



Lake and Water Governance Research Trajectories in Stakeholder Engagement and Participation

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ABSTRACT

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Global water governance faces a multidimensional crisis, with two billion people lacking safe drinking water access and lake ecosystem degradation threatening food security. Despite recognition of stakeholder engagement's importance, no comprehensive bibliometric study has systematically mapped this research evolution. This study analyzes lake and water governance research evolution from 2000 to 2025, maps dominant themes, identifies international collaboration networks, and highlights research gaps in developing countries. Bibliometric analysis following PRISMA protocol used Scopus and Web of Science databases. From 1,385 initial documents, 660 articles were analyzed after duplicate removal and relevance screening using Biblioshiny for science mapping and network visualizations. Results revealed a 15.78% annual growth rate, peaking at 73 articles in 2024. Dominant concepts included management, governance, climate change, and stakeholder participation. The United States led with 355 publications, followed by Australia and the Netherlands. Geographic disparities showed OECD dominance, with Africa-South Asia underrepresented. International collaboration reached 32.27%. Water governance research has transitioned toward adaptive-participatory paradigms; however, persistent North-South disparities emphasize the need for democratizing research and strengthening developing country capacity.

1. INTRODUCTION

Over the past two decades, water resource governance has undergone a fundamental transformation from a technocratic approach dominated by technical-hydraulic solutions toward a more holistic, participatory, and adaptive paradigm. This shift has been driven by the recognition that contemporary water challenges—ranging from water scarcity affecting 2 billion people to aquatic ecosystem degradation threatening global food security—cannot be resolved through technical interventions alone, but rather require governance reforms that integrate social, political, economic, and ecological dimensions [1]. The global water crisis, exacerbated by climate change, population growth, and rapid urbanization, has positioned water governance as one of the most critical issues on the sustainable development agenda. Governance failure, rather than physical water scarcity, constitutes the root cause of most water crises facing the world today, underscoring the urgency of institutional and policy reforms centered on stakeholder participation [2].

The concepts of stakeholder engagement and public participation have emerged as fundamental pillars in modern water governance, driven by principles of deliberative democracy and recognition of the plurality of values and knowledge in natural resource management. Participatory

approaches in water governance represent not merely a normative response to demands for democratization, but also a pragmatic strategy to enhance the effectiveness, legitimacy, and sustainability of water management decisions [3]. Effective stakeholder engagement processes in water management have demonstrated significant long-term benefits compared to non-participatory approaches, including better policy outcomes, improved governance quality, and enhanced cost efficiency [4]. Nevertheless, implementing participatory approaches faces significant challenges, including power imbalances, uneven capacities, and the risk of participation fatigue that can erode the effectiveness of deliberative processes [5].

The evolution of water governance paradigms cannot be separated from the context of climate change, which presents unprecedented uncertainty and complexity. Climate change has intensified the global hydrological cycle, causing increased frequency and intensity of extreme events such as floods and droughts, which in turn demand more adaptive and responsive governance approaches [6]. The concept of adaptive water governance offers a framework for managing uncertainty through social learning, policy experimentation, and institutional flexibility [7]. This approach recognizes that water governance systems must be capable of evolving and adapting to changing social-ecological conditions, requiring

effective feedback mechanisms and capacity for systemic transformation when necessary.

Research on lake governance specifically presents additional dimensions of complexity, given the unique characteristics of lake ecosystems as closed landscape-connected social-ecological systems. Lakes provide vital ecosystem services—including drinking water provision, food production, microclimate regulation, and recreational-cultural values—yet remain highly vulnerable to anthropogenic pressures such as eutrophication, sedimentation, and pollution [8]. Global lake degradation has reached a critical point, with 50% of the world's large lakes experiencing significant water quality decline over the past three decades [9]. The complexity of lake management is compounded by multi-jurisdictional characteristics, where a single water body may fall under multiple administrative authorities, often holding different priorities and approaches, necessitating sophisticated coordination and collaboration mechanisms.

Within the context of the Sustainable Development Goals (SDGs), effective water governance becomes a fundamental prerequisite for achieving not only SDG 6 (Clean Water and Sanitation) but also contributes directly and indirectly to nearly the entire SDG agenda. The systemic interconnections between water and other development dimensions are critical, where failures in water governance can trigger domino effects that impede the achievement of sustainable development goals overall [10]. However, despite growing recognition of the importance of water governance, significant gaps remain in understanding how water governance concepts and practices have evolved, what factors drive change, and how scientific knowledge in this field is produced and disseminated.

Bibliometric analysis offers a systematic approach to mapping the intellectual landscape of water governance research, identifying trends, collaboration patterns, and conceptual evolution shaping this field. While several reviews have examined specific aspects of water governance, for instance, water governance [11], participatory water management [12], no comprehensive bibliometric analysis has specifically explored the evolution of lake and water governance research with a focus on stakeholder engagement and public participation dimensions. This gap becomes increasingly critical given the surge in research publications in this field, requiring systematic synthesis to identify achievements, gaps, and future directions.

