–2024 (14 years), comprising 501 documents from 278 sources, including journals, books, and conference proceedings. On average, each document was cited 12.19 times, with a mean age of 3.18 years, indicating a recent research focus. The annual growth rate was 5.5%, reflecting stable output.

Keyword analysis identified 2254 author keywords (Keywords Plus, WoS) and 1514 author-generated keywords (Scopus), showing extensive keyword use. A total of 2191 authors contributed, with only 17 publishing single-authored papers. The average of 5.56 co-authors per document highlights strong collaboration, while international co-authorship accounted for 20.96%, indicating moderate global partnerships.

Journal articles dominated (443), followed by reviews (51), with other types such as book chapters, conference papers, and data papers appearing less frequently. Citation analysis measured average citations per document and annual citation rates to identify high-impact years. Co-citation analysis clustered documents into thematic groups, while social network analysis mapped collaborations among authors, institutions, and countries. Overlay visualisation combined network and citation data to highlight key nodes.

Table 1. Main information about data.

DESCRIPTION	RESULTS
MAIN INFORMATION ABOUT DATA	
Timespan	2011:2024
Sources (Journals, Books, etc)	278
Documents	501
Annual Growth Rate %	5.5
Document Average Age	3.18
Average citations per doc	12.19
DOCUMENT CONTENTS	
Keywords Plus (ID)	2254
Author's Keywords (DE)	1514
AUTHORS	
Authors	2191
Authors of single-authored docs	17
AUTHORS COLLABORATION	
Single-authored docs	17
Co-Authors per Doc	5.56
International co-authorships %	20.96
DOCUMENT TYPES	
article	443
article; book chapter	1
article; data paper	1
article; early access	1
article; proceedings paper	3
review	51
review; early access	1

4.2 Publication Trends

Figure 2 shows the publication trends from the Scopus and Web of Science databases. In Scopus, there has been steady growth in publications on sensor-based water quality monitoring systems, increasing from 1 article in 2011 to 77 articles in 2023. The highest output was in 2021 with 86 documents. The annual growth rate was 5.5% and the average citations per document was 42.9.

Results from Web of Science also show a growth trend, with publications rising from 1 in 2015 to 34 in 2022. The annual growth rate matched Scopus at 5.5%, while the average citations per document were higher at 53.3.

Overall, these metrics indicate growing research activity and scholarly impact in this field over the past decade. The lack of publications before 2015 suggests this is an emerging research area that gained prominence in recent years. Continued growth is expected based on the positive trajectory and high citation rates observed in the last 3-5 years.

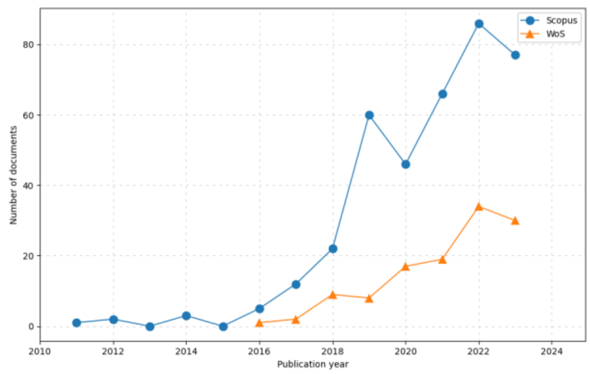

Fig. 2: The publication trends (2011-2024).

4.3 Top 20 Influential Authors

Table 2 shows the top 20 authors contributing research on sensor-based water quality monitoring identified by total publications, annual growth rate, average citations, and h-index.

The most productive authors in sensor-based water quality monitoring research were Alahi M.E.E., Mukhopadhyay S.C., and Chen Y., with 6 publications each. These three authors contributed significantly to the knowledge base through their high publication output.

Wang Y. stood out for having the highest average citations per document (60) and h-index (4) among the top authors. This indicates Wang Y.'s research has gained noticeable visibility and scholarly impact.

Several emerging influential authors were identified, such as Olatinwo S.O., Kumar M., and Zulkifli C.Z. They had positive annual growth rates, suggesting their publications in this field are steadily increasing.

The percentage of documents published recently in 2023-2024 was highest for Kumar M. (100%), Trevathan J. (75%), and Zulkifli C.Z. (75%). This shows their research productivity and contributions remained strong in the most recent years.

In terms of annual growth rates, most top authors had negative or zero growth, indicating their publications peaked in prior years and waned more recently. The few exceptions with positive growth were Olatinwo S.O., Joubert T.H., Kumar M., and Zheng, Y.

