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Bibliometric Analysis of Water Use and Irrigation in Agriculture

Loso Judijanto
IPOSS Jakarta, Indonesia

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ABSTRACT

This bibliometric analysis explores the evolving landscape of research on water use and irrigation in agriculture, with a focus on key themes such as soil carbon sequestration, groundwater depletion, nutrient management, and the water footprint. By examining the most-cited studies in the field, the study highlights the significant contributions of these topics to global food security and climate change mitigation. The analysis reveals the interconnectedness between environmental management, agricultural practices, and technological advancements, suggesting a need for integrated approaches in both policy and practice. While the study is based on citation data from indexed journals, it provides valuable insights for policymakers, practitioners, and researchers, emphasizing the importance of sustainable water management strategies. The findings contribute to theoretical frameworks by illustrating the complex relationships within agricultural sustainability, providing a foundation for future research in this crucial area.

Corresponding Author:

Name: Loso Judijanto
Institution: IPOSS Jakarta, Indonesia
Email: losojudijantobumn@gmail.com

1. INTRODUCTION

Agriculture remains the backbone of global food security, contributing significantly to the socioeconomic development of many nations. With the world population projected to surpass 9 billion by 2050, the demand for agricultural products is expected to rise substantially, placing immense pressure on agricultural systems to produce more with limited resources [1], [2]. Among these resources, water is particularly critical, as it is indispensable for plant growth, soil fertility, and sustaining crop yields. Irrigation, therefore, serves as a vital agricultural practice that enhances crop productivity, mitigates the risks of drought, and ensures consistent food supply in regions with irregular rainfall [3], [4]. However, the increasing reliance on irrigation intensifies concerns about water scarcity, efficiency, and sustainable management practices in agriculture [5].

Water use in agriculture is influenced by multiple factors, including climate variability, soil characteristics, crop types, and technological advancements in irrigation systems. Traditional methods such as flood irrigation, while simple and cost-effective, are often associated with water losses, soil degradation, and inefficient resource utilization [6]. Conversely, modern irrigation techniques like drip and sprinkler systems offer higher efficiency, precision water delivery, and reduced environmental impacts [7]. Yet, the adoption of these technologies varies widely across regions due to economic, infrastructural, and knowledge constraints. Consequently, understanding global trends, research focus, and technological dissemination in agricultural water use is essential for guiding policy and research priorities [8], [9].

Recent decades have witnessed a growing interest in bibliometric studies as a method to analyze scientific outputs, research trends, and collaborative networks in specific fields. Bibliometric analysis allows researchers to evaluate the volume, quality, and thematic focus of publications, providing insights into the evolution of knowledge and identifying gaps that warrant further investigation [10]. In the context of water use and irrigation in agriculture, bibliometric approaches can uncover patterns in research productivity, regional focus, and thematic shifts over time. Such analyses are invaluable for policymakers, researchers, and practitioners seeking evidence-based strategies to improve water management and enhance agricultural productivity sustainably.

Water scarcity poses one of the most pressing challenges to global agriculture. Approximately 70% of freshwater withdrawals worldwide are attributed to irrigation, yet inefficient water management contributes to resource depletion, reduced crop yields, and environmental degradation [11], [12]. Climate change exacerbates these challenges, altering precipitation patterns and increasing the frequency of drought events, particularly in arid and semi-arid regions. Therefore, scientific research that addresses water-efficient irrigation practices, technological innovations, and sustainable resource management is vital to support resilient agricultural systems. Identifying trends in this research through bibliometric analysis can help align future studies with pressing global needs.

Furthermore, international efforts such as the United Nations Sustainable Development Goals (SDGs) emphasize the importance of sustainable water management and food security. SDG 6 aims to ensure availability and sustainable management of water and sanitation for all, while SDG 2 targets ending hunger and achieving food security through sustainable agricultural practices. The intersection of these goals highlights the critical role of irrigation efficiency and water use optimization in achieving global sustainability objectives. By examining the evolution of research in this area, scholars and policymakers can better understand knowledge gaps, research priorities, and collaborative opportunities that can accelerate progress toward these global targets.