Therefore, this study aims to address this gap by conducting a comprehensive bibliometric analysis of lake and water governance research during the period 2000-2025, with particular focus on the evolution of stakeholder engagement and public participation concepts and practices. Through systematic analysis of 660 publications from Scopus and Web of Science databases, this research seeks to: (1) map the thematic and conceptual evolution in water governance research; (2) identify collaboration patterns and knowledge networks shaping scientific production in this field; and (3) reveal research gaps and opportunities for future knowledge development, particularly in the context of developing countries and implementation of more inclusive participatory approaches. The findings from this study are expected to provide crucial insights for researchers, practitioners, and policymakers in developing more effective, inclusive, and sustainable water governance approaches to address 21st-century water challenges.

2. METHODOLOGY

Bibliometric analysis has evolved into a fundamental method in scientific research since its introduction by Eugene Garfield in the mid-20th century, providing a systematic approach to mapping the intellectual landscape and evolution of scientific fields [13]. This method, situated within the domain of scientometrics, enables researchers to apply quantitative and statistical techniques in analyzing scientific publication patterns, citation networks, and research collaboration dynamics [14, 15]. In the context of water governance research, bibliometric approaches offer unique capabilities to identify research trends, measure scientific impact, map conceptual evolution, and reveal knowledge gaps requiring further attention [16]. By systematically analyzing publication metadata, this method enables a comprehensive understanding of the structure and dynamics of lake and water governance research, including the identification of influential researchers, leading institutions, and international collaboration networks that shape academic discourse in this field.

This study employs a combination of Scopus and Web of Science (WoS) databases as primary data sources, considering that both databases represent leading bibliographic repositories with global coverage and rigorous curation standards [17]. Scopus, managed by Elsevier, was selected for its extensive coverage encompassing more than 25,000 active journals from 5,000 international publishers, with particular strength in environmental sciences and engineering relevant to water governance research [18]. Meanwhile, Web of Science from Clarivate Analytics provides a complementary perspective with more selective indexing yet deeper historical publication coverage, enabling longitudinal analysis of research evolution since 2000. The combination of both databases reduces coverage bias and enhances analytical comprehensiveness, consistent with recommendations regarding multiple database usage in bibliometric studies to ensure a more accurate representation of the global research landscape [19].

2.1 Data collection and search strategy

This research implements the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol to ensure transparency and reproducibility in the literature selection process. The updated PRISMA 2020 framework was employed with four main phases: identification, screening, eligibility assessment, and inclusion, enabling systematic documentation of each article selection stage [20]. For the identification phase, we utilized a combination of Scopus and Web of Science databases with a comprehensive Boolean search strategy to capture the entire spectrum of lake and water governance research focusing on stakeholder engagement (Figure 1).

The search strategy was designed using the query string: ("lake governance" OR "water governance" OR "freshwater governance") AND (stakeholder* OR "stakeholder engagement" OR "stakeholder participation"), applied to title, abstract, and keyword fields. The selection of search terms was based on a preliminary literature review and consultation with domain experts to ensure comprehensive yet focused coverage of the research topic. The search was conducted on 06 August 2025 for the publication period 2000-2025, encompassing 25 years of research evolution in this field. This timeframe was

selected to capture significant developments in water governance paradigms, including the transition from technocratic approaches toward participatory models that rapidly evolved following the adoption of Integrated Water Resources Management (IWRM) in the early 2000s.