Overall, this analysis identifies both established researchers who laid the early groundwork as well as rising scholars who are advancing sensor-based water quality monitoring into the future. The combined contributions of these highly productive authors have shaped the research domain over the past decade.

Table 2. Top 20 Influential Authors.

Author	Total	AGR	ADY	PDLY	h Index
Alahi M.E.E.	6	-1.5	0.5	16.7	6
Mukhopadhyay S.C.	6	-2	0.5	16.7	6
Chen Y.	5	-1	0.5	20	5
Olatinwo S.O.	5	0.5	1	40	4
Wang Y.	5	0	1.5	60	4
Akhter F.	4	-1.5	0.5	25	4
Joubert T.H.	4	0.5	0.5	25	3
Liu Y.	4	0	0.5	25	4
Siddiquei H.R.	4	-1.5	0.5	25	4
Trevathan J.	4	-0.5	1.5	75	2
Zulkifli C.Z.	4	0.5	1.5	75	1
Abdullah N.F.	3	-0.5	1	66.7	2
Kumar M.	3	0.5	1.5	100	3
Nordin R.	3	-0.5	1	66.7	2
Sattar A.	3	-0.5	1	66.7	2
Singh R.	3	-0.5	0	0	3
Wang, M.	3	0.5	1	66.7	1
Zhang Z.	3	-1	0.5	33.3	2
Zheng, Y.	3	0.5	1	66.7	1
Zhang X.	2	-1	0	0	2

Note: AGR= Annual growth rates; ADY= Average paper per year; PDLY= percentage of documents published in 2023 and 2024

4.4 Top 20 Contributing Countries

Figure 3 presents the top 20 countries contributing to research on sensor-based water quality monitoring. India had the highest total publications with 149, followed by China with 70. Several emerging countries showed positive annual growth rates (AGR), such as Thailand (1.5%), Pakistan (1%), and South Africa (1%). This suggests their research productivity in this field is accelerating.

The countries with the highest percentage of recent publications in 2023-2024 (PDLY) were Thailand (70%), Pakistan (66.7%), and India (39.6%). Their strong recent output signifies growing national research engagement. Established leaders like India, China, and Malaysia contributed high total publications, reflecting early and sustained contributions. However, their negative or flat AGR indicates a slowing momentum recently.

By contrast, countries with positive AGR like South Africa, Brazil, Japan, and Mexico display rising strength despite moderate total outputs so far. Their growth trajectories mark them as emerging research nations to watch.

Overall, the landscape reveals shifting dynamics, with traditional powers like China and the UK slowing down while others like Thailand and South Africa gain ground. Continued monitoring of country-level trends will be important to understand the changing geography of sensor-based water quality monitoring research.

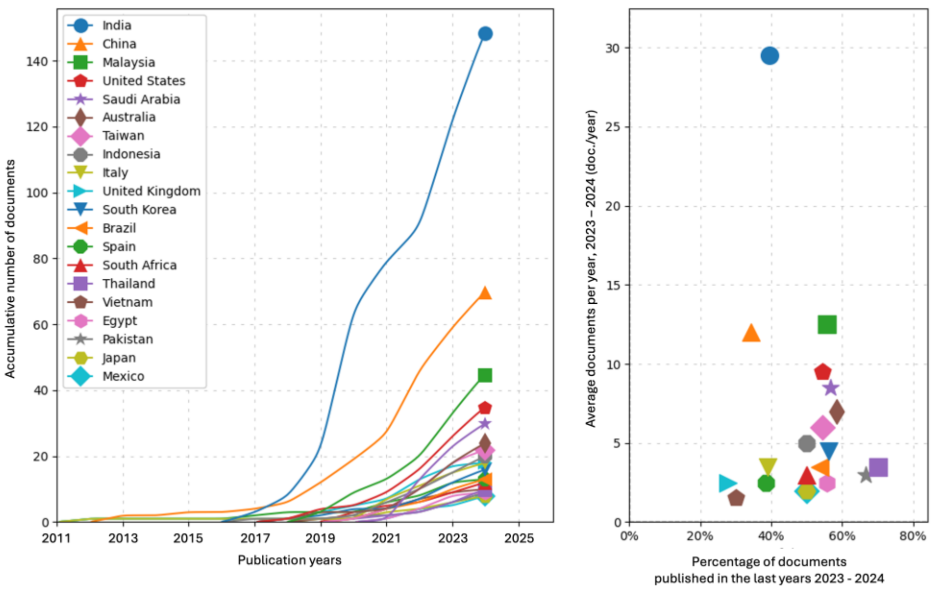

Fig. 3: Top 20 countries contributing to research on sensor-based water quality monitoring.