Despite the extensive research on agricultural water use and irrigation practices, knowledge remains fragmented, and trends in research productivity, collaboration, and thematic focus are not comprehensively mapped. Existing studies often emphasize localized empirical research or technical assessments, with limited attention to synthesizing global knowledge patterns. This fragmentation hinders the ability to identify emerging technologies, regional disparities, and priority areas for sustainable irrigation research. Moreover, with increasing water scarcity and climate-related challenges, a systematic understanding of research trends is essential to guide future studies and inform policy-making effectively. This study aims to conduct a comprehensive bibliometric analysis of water use and irrigation in agriculture.

2. METHODS

This study employed a bibliometric approach to analyze research trends, productivity, and collaboration patterns in the field of water use and irrigation in agriculture. Bibliometric analysis is a quantitative method used to assess the structure, development, and impact of scientific literature within a specific domain.

For this study, relevant publications were systematically retrieved from Scopus using a combination of keywords such as "water use," "irrigation," "agriculture," "water management," and "crop irrigation." The search was limited to articles, reviews, and conference papers published in English to ensure consistency in data analysis and comparability of findings across studies.

Data cleaning and preprocessing were conducted to remove duplicate records, irrelevant publications, and incomplete metadata. The extracted bibliometric data included publication year, authorship, institutional affiliation, country, journal source, and citation metrics. Additionally, keyword co-occurrence and thematic analysis were performed to identify research trends, emerging topics, and areas of high scientific impact. VOSviewer was employed to map collaboration networks among authors, institutions, and countries, as well as to illustrate thematic clusters and evolution of research topics over time.