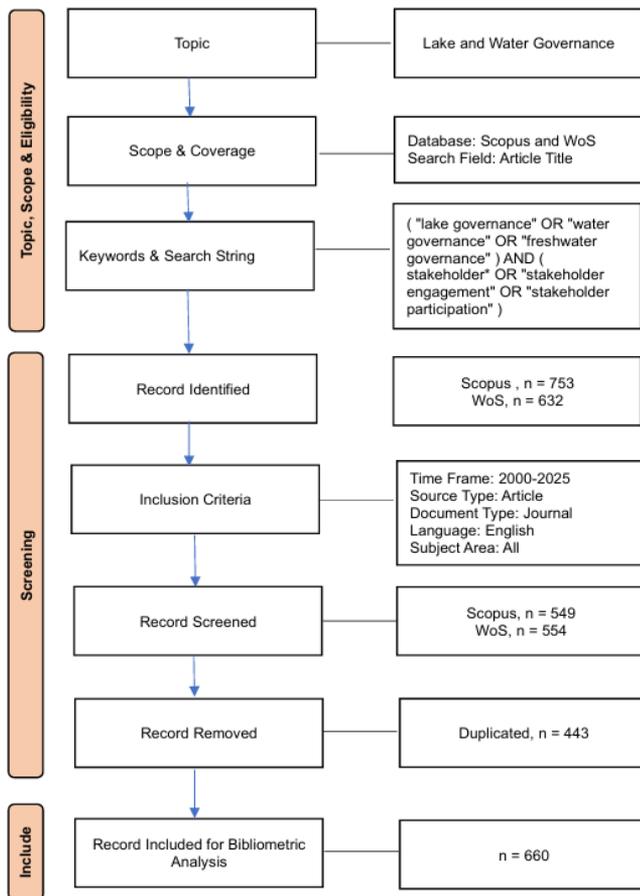


Figure 1. PRISMA flow diagram

The initial search yielded 753 documents from Scopus and 632 documents from Web of Science, totaling 1,385 documents. Applied inclusion criteria comprised: (1) peer-reviewed journal articles in English to ensure quality and international accessibility; (2) explicit focus on lake or water governance with stakeholder engagement components; and (3) final publications (excluding in-press or early access articles that might be subject to change). Restricting document type to "article" and language to "English" reduced the count to 549 documents from Scopus and 554 documents from Web of Science, totaling 1,103 documents. After removing 443 duplicate documents using R Studio with the bibliometrix package [16], 660 unique documents remained. Further screening based on content relevance produced a final dataset of 660 articles meeting all criteria for in-depth bibliometric analysis. The complete PRISMA flow diagram documents each stage of the selection process (Figure 1), including exclusion reasons for methodological transparency.

2.2 Data analysis

The bibliometric analysis in this study was conducted using Biblioshiny, a web-based R application that serves as an extension of the Bibliometrix package version 4.1.4, providing a user-friendly graphical interface for comprehensive bibliometric analysis without requiring advanced

programming expertise [16]. This platform was selected for its capability to integrate various bibliometric analysis techniques within a single ecosystem, ranging from descriptive statistics to complex network visualizations, as well as its compatibility with data formats from Scopus and Web of Science. Biblioshiny facilitates multi-dimensional analysis encompassing: (1) performance analysis to measure productivity and scientific impact; (2) science mapping to visualize intellectual structure and conceptual evolution; and (3) network analysis to reveal collaboration and co-citation patterns.

The analysis process began with importing the cleaned dataset into Biblioshiny, where data from both databases were merged and harmonized to eliminate inconsistencies in author names, affiliations, and keywords. Descriptive analysis was performed to generate an overview of the dataset, including the temporal distribution of publications, author and institutional productivity, and document characteristics. For network analysis, we employed the Louvain clustering algorithm to identify research communities and normalized co-citation analysis to map the intellectual evolution of this field. Keyword co-occurrence analysis was conducted with a minimum threshold of 5 occurrences to ensure statistical significance, producing visualizations that illustrate dominant themes and conceptual relationships in water governance research.

Thematic evolution was analyzed using the Sankey diagram method, dividing the research period into five time intervals (2000-2005, 2006-2010, 2011-2015, 2016-2020, 2021-2025) to track shifts in research focus and the emergence of new themes. International collaboration analysis was performed at both the country and institutional levels, utilizing metrics such as the collaboration index and total link strength to measure research cooperation intensity. To ensure result robustness, we applied sensitivity analysis by varying threshold parameters and comparing results with alternative methods. Result visualization employed a combination of network plots, heat maps, tree maps, and word clouds to present findings comprehensively and interpretably, enabling identification of patterns, trends, and gaps in the lake and water governance research landscape.

3. RESULTS

The bibliometric analysis in this study was conducted to examine the development of research related to lake and water governance, utilizing Scopus and Web of Science (WoS) databases as primary data sources to analyze publication patterns, citation networks, and research impact intensity. The analytical approach applied encompasses several dimensions: dataset overview, temporal distribution of publications, source and author productivity, international and institutional collaboration, high-impact documents, thematic research evolution, and keyword mapping. The findings obtained from both databases are presented systematically as follows.

3.1 Main information

This study limited its analytical scope by including only articles published between 2000 and 2025. As shown in Table 1, the field has experienced significant development with a total of 660 documents published from 241 different sources. The annual growth rate of 15.78% demonstrates continuously

increasing research interest in this topic, with an average document age of 6.06 years, indicating that most research remains relatively recent and relevant. Notably, each document has an average of 15.31 citations, signifying the substantial scientific impact of these publications. The involvement of 2,263 authors, with 96 single authors, demonstrates the dominance of collaborative research in this field, reinforced by an average of 4.08 co-authors per document and an international collaboration rate of 32.27%. Regarding document types, journal articles dominate with 627 publications (95%), while the remainder consists of articles in press, book chapters, and conference proceedings, indicating that research in lake and water management has achieved a high level of academic maturity with a primary focus on high-quality publications in accredited journals.