4.5 Co-Authorship Networks

Figure 4 shows the analysis of the co-authorship network based on the VOSviewer mapping. The co-authorship network reveals several key collaborations. Mukhopadhyay S.C. and Alahi M.E.E. had the strongest connection with 13 links and were located in the core IoT and wireless sensing cluster. Their joint publications and citations also ranked among the highest, marking them as leading collaborators advancing water quality monitoring research.

Akhter F. and Siddiquei H.R. formed another closely tied pair in the IoT cluster, reflecting their aligned research interests. Other notable links existed between Olatinwo S.O. and Joubert T.H. in the smart agriculture cluster, and between Chen Y. and Wang Y. in the water quality parameters group.

Certain authors like Kumar M., Zulkifli C.Z., and Singh R. occupied peripheral positions with no collaborations so far. Their solo authorship status presents opportunities to bring them into collaborative networks to increase connectivity across clusters.

The emerging techniques cluster contained weaker links overall, with authors like Sattar A. and Trevathan J. having few co-authorships despite reasonable productivity and impact. Strengthening ties between data analytics scholars and other clusters could promote cross-pollination of techniques and applications.

By integrating network and performance data, this analysis yields insights into impactful collaborations while also identifying possibilities to enhance connections through targeted co-authorships. This can help advance the holistic growth of the research domain.

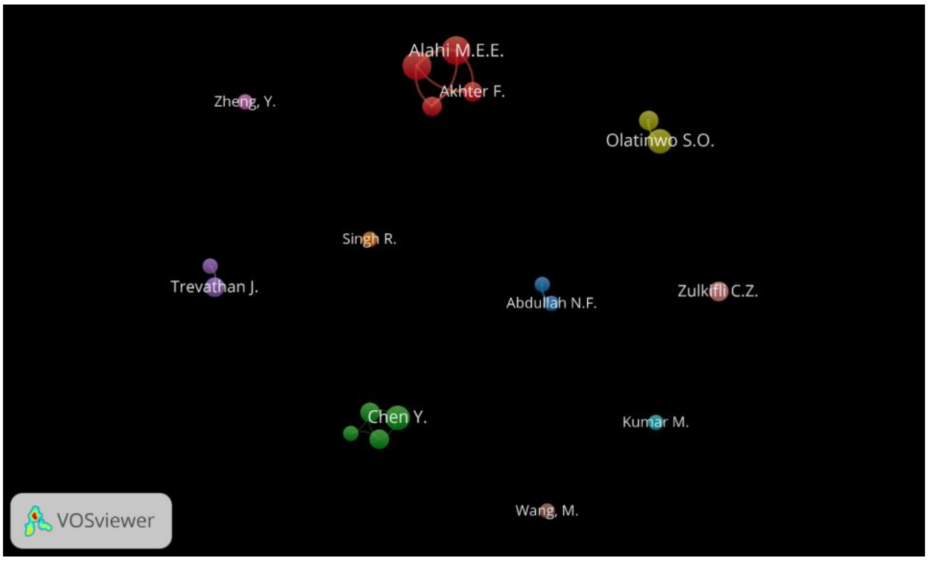

Fig. 4: The co-authorship networks.

4.6 Co-Occurrence Analysis of Author Keywords

Co-occurrence analysis of author keywords was conducted using full counting, with a minimum threshold of 10 occurrences. This resulted in 25 keywords meeting the threshold. Total link strength was calculated for each keyword to determine the top terms. Five clusters emerged from the analysis as shown in Figure 5:

Cluster 1: IoT and Wireless Sensing
This cluster contained keywords related to IoT, wireless sensing, smart systems, and cloud computing. Central terms were "internet of things", "wireless sensor network", "smart city", and "cloud". This reflects a focus on enabling technologies for remote water quality monitoring.

Cluster 2: Water Quality Parameters
Key concepts in this cluster were associated with monitoring specific water parameters like "pH", "turbidity", and "temperature". This points to research detecting and analyzing key water contaminants and indicators.

Cluster 3: Sensing Systems and Methods
Core keywords were "sensor", "monitoring", "arduino", and "water quality", highlighting work on developing and deploying sensor-based systems to monitor water.

