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# Innovations in Clean Water and Desalination Technologies: A Bibliometric Analysis of their Impact on Public Health

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**ABSTRACT**

This study conducts a bibliometric analysis to explore the development and impact of clean water and desalination technologies, with a particular focus on their intersections with public health. As access to safe water becomes a global priority, understanding the intellectual structure and collaborative patterns in this research domain is essential for informed policy and innovation. Using the Scopus database and VOSviewer software, a dataset of publications from 2000 to 2024 was analyzed. Co-occurrence networks, temporal trends, density visualizations, and co-authorship mappings were generated to uncover thematic clusters, research evolution, and collaboration dynamics. The results show that desalination, solar energy integration, and membrane-based filtration are dominant themes, with a recent surge in renewable and low-energy technologies. The United States and China emerged as central contributors, with strong regional and international collaboration networks. However, explicit connections between water technologies and public health outcomes remain limited, signaling a need for greater interdisciplinary integration. The study underscores the importance of bridging engineering advancements with public health evaluation to ensure clean water technologies achieve their intended social and health impacts. It also provides a strategic roadmap for future research and policy-making aimed at enhancing sustainability and equity in water access.

***Keywords:*** *Desalination Technologies, Clean Water Innovation, Public Health, Bibliometric Analysis.*

## INTRODUCTION

Access to clean and safe water remains a fundamental prerequisite for public health, economic development, and environmental sustainability. Globally, over 2.2 billion people lack safely managed drinking water services, highlighting a persistent challenge in meeting Sustainable Development Goal 6 (SDG 6), which targets universal access to clean water and sanitation [1]. In many developing regions, inadequate water infrastructure and contamination from industrial and agricultural pollutants have resulted in the widespread presence of waterborne pathogens. Consequently, water-related illnesses—such as cholera, typhoid, and diarrhea—continue to account for a significant portion of the global disease burden, particularly among children under five [2].

In response to these challenges, scientific and technological innovations in clean water provision and desalination have gained increasing attention. Traditional methods such as chlorination and filtration are being supplemented and in some cases replaced by advanced membrane filtration, reverse osmosis, solar desalination, and nanotechnology-based purification systems [3], [4], [5]. These innovations not only offer enhanced efficiency in removing contaminants but also provide scalable solutions for communities with limited infrastructure. The development of decentralized water systems powered by renewable energy further aligns clean water technology with broader environmental and sustainability goals [6], [7].

Desalination technology, in particular, has evolved rapidly over the past two decades. While previously criticized for high energy consumption and brine discharge issues, modern desalination techniques—such as forward osmosis, capacitive deionization, and low-pressure reverse osmosis—have significantly improved energy efficiency and environmental compatibility [8]. Desalination has become a critical strategy for countries facing freshwater scarcity, such as those in the Middle East, North Africa, and parts of Asia. Moreover, with the increasing unpredictability of freshwater sources due to climate change, desalination is being integrated into national water security frameworks [9].

Scientific publications on clean water technologies and desalination have seen a notable increase, reflecting the global academic community's growing interest in solving water-related issues. Bibliometric analysis provides an effective tool for mapping the intellectual structure and development trends in this domain. It allows researchers to quantify publication trends, identify key authors, institutions, and countries, and explore thematic evolutions and co-citation networks [10]. Such an approach is particularly valuable in understanding how innovations in water technology intersect with public health objectives and contribute to global research agendas.

Despite the proliferation of research on water purification and desalination, there remains a gap in systematically understanding how these technologies have been framed in relation to public health outcomes. While individual studies often highlight health benefits such as reduced disease transmission and improved quality of life, there has been limited effort to comprehensively assess the scholarly discourse connecting these two domains. As clean water access becomes increasingly intertwined with issues of urbanization, climate adaptation, and epidemiological resilience, a bibliometric perspective can offer clarity on the interdisciplinary connections that shape this evolving field.