Table 1. Descriptive main information about the collection

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2000:2025
Sources (Journals, Books, etc.)	241
Documents	660
Annual Growth Rate %	15,78
Document Average Age	6,06
Average citations per doc	15,31
DOCUMENT CONTENTS	
Keywords Plus (ID)	1324
Author's Keywords (DE)	2011
AUTHORS	
Authors	2263
Authors of single-authored docs	96
AUTHORS COLLABORATION	
Single-authored docs	104
Co-Authors per Doc	4,03
International co-authorships %	32,27
DOCUMENT TYPES	
article	627
article article	5
article; book chapter	12
article; early access	6
article; proceedings paper	9
article; retracted publication	1

3.2 Annual production trends

Figure 2 provides information on annual scientific publication trends in lake and water governance topics, focusing on stakeholder engagement during the period 2000-2025. The data reveal that scientific production experienced slow growth until 2010, then increased significantly, particularly from 2015 onward, reaching peaks in 2021 and 2024 with more than 70 articles per year. This surge reflects growing global attention to water resource governance and stakeholder participation, aligned with sustainability issues and climate change. The sharp fluctuations after 2021 may be attributed to external dynamics such as the pandemic or shifts in research funding priorities. It should be noted that the 2025 publication count represents preliminary data, as the database search was conducted in August 2025; therefore, the apparent decline in 2025 should not be interpreted as a decreasing trend but rather as incomplete full-year data. Scientific production in this field demonstrates a strong positive trend, signaling a global scientific focus shift toward inclusive and collaborative water governance. To address various 21st-century challenges, fundamental changes in water governance are required toward

more flexible approaches involving active participation from diverse stakeholders and comprehensive integration [21].

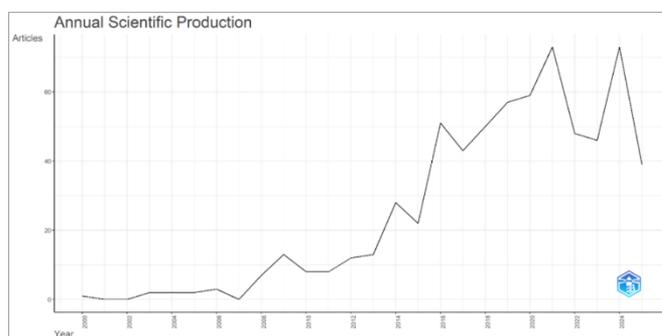


Figure 2. Article production from 2000 to 2025

3.3 Citation trends

The annual citation overview analysis in Table 2 reveals interesting patterns in the academic impact of lake and water governance publications. The average citations per article show a consistent increasing trend from 2006 (24.33), reaching its highest point in 2011 (39.88), followed by fluctuations at high levels until 2015 (35.45). The period 2011-2015 can be categorized as a golden era with average citations above 30, indicating that publications from this period provided fundamental contributions that continue to be referenced by subsequent researchers. However, a drastic decline is evident from 2016 onward, continuing through 2025 (0.15), which represents a normal phenomenon in bibliometric analysis as recent publications require time for citation accumulation—evident from the Citable Years value decreasing from 20 years (2006) to just 1 year (2025). Interestingly, despite the number of publications (N) increasing rapidly from 3 articles (2006) to 73 articles (2021), the average citations per year show variability with peaks in 2015 (3.22) and 2020 (3.01), indicating that increased publication quantity does not always correlate directly with scientific impact, and confirming the importance of a 3-5 year maturation period for an article to achieve optimal visibility and recognition within the academic community.

Table 2. Annual citation summary

Year	Mean TC per Article	N	Mean TC per Year	Citable Years
2006	24.33	3	1.22	20
2008	12.71	7	0.71	18
2009	18.62	13	1.10	17
2010	18.38	8	1.15	16
2011	39.88	8	2.66	15
2012	39.00	12	2.79	14
2013	19.62	13	1.51	13
2014	33.61	28	2.80	12
2015	35.45	22	3.22	11
2016	29.45	51	2.94	10
2017	16.44	43	1.83	9
2018	20.54	50	2.57	8
2019	15.23	57	2.18	7
2020	18.07	59	3.01	6
2021	10.78	73	2.16	5
2022	7.65	48	1.91	4
2023	3.93	46	1.31	3
2024	2.95	73	1.48	2
2025	0.15	39	0.15	1

3.4 Most relevant sources

Table 3 demonstrates the dominance of the journal *Water* with 71 articles, confirming its position as the primary platform for research dissemination in this field. Environmental policy journals such as *Environmental Science & Policy* (29 articles) and *Water Policy* (29 articles) occupy second position, indicating that water governance discussions focus not only on technical hydrological aspects but also strongly emphasize policy and regulatory dimensions. The presence of interdisciplinary journals such as *Ecology and Society* (27 articles) and *Sustainability* (25 articles) reflects a holistic approach to understanding water governance that integrates ecological, social, and sustainability perspectives. Regional and development-specific journals such as the *International Journal of Water Resources Development* (18 articles) and *Water International* (15 articles) signify the importance of geographical and developmental contexts in this research. Notably, the presence of *Water Alternatives-An Interdisciplinary Journal on Water Politics and Development* (12 articles) underscores the political and power dimensions in water governance that increasingly receive academic attention. This publication distribution confirms that lake and water governance research has evolved into a mature multidisciplinary field, with the journal *Water* as a central hub, yet maintaining diverse perspectives through policy, ecology, and development journals that collectively form a comprehensive intellectual landscape for understanding the complexity of water resource management in the context of stakeholder engagement and public participation.