3. RESULTS AND DISCUSSION

3.1 Keyword Co-Occurrence Network

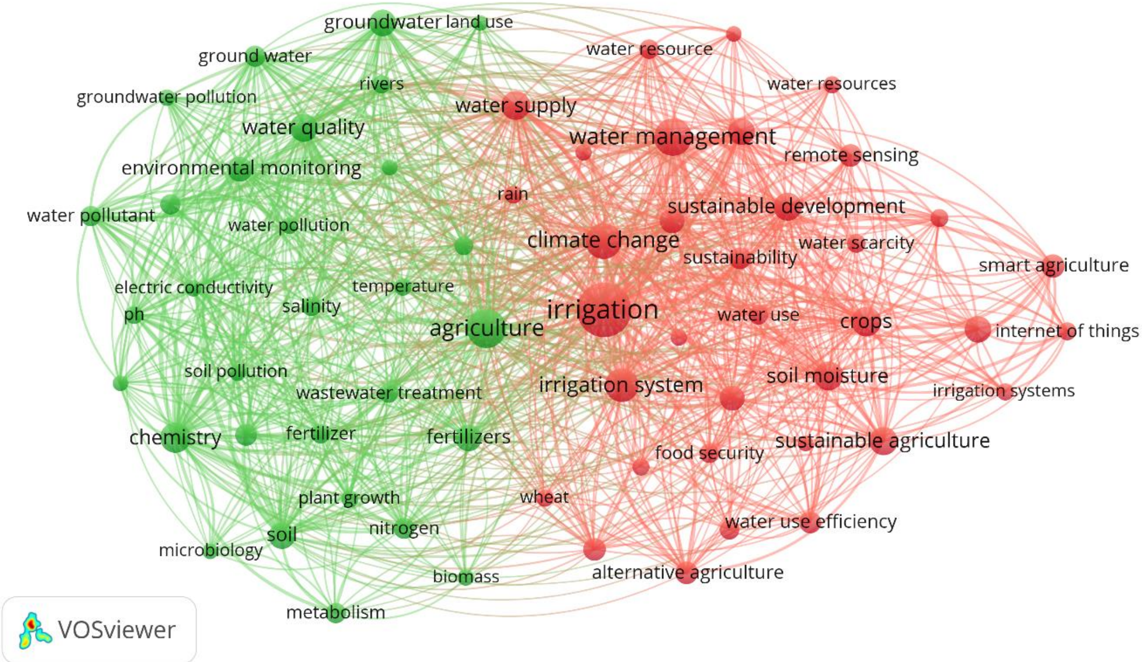

Figure 1. Network Visualization

Source: Data Analysis Result, 2025

Figure 1 displaying the relationships between various research terms related to water use and irrigation in agriculture. The network is color-coded into two primary clusters. The red cluster is closely associated with water-related topics, including irrigation, water resources, water management, and climate change. This cluster highlights themes around water scarcity, irrigation systems, soil moisture, sustainable agriculture, and the role of technology like remote sensing and the Internet of Things (IoT) in water management. These terms suggest a focus on modernizing agricultural practices to address water scarcity, improve efficiency, and support sustainable farming systems. The green cluster, on the other hand, centers on the quality of water and its relationship with agricultural processes. Key terms in this cluster include water quality, groundwater, salinity, and wastewater treatment. These terms reflect research areas focused on maintaining the health of water systems, addressing pollution, and ensuring water quality for agricultural use. This cluster also includes chemistry-related topics like pH, soil pollution, and fertilizers, pointing to a scientific approach to improving agricultural outcomes through better water and soil management practices.

The overlap between the two clusters indicates the interconnectedness of water quality and efficient water use in agricultural practices. For example, the relationship between irrigation (a red cluster term) and water quality (a green cluster term) is essential in designing systems that ensure both efficient water distribution and the maintenance of healthy water resources. Terms like "fertilizers" and "soil" are placed in the intersection, showing that soil health is integral to both water quality and irrigation efficiency.

The presence of "climate change" and "sustainability" in the red cluster also signals that many studies on water use and irrigation in agriculture are framed within the broader context of climate change impacts and sustainability goals. Research on climate change is crucial because it influences water availability and demand, further complicating agricultural water management. Studies in this area are exploring how agricultural systems can adapt to changing water patterns and how to mitigate the effects of droughts, floods, and other extreme weather events on crop production.

Terms like "sustainable agriculture," "alternative agriculture," and "food security" underline the critical importance of balancing water efficiency with environmental sustainability and the need to secure global food systems. These terms point to an emerging research direction that integrates social and ecological dimensions with technological and scientific advancements to promote a sustainable future for agriculture.