Cluster 4: Smart Agriculture
Agriculture applications were prominent through keywords like "precision agriculture", "smart farming", "hydroponics", and "artificial intelligence". The cluster captures the use of smart sensor systems in agricultural water management.

Cluster 5: Data Analytics
The emerging techniques of "machine learning" and "deep learning" formed this cluster. It reflects a focus on applying advanced analytics to extract insights from sensor-based water data.

4.7 Thematic Mapping for Future Directions

Bibliographic coupling analysis uncovered four prevalent themes that categorize the knowledge structure of sensor-based water quality monitoring research. Thematic mapping techniques identified niche themes that drive specificity, motor themes that connect other topics, declining themes that are losing momentum, and basic themes that provide background context.

Niche themes represent rapidly emerging research areas, while motor themes denote established foundations that enable idea flows between speciality domains. Declining or basic themes signify formerly influential topics or broadly relevant backgrounds that are now less of a focal point. Mapping the thematic structure in this way provides strategic insights into the core, connecting, declining, and contextual knowledge elements in a research field. In the case of sensor-based water quality monitoring, this present study revealed four key themes in the literature, categorized (Refer to Figure 6) as niche themes, motor themes, declining themes, and basic themes based on Callon centrality, Callon density, and cluster frequency, as follows:

Niche Themes
"Internet of Things" - Highest Callon centrality (23.68) and cluster frequency (994), marking it as a niche theme driving research specificity.

Motor Themes
"Water management" - High Callon density (48.77) and centrality (13.36), signifying its role as a motor theme connecting other topics.
"Environmental monitoring" - Also a motor theme with elevated density (67.03) and centrality (20.10).

Declining or Basic Themes
"Internet" - Despite top-ranked centrality (12.89), its low density (47.04) indicates a declining or basic theme.

The prominence of IoT and water management as niche and motor themes, respectively, demonstrates their central roles in current sensor-based water quality monitoring research. Environmental monitoring likewise stands out as a core connecting topic in the literature.

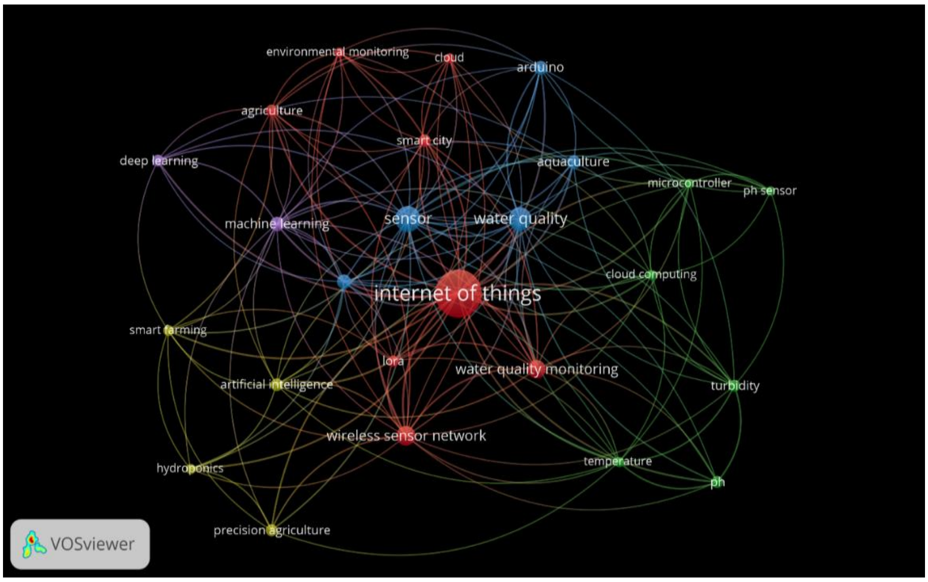

Fig. 5: The co-occurrence of the author's keywords networks.