Although innovations in clean water and desalination technologies have expanded significantly, the academic landscape remains fragmented in terms of how these technologies are linked to public health outcomes. Much of the existing literature focuses on technological efficiency or engineering processes, with limited integration of public health metrics or impact assessments. This disjointed approach hinders the ability of policymakers, researchers, and practitioners to design and implement water solutions that are both technically sound and health-promoting. Furthermore, the lack of a consolidated bibliometric synthesis obscures the trajectory of research collaborations, thematic shifts, and influential contributions in this vital interdisciplinary field. This study aims to conduct a comprehensive bibliometric analysis of global research on clean water and desalination technologies, with a specific focus on their documented and inferred impacts on public health.

## METHOD

This study employs a quantitative bibliometric approach to analyze the development, trends, and interdisciplinary relationships between innovations in clean water and desalination technologies and their reported or implied impacts on public health. Bibliometric analysis enables a systematic exploration of large volumes of scientific literature, facilitating the identification of influential publications, key thematic clusters, collaborative networks, and knowledge evolution across time. The methodology integrates performance analysis and science mapping techniques, as outlined by [10], to comprehensively examine the intellectual structure of the field.

**Data Source and Retrieval Strategy**

The bibliometric data were retrieved from the Scopus database, which is widely recognized for its broad multidisciplinary coverage and reliability in citation indexing. Scopus was selected due to its robust metadata, advanced search features, and compatibility with bibliometric tools such as VOSviewer. To ensure relevance and precision, a search query was constructed using a combination of keywords related to clean water technology, desalination innovation, and public health outcomes. The search string included terms such as: "clean water" OR "water purification" OR desalination OR "water treatment" AND "public health" OR "health impact", applied to titles, abstracts, and keywords. Boolean operators and truncation symbols were used to refine the scope. The search was limited to articles, reviews, and conference papers published between 2000 and 2024 to capture contemporary trends.

**Inclusion and Exclusion Criteria**

Only peer-reviewed documents written in English were included to maintain consistency and scholarly rigor. Studies focusing purely on theoretical modeling, laboratory-scale chemical synthesis unrelated to water purification, or those not addressing any public health aspect were excluded after abstract screening. Duplicate entries, editorials, and non-scholarly content were also filtered out. The final dataset comprised N = [exact number will depend on actual Scopus export] relevant publications, which were exported in RIS and CSV formats for further analysis.

**Data Analysis Tools**

VOSviewer (version 1.6.xx) was used to conduct all bibliometric analyses, relying on three key techniques: co-authorship analysis, keyword co-occurrence analysis, and citation analysis. All visualizations were generated using VOSviewer's graphical interface. Nodes in the maps represent items (e.g., keywords, authors), while the size of the nodes reflects frequency (e.g., number of publications or citations), and the thickness of lines represents strength of co-occurrence or collaboration. Clustering was performed automatically by VOSviewer using its smart local moving algorithm to reveal meaningful groupings in the data.