Table 3. The most relevant source

Sources	Articles
Water	71
Environmental Science & Policy	29
Water Policy	29
Ecology and Society	27
Sustainability	25
International Journal of Water Resources Development	18
Water International	15
Environmental Management	12
Water Alternatives-An Interdisciplinary Journal on Water Politics and Development	12
Water Resources Management	11

3.5 Leading authors

Table 4 presents profiles of leading authors in lake and water governance research based on bibliometric metrics, including h-index, g-index, m-index, total citations (TC), number of publications (NP), and initial publication year (PY_start). Newig J leads with the highest h-index and g-index (7), m-index of 0.7, and TC reaching 338 from 7 publications since 2016, demonstrating consistency and significant research impact within a relatively short period. Collins K and White D follow with h-index and g-index of 6 each, though White D shows higher efficiency with an m-index of 0.545 despite lower TC (200) compared to Collins K (340). Pahl-Wostl C, despite having an h-index of 5, recorded impressive TC (269) from 5 publications since 2012, indicating high quality and relevance of their work in adaptive water governance. The group of authors with h-index 5-6, such as Adamowski J, Gerlak A, Hurlbert M, and Ison R, demonstrate

substantial contributions with TC varying between 93-248, reflecting diverse approaches and research focuses within the water governance domain. Authors who began publishing more recently, such as Koop S (2018) and Ricart S (2017), show strong momentum with high m-indices (0.625 and 0.556), indicating their potential as influential emerging researchers in the evolution of stakeholder engagement and participation research in water resource governance.

3.6 Leading countries

The geographical mapping of scholarly output on lake and water governance demonstrates a clear hierarchy favoring industrialized countries, where the United States maintains a commanding position with 355 studies, evidencing its substantial scientific infrastructure and financial commitment to water resource investigations. With 186 scholarly works, Australia secures the second position, highlighting the country's focused efforts on water management challenges arising from its distinctive environmental and geographical characteristics. Table 5 illustrates Europe's remarkable presence in this field, where collective contributions from the Netherlands (173), United Kingdom (167), Germany (140), Spain (83), and Italy (77) total 640 studies, reinforcing the continent's scholarly prominence in water governance facilitated by comprehensive EU Water Framework Directive regulations. Despite its modest geographical size, the Netherlands demonstrates remarkable research output, leveraging its centuries-old water management experience and status as an international center of excellence for water governance knowledge. Comparative assessments involving Germany, the Netherlands, Australia, China, and South Africa reveal how various governance frameworks embody different theoretical and applied strategies for achieving sustainable water management [22]. In the North American context, while the United States maintains clear leadership, Canada's 130 studies indicate strong engagement with cross-border water resource management investigations. China's contribution of 83 publications from Asia reflects expanding scholarly production aligned with the nation's multifaceted water governance complexities. With 73 studies, South Africa stands as the continent's leading contributor, demonstrating its role in tackling water shortage problems and developing participatory governance approaches. These patterns reveal substantial disparities in global research production, where OECD nations dominate scholarly output while countries experiencing severe water crises remain significantly underrepresented in scientific discourse. Notably, sub-Saharan African nations facing acute water stress—such as Ethiopia, Kenya, Nigeria, and the Democratic Republic of Congo—remain marginally represented despite their urgent water governance challenges. Similarly, South Asian countries, including India, Bangladesh, and Pakistan, which collectively face some of the world's most pressing water scarcity and transboundary water management issues, demonstrate disproportionately low research visibility relative to their population size and the severity of their water crises. Middle Eastern and North African (MENA) regions, particularly Yemen, Iraq, and Jordan, also remain underrepresented despite experiencing critical water scarcity conditions. The necessity of broadening comparative water governance studies to include marginalized areas, especially in the Global South, becomes crucial for documenting varied socio-environmental settings and governance innovations [23].

Table 4. Leading author

Author	h Index	g Index	m Index	TC	NP	PY Start
NEWIG J	7	7	0.7	338	7	2016
COLLINS K	6	6	0.4	340	6	2011
WHITE D	6	6	0.545	200	6	2015
WIEK A	6	6	0.5	165	6	2014
ADAMOWSKI J	5	5	0.417	227	5	2014
GERLAK A	5	6	0.294	93	6	2009
HURLBERT M	5	6	0.294	248	6	2009
ISON R	5	6	0.333	191	6	2011
KOOP S	5	5	0.625	104	5	2018
KUZDAS C	5	5	0.417	134	5	2014
MEDEMA W	5	5	0.417	227	5	2014
PAHL-WOSTL C	5	5	0.357	269	5	2012
RICART S	5	7	0.556	76	7	2017
SCHULZ C	5	5	0.556	71	5	2017
AKHMOUCH A	4	5	0.4	255	5	2016