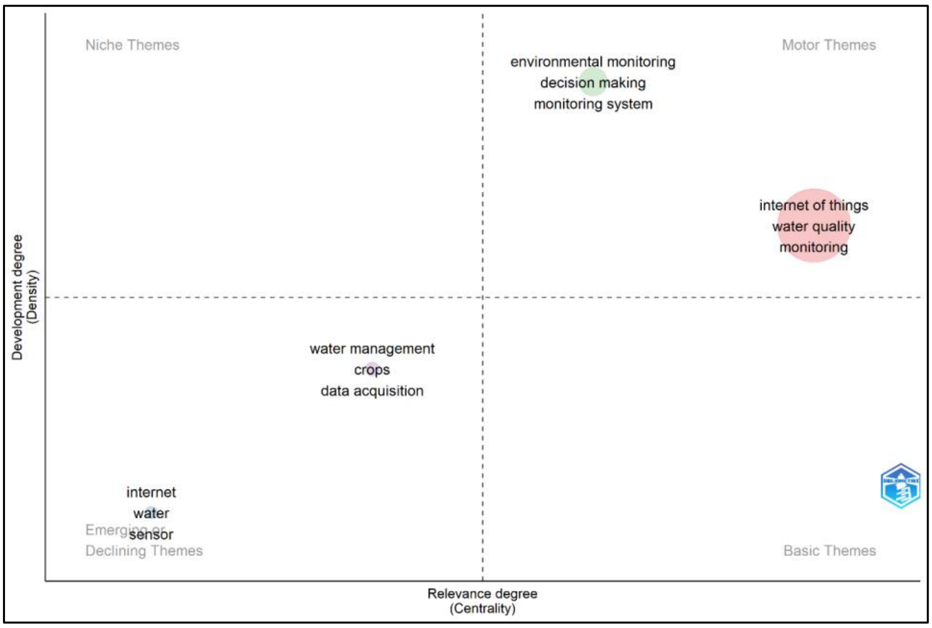

Fig. 6: Thematic map for trending niche areas.

4.8 Discussions

This study provides the first comprehensive review of research activity, trends, and knowledge structure in the emerging domain of sensor-based water quality monitoring. By combining publication and collaboration analyses with bibliometric mapping, it highlights the conceptual foundations and evolving directions of this field.

Several findings stand out. First, publication trends confirm rapid growth over the past decade, consistent with [9], who documented the rising adoption of IoT and sensor-based approaches for water monitoring. Continued expansion is expected as technologies advance and applications extend to smart cities, precision agriculture, and environmental management [10].

Second, productivity and citation metrics identify several influential authors, yet the field remains fluid, with new researchers gaining visibility. Unlike mature domains where citations consolidate around established scholars, this indicates opportunities for emerging voices to shape research trajectories.

Third, India, China, and Malaysia dominate output, mirroring [11], who noted their leadership in IoT and sensor research, supported by strong engineering and technology sectors. Meanwhile, increasing contributions from countries such as Thailand and South Africa reflect growing geographical diversity, reinforcing the openness of this research niche.

Fourth, publication outlets are concentrated in sensor, IoT, and engineering journals, reflecting the technological nature of the field. However, many articles appear in lower-visibility regional titles. Publishing in higher-impact international journals could enhance visibility and influence, particularly within biosystems engineering and related domains.

Fifth, seminal studies have established technological frameworks, systems designs, and methodological advances. Yet, relatively few integrate social, policy, or governance perspectives, in contrast to fields such as smart cities, where interdisciplinary approaches are common [12,13]. Future work should bridge technical innovations with social science, public policy, legal, and ethical dimensions to ensure broader applicability and adoption.

Finally, thematic mapping reveals water management and environmental monitoring as core clusters, with the Internet of Things emerging as the dominant niche. This mirrors the technology-application dichotomy observed in IoT research by [15]. Integrative studies combining IoT methodologies with practical domain applications, particularly through mixed-methods approaches, could provide richer insights into development, deployment, and impacts of sensor-based water monitoring systems.

In sum, this bibliometric review offers a valuable knowledge synthesis of sensor-based water quality monitoring. It characterizes the field’s current state, identifies gaps, and highlights pathways for future advancement. The multi-dimensional analysis also serves as a model for evaluating other interdisciplinary domains that span technological innovation, engineering design, and applied environmental management.

5 Conclusion

This bibliometric analysis offers a comprehensive overview of sensor-based water quality monitoring research, examining publication trends, contributors, collaboration networks, and thematic structures. Results show rapid growth in publications and citations over the past decade, reflecting the field’s rising prominence. While India, China, and Malaysia dominate output, contributions are expanding globally, creating opportunities for emerging scholars to shape the research landscape.

Key themes include the Internet of Things, water management, and environmental monitoring, underscoring the need to link technological innovation with applied practice. However, limited interdisciplinarity highlights gaps in integrating social, policy, and governance perspectives.

To strengthen impact, researchers are encouraged to publish in high-visibility journals, employ mixed-methods approaches, and build collaborations across disciplines and regions. Overall, this review maps the intellectual foundations and strategic directions of sensor-based water quality monitoring, offering guidance to maximize research visibility, foster interdisciplinary integration, and advance sustainable water resource management.

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