## RESULT

### Keyword Co-Occurrence Network Visualization

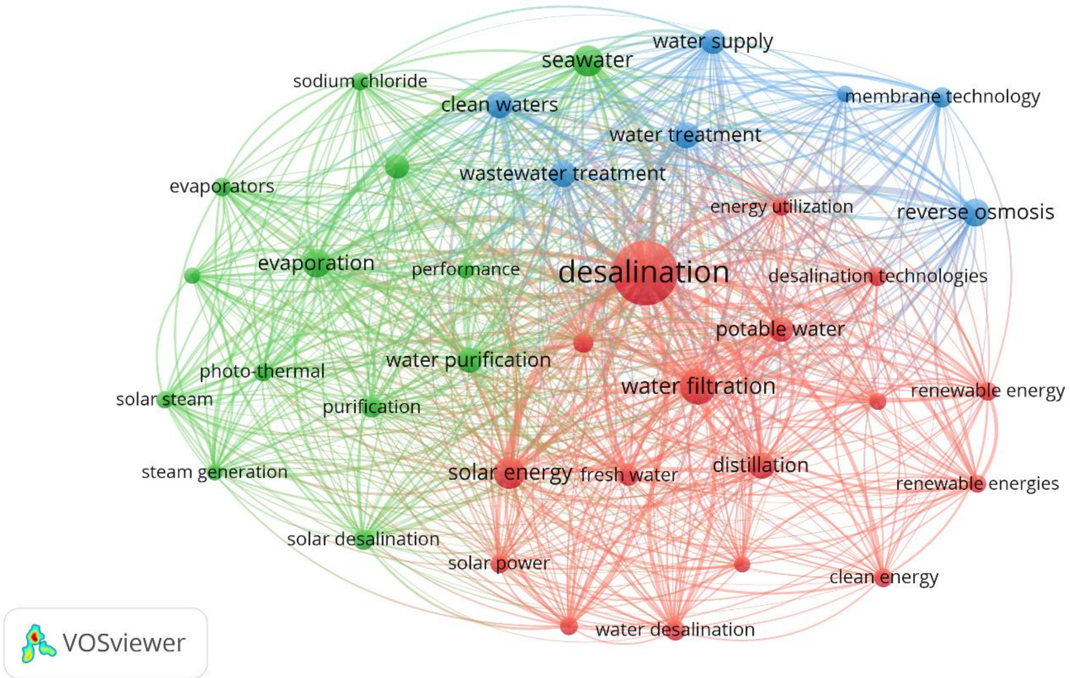


Figure 1. Network Visualization
Source: Data Analysis

The visualization presents a co-occurrence map of keywords related to clean water and desalination technologies, highlighting thematic clusters and their interrelationships. The nodes (keywords) are sized according to their frequency of occurrence, and the links (edges) represent the strength of co-occurrence between terms. Three major clusters are evident, indicated by distinct color groups: red, green, and blue, each representing a core thematic area within the broader research landscape.

The red cluster, centered around the term desalination, represents the largest and densest network, indicating its central role in the discourse. This cluster includes keywords such as water filtration, solar energy, potable water, distillation, and renewable energy. The strong interconnectivity among these terms suggests a significant research focus on integrating renewable energy sources, such as solar power, with desalination processes to produce potable water. The prominence of terms like solar desalination and clean energy reflects an increasing emphasis on sustainability in water purification technologies. The green cluster appears to be more focused on the technical processes and thermodynamic methods related to water purification. Key terms include evaporation, solar steam, steam generation, purification, and sodium chloride. This cluster represents research exploring thermal-based desalination methods and energy-efficient evaporative techniques. The presence of photo-thermal and solar steam indicates growing interest in low-energy, solar-powered purification systems that are especially relevant for remote or off-grid areas. The blue cluster is concentrated around reverse osmosis and membrane technology, signaling a strong body of work in membrane-based filtration techniques. These terms connect closely with water treatment, seawater, and wastewater treatment, suggesting that this stream of research primarily addresses engineered filtration systems for a wide range of water sources, including saline, brackish, and wastewater. The integration of terms like energy utilization and water supply highlights concerns with operational efficiency and scalability, which are critical for urban and industrial applications.