Table 5. Leading countries

Country	Region	Frequency
USA	North America	355
Australia	Oceania	186
Netherlands	Europe	173
UK	Europe	167
Germany	Europe	140
Canada	North America	130
China	Asia	83
Spain	Europe	83
Italy	Europe	77
South Africa	Africa	73

3.7 Most relevant affiliations

Figure 3 reveals the institutional landscape in lake and water governance research, with the Australian National University leading dominantly with 27 articles, affirming Australia’s position as a global center of excellence in water resource management research. Strong North American institutional presence is evident through Arizona State University and the University of Arizona, each contributing 26 articles, reflecting regional focus on water management challenges in the arid and semi-arid southwestern United States. Utrecht University from the Netherlands, with 24 articles, reinforces the country’s reputation as a leader in water governance innovation, supported by historical expertise in delta management and polder systems. Canadian university engagement through the University of Waterloo (23 articles) and the University of British Columbia (21 articles) demonstrates institutional commitment to transboundary water governance research and integrated water resource management. Notably, the presence of the University of Tehran (21 articles) indicates a significant Middle Eastern contribution to global water governance discourse, likely driven by acute water scarcity challenges in the region. Wageningen University (20 articles) strengthens Dutch dominance with a focus on interdisciplinary approaches integrating environmental science, agriculture, and governance. University of Leeds (19 articles) and Open University (18 articles) complete the European representation, demonstrating diversity in methodological and conceptual approaches. This distribution underscores expertise concentration in developed country institutions while indicating the need for research capacity strengthening in institutions from developing countries facing the most pressing water governance challenges.

3.8 Keyword co-occurrence analysis

The keyword co-occurrence network visualization in Figure 4 reveals the intellectual structure of lake and water governance research through the visualization of relationships among key concepts. At the visualization’s core, three dominant nodes emerge: "management," "governance," and "policy," displayed in the largest sizes, indicating these concepts’ centrality in academic discourse. Keyword co-occurrence analysis serves as a powerful tool for uncovering the intellectual structure and thematic relationships within a research domain, revealing how concepts interconnect to form knowledge networks [24]. The "management" node functions as the central hub connecting various operational and strategic aspects of water resource management. The dominant red cluster encompasses core concepts such as "climate change," "adaptation," "resilience," and "vulnerability," reflecting the urgency of climate change adaptation in contemporary water governance. The strong presence of "organization," "institutions," and "implementation" in this cluster affirms the importance of institutional dimensions in translating policy into concrete action.

The green cluster encompassing "water governance" and "sustainability" demonstrates paradigm evolution from traditional water management toward sustainable and participatory governance. The close relationship between "sustainability" and other nodes underscores the sustainability principle integration across all water governance aspects. The evolution from traditional water management to integrated governance approaches reflects a fundamental paradigm shift in how scholars conceptualize the relationship between human systems and water resources [25]. The blue cluster comprising "stakeholder," "water management," "governance approach," and "water supply" reflects inclusive approaches involving multi-stakeholder decision-making. The strategic position of "stakeholder" connected to various nodes signifies a shift from top-down approaches toward more participatory and democratic governance models.

The presence of concepts such as "cooperation," "collaboration," and "public participation" distributed across various clusters indicates academic consensus regarding the importance of collaborative approaches in addressing water governance complexity. The "politics" and "power" nodes connected to "governance" acknowledge the inherent political dimension in water resource allocation and management. The emergence of "river basin," "basin," and "conservation" demonstrates adoption of ecosystem-based integrated

paradigms have transformed from traditional technical-managerial approaches toward more adaptive, participatory, and sustainable models. This analysis also maps geographic and institutional disparities in knowledge production, the dominance of specific research themes, and critical implications for policy development and future research agendas, particularly within the context of global climate change and water resource sustainability challenges.

4.1 Growth in research interest

The bibliometric analysis demonstrates significant growth in academic interest toward lake and water governance research, with an annual growth rate reaching 15.78% and a peak production in 2024 with 73 articles. This trend reflects increasing global awareness of the escalating water crisis, where approximately 2 billion people currently lack access to safe drinking water and 3.6 billion experience water scarcity for at least one month annually [1]. The surge in publications beginning in 2015 correlates with the adoption of the Sustainable Development Goals (SDGs), particularly SDG 6, which explicitly targets sustainable water management, alongside growing recognition that effective water governance requires participatory and inclusive approaches [2].

The 2011-2015 period, exhibiting the highest average citations (exceeding 30 per article), indicates that publications from this period established crucial conceptual foundations for subsequent research. These foundational works likely introduced adaptive water governance frameworks and stakeholder-based approaches that subsequently became dominant paradigms in the literature. The paradigmatic shift from command-and-control water management toward adaptive governance has emerged as a critical response to uncertainties posed by climate change and complex socio-ecological dynamics [28].