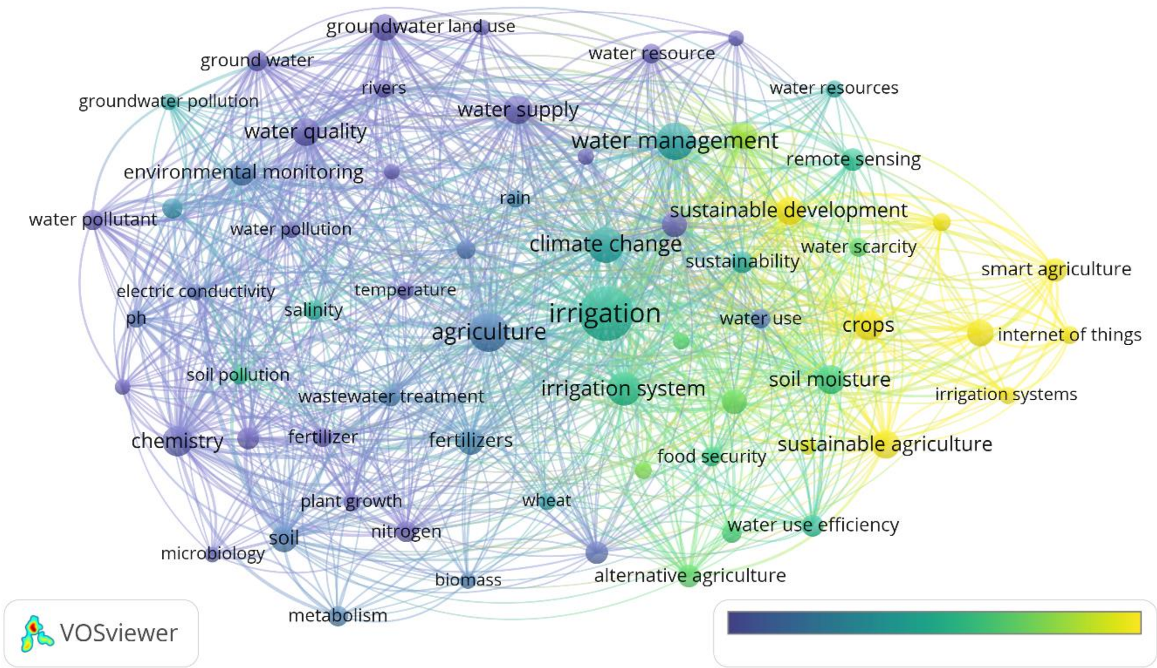

Figure 2. Overlay Visualization

Source: Data Analysis Result, 2025

Figure 2 showing a more nuanced network of terms related to irrigation and water use in agriculture. The color gradient, transitioning from purple to yellow, suggests the strength or frequency of co-occurrence relationships between these terms. The more intense yellow and green clusters signify highly interconnected and frequently cited concepts, while purple and blue represent less frequent but still significant connections. This highlights the evolving interdisciplinary nature of the research on water use and irrigation, where terms related to water management, climate change, and sustainable agriculture dominate the central cluster, while other terms like "soil," "fertilizers," and "ph" are located on the periphery.

The central cluster includes terms like "irrigation," "water management," and "climate change," underlining the current focus on climate change's impact on water resources and agricultural productivity. The interconnections between these terms suggest an emphasis on how irrigation and water management practices must adapt to new challenges posed by shifting climate patterns. Other critical topics in the network, such as "water quality," "sustainable development," and "water scarcity," reflect the need for integrated approaches that consider both the scientific and societal dimensions of water use in agriculture. These terms suggest that the research is not solely focused on improving technical solutions but also on promoting sustainable agricultural practices that minimize water waste and support long-term environmental health.

On the periphery, there are additional clusters related to advanced technologies like "smart agriculture," "Internet of Things (IoT)," and "remote sensing." These terms highlight the increasing role of digital technologies in optimizing irrigation systems and improving water efficiency. The visualization indicates a growing interest in integrating IoT and other smart technologies into irrigation systems, aiming for more precise and efficient water use in agriculture. The inclusion of terms like "food security" and "sustainable agriculture" suggests that researchers are concerned with ensuring that technological advancements also contribute to broader goals, such as improving food production and achieving sustainability in agricultural systems.