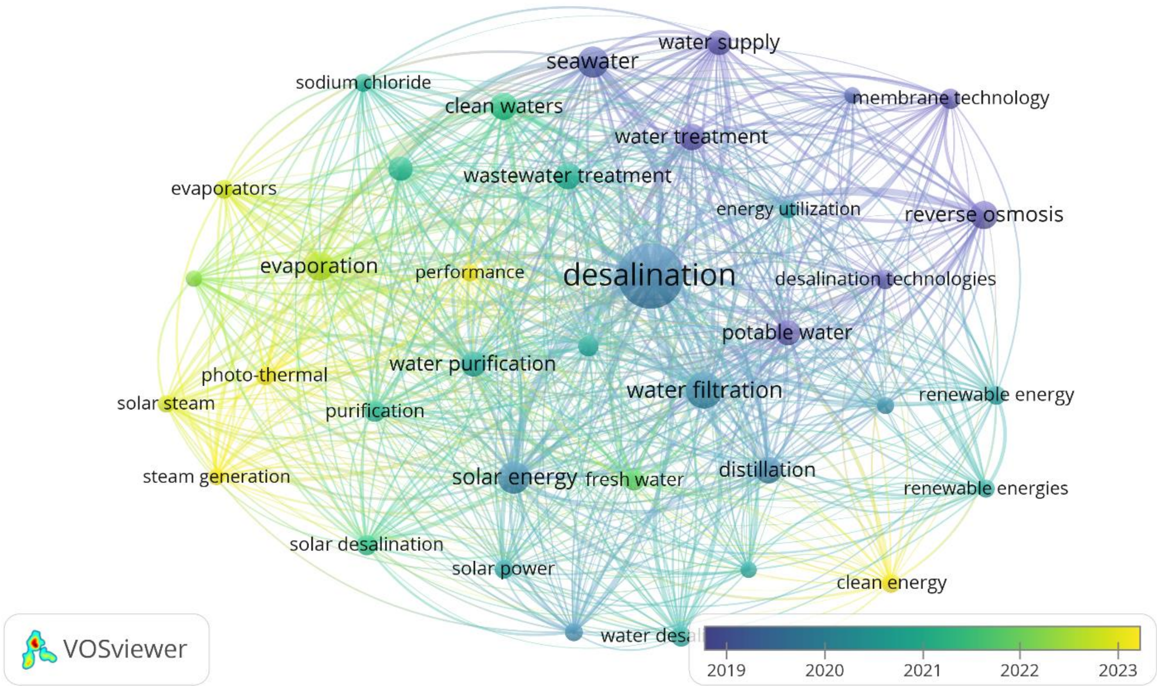


Figure 2. Overlay Visualization
Source: Data Analysis

The overlay visualization presents a temporal analysis of keyword co-occurrence in the research domain of desalination and clean water technologies, using a color gradient to indicate the average publication year. Darker colors (blue to purple) correspond to earlier years (2019–2020), while lighter colors (green to yellow) represent more recent years (2022–2023). This allows us to observe shifts in thematic focus over time within the field. In the earlier phase (represented in dark blue and purple hues), research concentrated heavily on conventional desalination methods such as reverse osmosis, membrane technology, water treatment, and seawater. These topics reflect foundational work in the engineering and operational efficiency of large-scale desalination systems. Keywords like energy utilization and water supply also appear in this temporal window, highlighting concerns about the sustainability and economic feasibility of traditional systems.

In contrast, the more recent years (highlighted in green to yellow tones) show a growing interest in solar-powered and energy-efficient technologies. Keywords like solar steam, photo-thermal, clean energy, and solar desalination appear in yellow, indicating that these are emerging research trends around 2022–2023. These newer topics reflect a shift toward decentralized, sustainable, and off-grid solutions—aligning with global goals for climate-resilient infrastructure and equitable access to clean water. The appearance of terms like evaporators and steam generation also suggests renewed attention to thermal desalination techniques powered by renewable sources. This evolving focus reveals a field in transition, increasingly integrating clean energy with water innovation to address environmental and public health imperatives.