Interestingly, despite increased publication quantity after 2020, scientific impact per article tends to decline, a common phenomenon in rapidly expanding research fields. This aligns with findings that water governance research proliferation often produces fragmented case studies lacking adequate conceptual integration [29]. Nevertheless, the geographic and thematic diversification evident in this period also signifies democratization of knowledge production and the emergence of new perspectives from the Global South, which is crucial given that developing countries face the most acute water governance challenges [30].

4.2 Implications for water resource management policy

This research's findings underscore the importance of policy reforms integrating adaptive and participatory governance principles in water resource management. The dominance of "management," "governance," and "policy" concepts in keyword analysis indicates that modern water policies must transcend traditional technical approaches toward more holistic and inclusive frameworks. Effective water policies require multi-level governance coordination involving central, regional, and local governments, alongside cross-sectoral integration among water, energy, food, and environmental domains [31]. This aligns with our findings showing high co-occurrence between "climate change," "adaptation," and "resilience," indicating that contemporary water policies must be designed considering climate uncertainty and long-term adaptation needs.

The international collaboration analysis in this research also highlights the importance of knowledge transfer and cross-national policy learning. Countries with high research productivity, such as the Netherlands and Australia, have developed innovative water governance models adaptable to other contexts. For instance, the Netherlands' "building with nature" approach and Australia's integrated water management have proven effective in addressing complex challenges such as sea-level rise and extreme drought [32]. However, policy adoption requires contextual adjustments considering institutional capacity, socio-economic conditions, and local hydrological characteristics.

4.3 Implementation challenges in developing countries

The geographic disparities identified in this bibliometric analysis—with OECD country dominance and minimal representation from Africa and South Asia—reflect structural challenges faced by developing countries in implementing effective water governance. Five primary barriers are identified: (1) weak institutional capacity, (2) financial constraints, (3) inadequate data and monitoring infrastructure, (4) high corruption levels, and (5) poor inter-agency coordination [33]. These challenges are exacerbated by colonial legacies that left centralized water management systems unsuitable for local contexts while disregarding traditional governance systems proven to be sustainable over centuries.

Our research indicates that although "stakeholder participation" and "public participation" concepts increasingly dominate the literature, their implementation in developing countries still faces significant obstacles. Participation is often tokenistic, where marginalized groups—particularly women, indigenous communities, and smallholder farmers—are only symbolically involved without genuine influence in decision-making [34]. Furthermore, the digital divide evident from minimal research contributions from LDCs indicates capacity gaps in generating and accessing scientific knowledge relevant to their local contexts.

Climate change adds new complexity layers, where developing countries, most vulnerable to climate change impacts, paradoxically possess the lowest adaptive capacity. Specific challenges include: increasing rainfall variability disrupting traditional irrigation systems, saltwater intrusion threatening coastal freshwater sources, and increasing hydrometeorological disaster frequency exceeding existing infrastructure capacity [35].

4.4 Research limitations

While this research provides comprehensive insights into the lake and water governance research landscape, several limitations warrant acknowledgment. First, reliance on Scopus and Web of Science databases may introduce publication bias, where grey literature, government reports, and local-language publications potentially containing important contextual insights are excluded from analysis. Mainstream bibliographic databases tend to underrepresent Global South research, potentially reinforcing epistemological biases in knowledge production. This exclusion likely results in significant underrepresentation of stakeholder engagement practices implemented in developing countries, where participatory water governance initiatives are often documented in NGO reports, government policy documents, and community-based

project evaluations rather than peer-reviewed journals. Consequently, indigenous knowledge systems, grassroots innovations in water management, and locally-adapted participatory approaches from regions such as sub-Saharan Africa, South Asia, and Latin America may be inadequately captured in our analysis, potentially skewing conclusions toward governance models prevalent in well-resourced institutional settings of the Global North. Moreover, bibliometric analysis is quantitative and may not capture qualitative nuances of conceptual evolution in this field [36]. Metrics such as citation counts do not always reflect research quality or practical impact and can be influenced by factors such as self-citation and citation cartels [37].

Third, the analysis period ending in 2025, with still-developing data for that year, may affect the interpretation of recent trends. Recent publications may not have achieved full visibility in citation networks, potentially causing underestimation of their impact. Fourth, focusing on English-language publications overlooks important contributions from research in other languages, particularly from countries like China, Russia, and Latin American nations with strong water research traditions in their local languages. This linguistic bias further compounds the underrepresentation of developing countries, as significant water governance scholarship and documentation of local stakeholder practices in these regions are published in native languages such as Mandarin, Spanish, Portuguese, Hindi, and Bahasa Indonesia, thereby limiting the generalizability of our findings to Global South contexts.

4.5 Future research directions

This bibliometric analysis reveals several areas requiring further research attention. First, longitudinal studies evaluating the long-term effectiveness of various participatory water governance models are needed. Most identified research consists of cross-sectional or short-term case studies, limiting understanding of intervention sustainability and scalability. Developing "longitudinal observatories" that monitor water governance system evolution over decades or longer is suggested to better understand institutional change dynamics [38, 39].