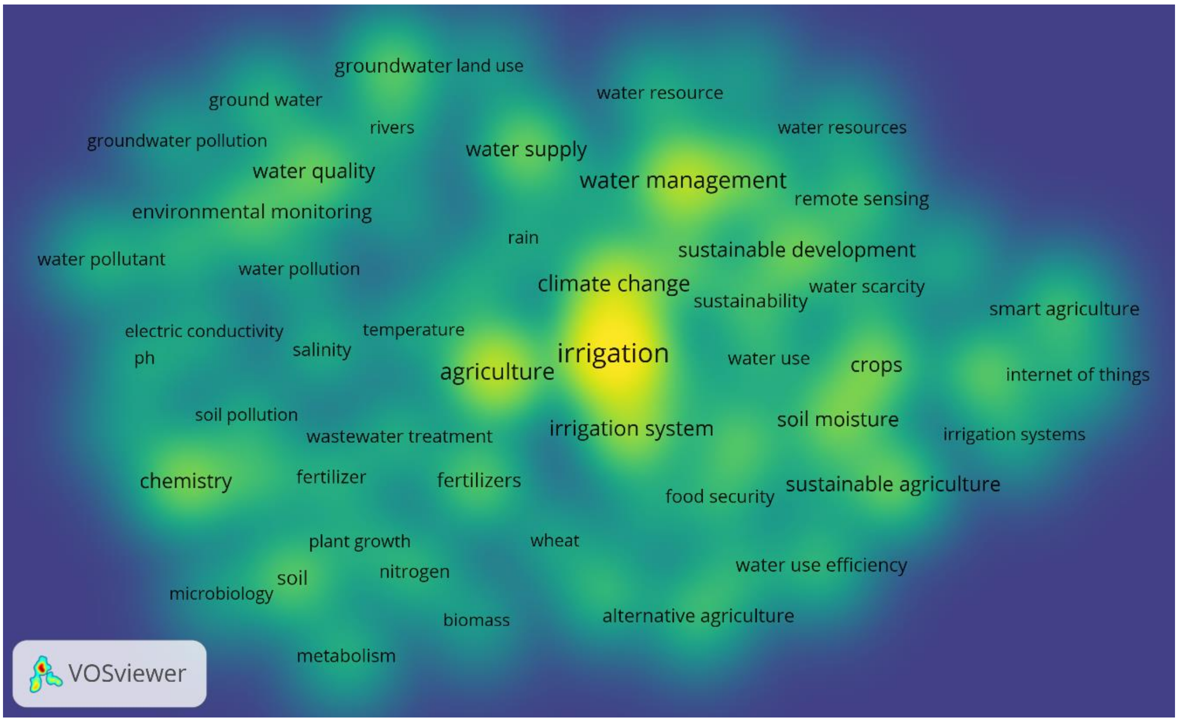

Figure 3. Density Visualization

Source: Data Analysis, 2025

Figure 3 highlights the density of research topics related to water use and irrigation in agriculture. The brightest areas in the center, marked by a yellow hue, show the highest density of interconnected terms such as "irrigation," "water management," "climate change," "agriculture," and "sustainability." These terms indicate the core focus of the research area, underscoring the significant attention given to improving irrigation systems and addressing climate change's impact on water use in agriculture. The research in this central zone emphasizes integrating sustainable practices and technological advancements to optimize water management in farming, ensuring water availability for crop production and mitigating water scarcity challenges. Outside the central cluster, the heatmap shows varying densities in topics related to water quality, soil moisture, and environmental monitoring. Terms like "water quality," "fertilizer," "chemistry," and "wastewater treatment" are clustered in areas of moderate intensity, suggesting a growing concern with maintaining water and soil health in agricultural systems. The presence of "smart agriculture" and "Internet of Things (IoT)" on the periphery highlights the increasing role of technology in addressing water management challenges.