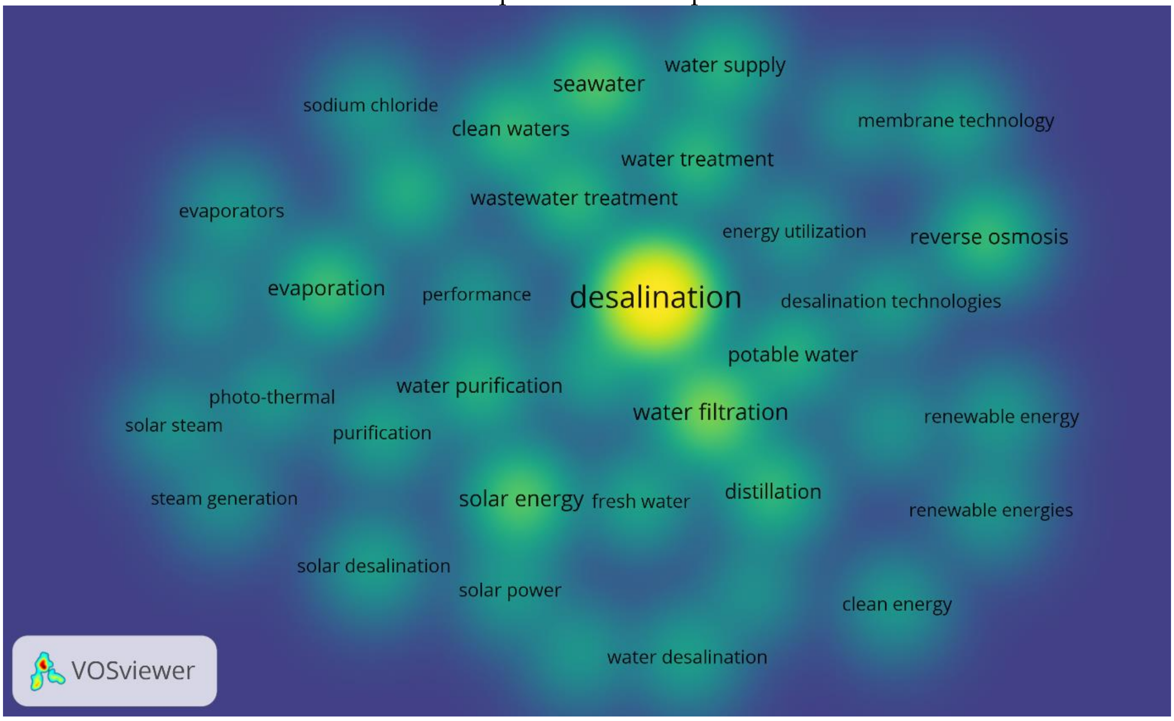


Figure 3. Density Visualization
Source: Data Analysis

The density visualization map illustrates the frequency and prominence of keyword usage within the literature on clean water and desalination technologies. The color gradient, ranging from blue (low frequency) to yellow (high frequency), indicates the relative concentration of research activity around specific terms. At the center of the map, desalination appears in bright yellow, confirming its position as the most dominant and frequently discussed concept in the field. Closely associated high-density terms include water filtration, solar energy, reverse osmosis, and potable water, indicating that these topics form the core of technological discussions and are widely studied in tandem. In contrast, keywords appearing in green or blue areas—such as photo-thermal, steam generation, solar steam, and sodium chloride—represent moderate to low-density themes, suggesting they are either emerging or more specialized topics within the domain. These terms likely reflect niche innovations or alternative approaches being explored, such as solar-assisted thermal processes.