Second, stronger integration between natural and social sciences is required to understand the water socio-ecological system complexity. Future research should explore the water-energy-food-climate nexus through transdisciplinary approaches involving not only researchers but also practitioners and local communities. Third, developing evaluation methods capable of capturing non-monetary values of good water governance, such as equity, legitimacy, and social resilience. Methodologies like "participatory evaluation" and "most significant change" can provide richer insights into multidimensional impacts of water governance interventions.

Fourth, research on digital technology's role in water governance transformation requires further exploration. While "smart water management" concepts are emerging in the literature, the understanding of how technologies like AI, blockchain, and IoT can enhance participation and transparency remains limited. There is a need for research on "digital water governance," exploring both the potential and risks of digitalization in developing country contexts [40]. Fifth, systematic cross-regional comparative studies are needed to identify contextual factors influencing the success or failure of specific water governance models.

4.6 Practical implications

This research's findings carry significant practical implications across various domains. In institutional capacity development contexts, international organizations such as the World Bank and UNDP need to allocate resources supporting local research and South-South research network development. Capacity-building programs must extend beyond technology transfer to include research and analytical capacity development, enabling developing countries to generate context-relevant knowledge. Investment in local "research infrastructure" yields higher returns compared to dependence on international consultants [41].

For water management practice, our findings emphasize the importance of adopting "adaptive management cycles" enabling continuous learning and strategy adjustment based on system feedback. Implementing this approach requires fundamental changes in water management organizations' culture, shifting focus from achieving rigid targets toward emphasizing learning and innovation. Practitioners should develop "communities of practice" facilitating experience exchange and peer-to-peer learning, particularly when facing unprecedented challenges like extreme climate change.

In public policy contexts, governments need to develop "water governance observatories" that systematically monitor and evaluate water governance system performance. Such observatories can function as "early warning systems" identifying emerging problems and facilitating proactive responses. The use of "governance dashboards" that provide real-time information about key water governance indicators to decision-makers and the public has been proposed [42]. Additionally, developing "regulatory sandboxes" can enable experimentation with innovative approaches in controlled environments before scaling up.

Finally, for education and human resource development, water-related study program curricula require reform to reflect modern water governance's interdisciplinary nature. Educational programs should integrate not only technical aspects but also social, political, and ecological dimensions of water management. Developing "water governance MOOCs" (Massive Open Online Courses) can democratize access to cutting-edge knowledge, particularly for practitioners in developing countries who may lack access to high-quality formal education.

5. CONCLUSIONS

This bibliometric research has revealed significant evolution in the lake and water governance research landscape during the 2000-2025 period, with an annual growth rate of 15.78% reflecting global urgency in addressing the water crisis. Analysis of 660 documents from 241 sources demonstrates a paradigmatic transformation from traditional technical-managerial approaches toward adaptive, participatory, and sustainable governance models. The dominance of key concepts such as "management," "governance," "policy," "stakeholder participation," and "climate change" in keyword co-occurrence networks indicates that contemporary discourse has integrated socio-ecological, institutional, and climate change dimensions as integral elements in water governance. Nevertheless, the analysis also reveals significant geographic disparities, with research concentration in OECD countries (United States,

Australia, Netherlands, UK) while developing countries facing the most acute water challenges remain underrepresented in scientific knowledge production. This disparity underscores the urgent need for research democratization and capacity strengthening in the Global South to achieve inclusive and equitable water governance.

The research findings carry important implications for various stakeholders in efforts to achieve SDG 6 and other water-related targets. For policymakers, this research emphasizes the importance of adopting adaptive management approaches that enable flexibility in confronting climate uncertainty, alongside developing multi-level governance coordination mechanisms that integrate local and indigenous perspectives. For practitioners and researchers, priority should be given to longitudinal studies evaluating long-term effectiveness of water governance interventions, developing performance indicators sensitive to local contexts, and strengthening North-South collaboration for knowledge and methodology transfer. The emergence of themes such as "resilience," "adaptation," and "ecosystem services" in recent periods signals a shift toward approaches acknowledging socio-ecological system complexity and the importance of nature-based solutions. Digital technology integration in water governance, though still in early stages, offers transformative potential for enhancing transparency, participation, and management efficiency, yet also requires careful attention to risks of digital exclusion and data privacy.

Moving forward, the success of sustainable lake and water governance will critically depend on the ability to bridge gaps between knowledge production and practical implementation, between global perspectives and local realities, and between technological innovation and traditional wisdom. This research, despite limitations from reliance on mainstream bibliographic databases and focus on English-language publications, provides a roadmap for developing more inclusive and transformative research agendas. With increasing pressure on water resources from climate change, population growth, and urbanization, investment in water governance research and capacity development is no longer optional but imperative. The future of water governance lies in the global community's ability to learn from collective experience, adapt to rapid change, and ensure that water as a human right is accessible to all without leaving anyone behind. Achieving this vision requires sustained commitment from all stakeholders to collaborate beyond disciplinary, geographic, and institutional boundaries in a spirit of global solidarity for our planet's sustainability.

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