3.2 Co-Authorship Network

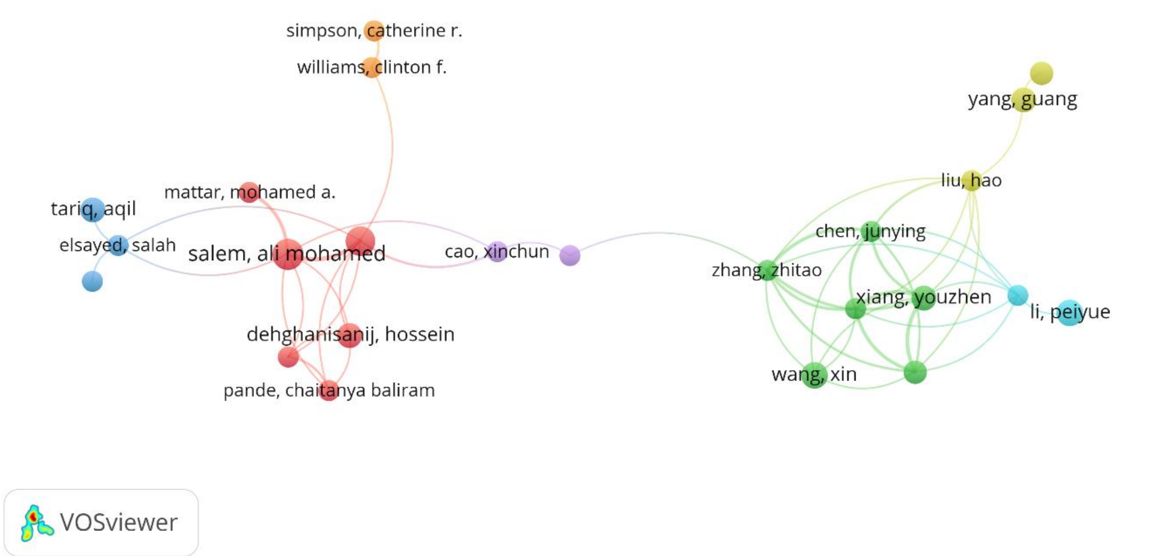

Figure 4. Author Collaboration Visualization
Source: Data Analysis, 2025

Figure 4 shows a co-authorship network from VOSviewer, illustrating the relationships between different authors in the field of water use and irrigation in agriculture. The nodes represent individual authors, with the size of each node indicating their number of publications or connections. Authors are grouped by color, and the edges between them represent co-authorship links. For example, authors like "Salem, Ali Mohamed" are highly connected with others, forming a central hub in the network. The network reveals clusters of closely collaborating authors, with some isolated nodes indicating authors with fewer collaborations. The visualization highlights the collaborative nature of research in this field, showing how authors work together on various topics within water management and irrigation.