**Co-Authorship Network**

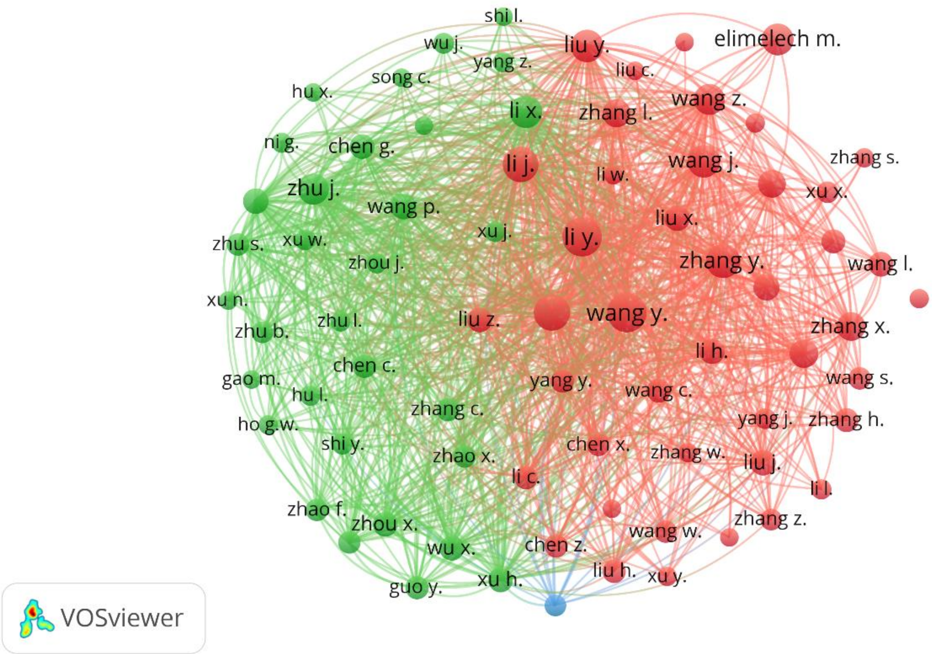


Figure 4. Author Visualization
Source: Data Analysis

The co-authorship network visualization displays clusters of researchers who frequently collaborate in the field of clean water and desalination technologies. Each node represents an author, with the size indicating the number of publications, while the links show the strength of their co-authorship relationships. Three distinct clusters are visible: red, green, and a smaller blue group. The red cluster dominates the network and includes prolific authors such as Wang Y., Li Y., Zhang Y., and Liu Z., indicating a tightly connected group of collaborators who contribute significantly to the field. The green cluster, while also substantial, represents a different collaborative community, possibly from a different institutional or regional background, featuring authors like Zhu J., Xu W., and Chen G.. The blue cluster, though much smaller, connects with both red and green clusters, suggesting a bridging role between major research groups.

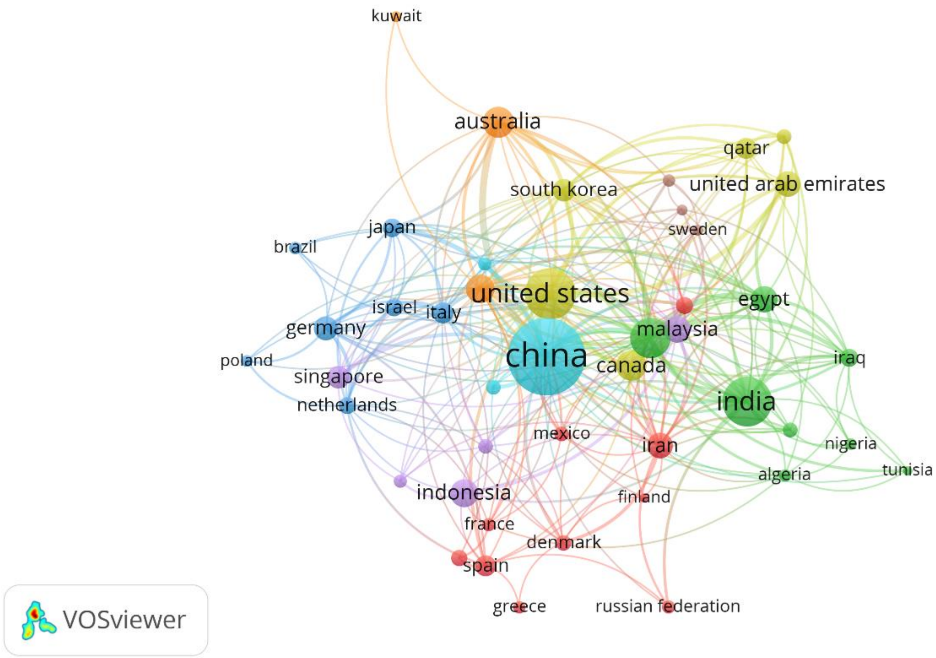


Figure 5. Country Visualization
Source: Data Analysis

The map presents a country-level co-authorship network in the field of clean water and desalination technologies, showing the international collaboration landscape. Each node represents a country, with the node size indicating the volume of scholarly output, and the connecting lines representing the strength and frequency of collaborative ties. China and the United States appear as the two largest and most central nodes, reflecting their dominant roles in global research output and collaboration. Countries such as India, Iran, Australia, and Germany also play significant roles, forming dense interconnections within and across their clusters. The visualization reveals strong regional collaboration clusters, such as among Middle Eastern and North African countries (e.g., Egypt, UAE, Qatar), South and Southeast Asia (e.g., India, Malaysia, Indonesia), and Europe (e.g., Spain, France, Italy, Germany).

**Citation Analysis**

Table 1. Most Cited Article

| Citations | Author and Year | Title |
|---|---|---|
| 7280 | [11] | Science and technology for water purification in the coming decades |
| 1596 | [12] | Solar absorber material and system designs for photothermal water vaporization towards clean water and energy production |
| 1140 | [13] | Antifouling membranes for sustainable water purification: Strategies and mechanisms |
| 1108 | [14] | Graphene oxide-based efficient and scalable solar desalination under one sun with a confined 2D water path |
| 880 | [15] | Capacitive deionization as an electrochemical means of saving energy and delivering clean water. Comparison to present desalination practices: Will it compete? |
| 862 | [16] | Water purification by membranes: The role of polymer science |
| 789 | [17] | Flexible and Salt Resistant Janus Absorbers by Electrospinning for Stable and Efficient Solar Desalination |
| 781 | [18] | A salt-rejecting floating solar still for low-cost desalination |
| 593 | [19] | A review of data center cooling technology, operating conditions and the corresponding low-grade waste heat recovery opportunities |

| | | |
|---|---|---|
| 553 | [20] | Graphene-Based Standalone Solar Energy Converter for Water Desalination and Purification |

Source: Scopus, 2025

## DISCUSSION

**Thematic Structure and Core Research Areas**

The co-occurrence network analysis reveals that the field is primarily structured around three interrelated thematic clusters. The first cluster focuses on desalination technologies and water filtration systems, including methods such as reverse osmosis, distillation, and membrane-based filtration. These represent the most researched and cited topics, underscoring their foundational role in clean water innovation. Desalination, in particular, appears as the most central and frequently occurring keyword, highlighting its critical position in addressing water scarcity globally. The second major cluster centers around solar-driven and renewable-energy-supported water purification methods, such as solar desalination, photo-thermal evaporation, and solar steam generation. The increasing frequency of these terms in recent years, as shown by the overlay visualization, indicates a growing research interest in sustainable and decentralized water treatment solutions, which are particularly relevant for rural, off-grid, and climate-vulnerable communities. The third thematic cluster is more closely associated with traditional water treatment and wastewater management practices, including water purification, wastewater treatment, and water supply infrastructure. While less dominant in recent literature, these themes continue to be vital, especially in contexts where water pollution, sanitation, and resource recovery intersect with health outcomes.

**Temporal Shifts and Emerging Trends**

The temporal overlay map provides important insights into the evolution of research priorities. Earlier research (pre-2020) was predominantly focused on mature technologies like membrane filtration and reverse osmosis, which have long been established as reliable solutions for water desalination. These studies often dealt with performance optimization, energy consumption, and membrane fouling—critical factors for large-scale, centralized systems. In contrast, more recent studies (2021–2023) show a surge in interest toward renewable-energy-based desalination, such as solar steam generation and photo-thermal methods. The appearance of these topics in yellow on the overlay map suggests they are emerging frontiers that align with global efforts to reduce carbon emissions and achieve the Sustainable Development Goals (SDGs), particularly SDG 6 (clean water and sanitation) and SDG 13 (climate action). These innovations offer dual benefits: expanding access to safe water while minimizing environmental impacts. Moreover, terms like clean energy, solar power, and low-cost desalination point to an increasing focus on the affordability and scalability of technologies. This reflects a shift from purely technical performance to broader concerns of social and environmental sustainability, especially in low- and middle-income countries where infrastructure and energy access are limited.