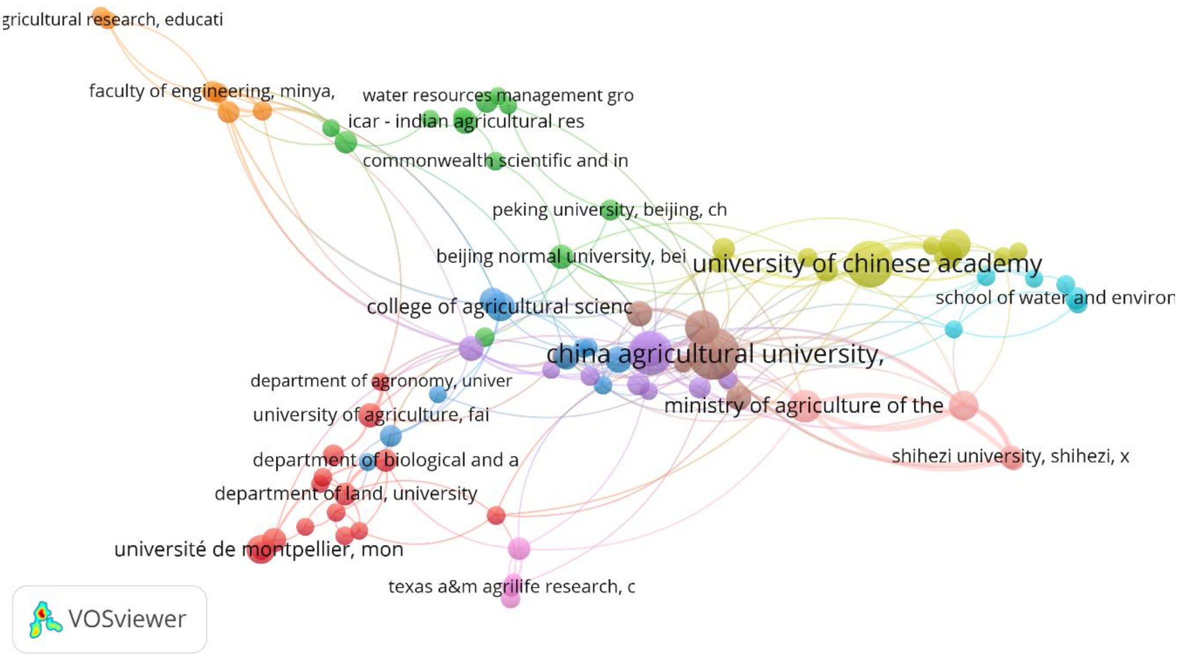

Figure 5. Affiliation Collaboration Visualization
Source: Data Analysis, 2025

Figure 5 depicts the co-authorship relationships between various institutions involved in agricultural research, particularly in the area of water use and irrigation. The nodes represent different institutions, with larger nodes indicating institutions with more collaborations. The colored clusters represent groups of institutions that are closely linked through joint research efforts, such as "China Agricultural University," "Peking University," and "Shihezi University." These connections suggest a high degree of collaboration between universities and research organizations in different regions, especially those focused on water management and agricultural science. The visual layout shows that certain institutions are central hubs in the network, indicating their significant role in driving research in this field, while others are more peripheral but still connected through various co-authorships.

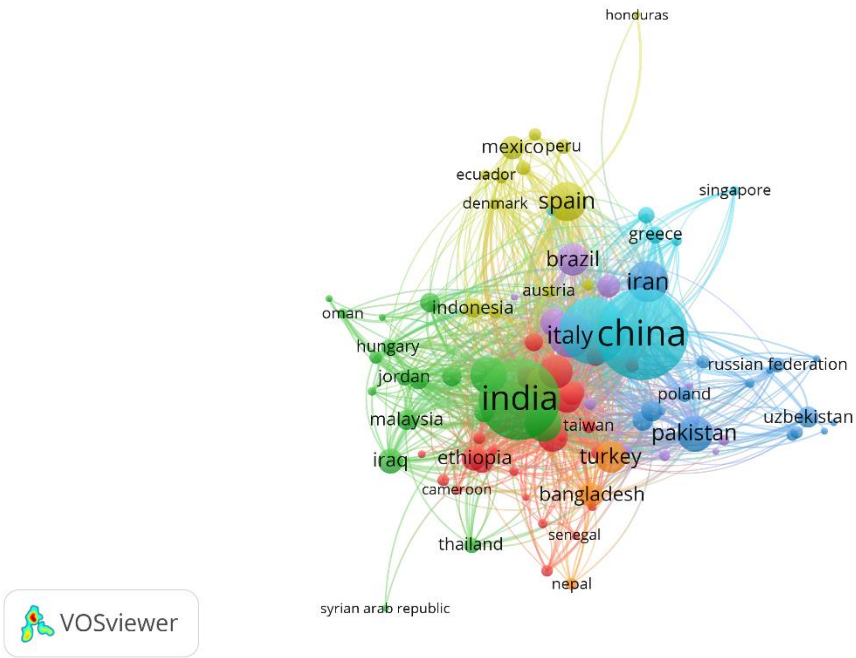

Figure 6. Country Collaboration Visualization

Source: Data Analysis, 2025

Figure 6 visualization displays the global distribution of research collaboration in the field of water use and irrigation across different countries. The nodes represent countries, with their size indicating the volume of research publications or collaborations, while the edges connecting them reflect co-authorship and research partnerships. The central cluster, dominated by large nodes such as China, India, and Italy, indicates a high concentration of collaborative research in these countries. The color coding shows regional groupings, with countries like Spain, Brazil, and the United States forming strong connections in one cluster, while other countries like Pakistan, Turkey, and Bangladesh are part of a separate network. The visualization emphasizes the interconnected nature of global research efforts, highlighting how different countries contribute to and collaborate on agricultural water management and irrigation studies.