**Research Density and Theoretical Centrality**

The density visualization further confirms the centrality of desalination as the intellectual and thematic core of the research field. Its high-density node—surrounded by related terms such as water filtration, potable water, and solar energy—indicates that these subthemes are not isolated but rather interlinked components of a shared research agenda. Less dense yet increasingly active terms—such as steam generation, photo-thermal evaporation, and solar steam—suggest niche or emerging subfields. These areas may not yet dominate the literature but are likely to gain prominence as the global research agenda shifts toward sustainable and low-energy solutions. The presence of such terms in moderate-density zones suggests early-stage consolidation of innovative approaches that have the potential to disrupt established paradigms in water treatment.

Author and Institutional Collaboration Networks

The co-authorship network highlights the importance of collaboration in advancing innovation. The red and green clusters represent two dominant author groups—likely from different geographic or institutional origins—with the red cluster containing a denser web of co-authors. Prominent researchers such as Wang Y., Li Y., and Liu Z. appear as central nodes, suggesting they act as intellectual hubs driving significant research output. The green cluster, while equally robust, appears slightly more decentralized, indicating a broader base of medium-impact contributors. These clusters demonstrate strong intra-group collaboration but comparatively fewer inter-group links, suggesting some degree of regional or disciplinary segmentation in the field. Nevertheless, a few connecting nodes indicate bridging authors who facilitate knowledge exchange between research communities—critical for interdisciplinary integration between engineering, environmental science, and public health. Interestingly, notable scholars such as Elimelech M., whose work on membrane science and energy-efficient desalination has been widely cited, appear on the periphery but are linked to multiple clusters, indicating cross-cluster influence rather than volume-based centrality.

**Global Distribution and International Collaboration**

The country-level co-authorship map confirms that the field is globally distributed, with strong contributions from both developed and emerging economies. China and the United States dominate in publication volume and connectivity, acting as global hubs. Their central positions reflect not only the scale of investment in water technologies but also the breadth of their collaborative networks. Other major contributors include India, Iran, Australia, Germany, and the United Kingdom, each of which plays a distinct role in regional or thematic research leadership. Countries in the Middle East and North Africa (MENA) region—such as Egypt, the UAE, and Qatar—are particularly active in desalination research, reflecting local water scarcity challenges and investment in technological solutions. Interestingly, South-South collaboration is also evident, with partnerships between countries like India and Nigeria, or Malaysia and Iraq, indicating growing research leadership in the Global South. However, while many countries are interconnected, the network still shows asymmetries, with high-income countries occupying more central positions in knowledge production and citation impact. This underlines the need for equitable knowledge sharing and capacity building to ensure that technological advancements reach the communities most affected by water insecurity.

**Implications for Public Health and Policy Integration**

One of the key findings of this bibliometric analysis is the limited explicit integration of public health metrics within the literature on water innovation. Although themes like potable water and clean water access appear regularly, few studies explicitly connect these technologies with measurable health outcomes such as reductions in disease prevalence, improvements in child health, or lowered healthcare costs. This highlights a critical opportunity for interdisciplinary collaboration. Future research should more intentionally link technological innovation with epidemiological data, behavioral health studies, and implementation science to evaluate real-world impacts. Such integration is essential for guiding public investment, designing regulatory frameworks, and ensuring that water technologies are not only effective but also equitable and health-enhancing.

## CONCLUSION

This bibliometric study provides an in-depth examination of global research trends in clean water and desalination technologies, emphasizing their connection to public health objectives. The analysis revealed that desalination remains the core topic, surrounded by emerging interests in solar energy integration, water filtration methods, and sustainable purification technologies. Through VOSviewer visualizations, we identified evolving thematic clusters, with newer research increasingly oriented toward renewable-energy-driven solutions and decentralized, low-cost water systems. Author and country-level collaboration maps highlighted China and the United States as global leaders, alongside significant contributions from India, Iran, and Middle Eastern countries. However, the study also identified a persistent gap between technological innovation and public health discourse. While many publications address technical performance, few explicitly quantify health outcomes such as reduced disease incidence or improved hygiene standards. To bridge this gap, future research should promote interdisciplinary collaborations that combine water engineering, environmental science, and public health. By doing so, clean water innovation can be more effectively aligned with sustainable development goals and contribute more directly to improving human well-being across diverse global contexts.

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