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3.3 Citation Analysis

Table 1. Top Cited Research

Citations	Authors and year	Title
6633	[13]	Soil carbon sequestration impacts on global climate change and food security
2952	[14]	Fragmentation and flow regulation of the world's large river systems
2407	[15]	Reducing environmental risk by improving N management in intensive Chinese agricultural systems
2359	[16]	Satellite-based estimates of groundwater depletion in India
2309	[17]	Closing yield gaps through nutrient and water management
2006	[18]	Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China
1877	[19]	The water footprint of humanity
1825	[20]	The state and fate of himalayan glaciers

Citations	Authors and year	Title
1803	[21]	Antibiotic resistance genes as emerging contaminants: Studies in northern Colorado
1799	[22]	The green, blue and grey water footprint of crops and derived crop products

Source: Scopus, 2025

Table 1 presents the top-cited research related to environmental and water management studies, with a focus on agricultural systems, water use, and sustainability. The highest-cited paper, "Soil carbon sequestration impacts on global climate change and food security" by [13], has been cited 6,633 times, emphasizing the crucial role of soil carbon in addressing climate change and ensuring food security. Other highly cited papers discuss critical issues like river fragmentation [14], groundwater depletion in India [16], and improving nitrogen management in agricultural systems in China [15]. Several papers also focus on water-related risks, such as health risks from heavy metals in wastewater-irrigated crops (Khan et al., 2008), the global water footprint [19], and the environmental impacts of water use in agriculture [22].

Discussion

Practical Implication

This bibliometric analysis of research on water use and irrigation in agriculture provides valuable insights for policymakers, agricultural practitioners, and researchers. The high number of citations for studies related to soil carbon sequestration, groundwater depletion, and nutrient management underscores the practical importance of these issues in the context of global food security and climate change. For policymakers, these findings highlight the need for integrating water and nutrient management strategies into agricultural policies to address both food security and environmental sustainability. The research also emphasizes the importance of monitoring groundwater resources and promoting efficient irrigation practices, as seen in the significant body of work on groundwater depletion and water footprint. Practitioners in the agricultural sector can use this information to improve farming techniques, such as optimizing water usage and enhancing soil health, to mitigate the risks of climate change and ensure sustainable crop production.

Theoretical Contribution

This study makes a significant theoretical contribution to the understanding of the interconnectedness between water use, irrigation, and agricultural sustainability. The network of research themes, such as water footprint, nitrogen management, and soil carbon sequestration, provides a comprehensive view of how different aspects of agriculture and water management are related. The high interconnectivity between these themes suggests that future theoretical frameworks should adopt a more integrated approach, considering the multiple dimensions of water management within the broader context of sustainable agricultural practices. Furthermore, the research highlights the need to explore the role of technology, such as remote sensing and IoT, in advancing water management solutions, thus opening new theoretical avenues for the integration of digital tools in agriculture.

Limitations of This Study

While this bibliometric analysis provides a valuable overview of key research areas and trends, it has several limitations. First, the analysis is based solely on citation data, which may not fully capture the quality or impact of the studies, as some high-impact papers may not have accumulated a large number of citations yet. Additionally, the study focuses on articles indexed in databases like Scopus, which may not encompass all relevant research, particularly from smaller journals or grey literature that might present valuable insights on water use and irrigation.

Moreover, the study does not delve into the specific methodologies or outcomes of the papers analyzed, which could provide a deeper understanding of the effectiveness of various water management strategies in practice. Future research could address these limitations by incorporating qualitative analyses of the methodologies and outcomes of the studies and expanding the scope to include non-indexed research.

4. CONCLUSION

This bibliometric analysis of research on water use and irrigation in agriculture highlights the critical intersection of water management, climate change, and agricultural sustainability. The study identifies key research themes, such as soil carbon sequestration, groundwater depletion, and nutrient management, that have garnered significant attention due to their importance for both food security and environmental sustainability. The analysis underscores the need for integrated strategies in agricultural policy and practice, emphasizing efficient water usage, sustainable farming techniques, and the role of technology in optimizing water management. Furthermore, the study contributes to theoretical frameworks by highlighting the interconnectedness of various agricultural and environmental factors, suggesting a more holistic approach to future research. Despite some limitations, such as reliance on citation data and the exclusion of non-indexed research, this study provides a comprehensive overview of the current state of knowledge in this field and serves as a valuable resource for guiding future research and practical applications in water use and irrigation.

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