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ADAPTING AGRICULTURE TO CLIMATE CHANGE: A BIBLIOMETRIC ANALYSIS OF DEFICIT IRRIGATION STRATEGIES.

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Tojiyev Sherzod
Fazliev Jamoliddin
Shokhimardanova Niginabonu

Sherzod Tojiev
Department Environmental Education and Promotion, Research Institute of Environment and Nature Conservation Technologies, Tashkent, 111101, Uzbekistan;
Email: sherzod09141998@gmail.com ORCID: https://orcid.org/0009-0008-1627-6235
Fazliev Jamoliddin
Bukhara State Technical University,Bukhara, 200100, Uzbekistan;
Email: jamolliddinfazliyev@gmail.com ORCID: https://orcid.org/0009-0003-3852-7115
Shokhimardanova Niginabonu
Independent researcher, Email: shaximardanovan@gmail.com
ORCID: https://orcid.org/0009-0009-4457-8481

Abstract: *Irrigation and agriculture face increasing challenges caused by climate change, requiring effective strategies such as deficit irrigation to maintain crop productivity. This study uses a bibliometric approach to analyze global research trends in deficit irrigation and its role in climate change adaptation. The methods used included a systematic search of publications in the Scopus database using keywords related to irrigation and agriculture, followed by a quantitative analysis of research output, authorship and collaboration networks. The results show an increasing number of publications with significant contributions from water-stressed regions and covering key research areas such as water use efficiency, soil moisture management and crop yield optimization. The discussion highlights the importance of integrating interdisciplinary approaches and new technologies to improve irrigation efficiency and resilience to climate change. In conclusion, deficit irrigation is a vital tool for sustainable agriculture, providing valuable insights to policymakers, researchers and practitioners seeking to adapt agricultural practices to changing environmental conditions.*

Key words: *irrigation, agriculture, deficit irrigation, climate change, bibliometric analysis*

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1 INTRODUCTION

The complex relationship between irrigation and agriculture lies at the very foundation of human civilization, allowing societies to overcome the vagaries of rainfall and achieve food security even in the driest regions. For thousands of years, the development of irrigation systems has been synonymous with agricultural prosperity, population growth, and the emergence of complex societies. Today, this ancient connection is being tested to its gravest extent. The world is experiencing an unprecedented confluence of circumstances: rapid climate change, a rapidly growing global population projected to reach nearly 10 billion by mid-century, and the alarming depletion of water resources on which irrigated agriculture depends. Agriculture, while being the largest consumer of freshwater globally (accounting for approximately 70% of total consumption, and up to 90% in many developing countries), is also the main cause of water scarcity and the sector most vulnerable to its consequences. The relentless demand for food, feed, and fiber is putting undue pressure on underground aquifers, leading to a sharp decline in groundwater levels in major agricultural regions such as the North China Plain, the Indo-Gangetic Plain, and California's Central Valley. The growing water crisis, exacerbated by the increasing frequency and intensity of droughts, heat waves, and unpredictable changes in precipitation patterns caused by climate change, has made the search for sustainable irrigation and agricultural systems one of the most urgent scientific and political challenges of our time[1].

In response to this growing pressure, the global scientific community is increasingly focusing on developing and improving water-efficient irrigation strategies that can decouple agricultural productivity from unsustainable water consumption. Among these, deficit irrigation (DI) has proven to be a particularly promising and widely researched approach. The basic idea behind the DI method is both simple and profound: instead of watering plants to meet their full evaporative needs, water stress is created in a targeted and controlled manner. This strategy exploits the inherent physiological resilience of plants, which often exhibit a nonlinear response to water availability. By strategically limiting irrigation during phenological stages less sensitive to stress, the direct water application method can significantly improve water use efficiency (WUE), defined as the ratio of yield to water input, without a proportional reduction in final yield. Deficit irrigation (DI) technologies have evolved significantly and include a range of techniques, from controlled deficit irrigation (CDI), which applies stress at specific growth stages to regulate foliage size and improve fruit quality, to partial root zone drying (PRZ), a technique in which alternating irrigation is applied between the two halves of the root system to induce hormonal signals that close the stomata, thereby reducing water loss and maintaining plant hydration levels.

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Recent advances such as delayed irrigation further demonstrate the potential for innovation in this area, showing that carefully timed irrigation can promote deeper root development and improve overall water efficiency in crops [3]. The benefits of deionized water extend beyond simply saving water; it has been shown to improve fruit quality by concentrating sugars and flavonoids in crops such as grapes and fruit trees, this will reduce unproductive evaporation from the soil surface and the associated accumulation of salts [4], and even reduce greenhouse gas emissions by creating less favorable conditions for methanogenesis and denitrification in the soil.

The scientific literature on irrigation and agriculture, with a particular focus on water-saving strategies such as desalination, has expanded significantly over the past two decades. This growth reflects the global recognition that future food security depends on our ability to produce more food with less water. The research covered a wide range of crops, from staple grains such as wheat and maize, to high-value horticultural and commercial crops, including cotton[6], tomatoes, and citrus. The scope of research has also expanded significantly, moving beyond a focus solely on crop yields and water use efficiency to encompass the multidimensional sustainability of irrigation practices. This has led to a growing number of studies examining the relationship between water, energy, and carbon, where water savings from pressurized drip and sprinkler systems must be weighed against the energy required for pumping[7]. Similarly, research is increasingly exploring the synergistic combination of deionization with other sustainable practices such as mulching[8], application of biochar, and integrated nutrient management to achieve co-benefits in crop yields, soil health, and environmental protection. However, the implementation of these technologies is not only a technical challenge; it is closely linked to farmer behavior, economic incentives, and governance structures, as studies of farmer collaboration in water management demonstrate and the need to develop targeted policies to support the implementation of sustainable agricultural practices in rural areas.

The sheer volume, diversity, and complexity of the literature on irrigation and agriculture, while testifying to the field's vitality, also poses a significant challenge. Traditional review articles, while valuable for synthesizing knowledge on specific subtopics, are often limited by their subjective nature and their inability to systematically capture the overall intellectual structure of this vast and rapidly expanding field of study. Bibliometrics provides a set of quantitative tools for analyzing large sets of publication data, allowing researchers to objectively identify key trends, map collaboration networks between authors and institutions, identify the most influential works and journals, and

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describe the evolution of major research topics[10]. In the context of irrigation and agriculture, bibliometric approaches have proven useful in mapping the interrelationships between water, energy and food, tracking progress in precision irrigation technologies, and generalization of the results of research on soil salinization[11]. These application examples highlight the potential of bibliometrics to create a holistic, objective and data-driven roadmap for such an important and multifaceted field as irrigation and water management in agriculture.

In the face of increasing climate variability and pressure on water resources, irrigation has become a central component of sustainable agricultural development. Growing demand for efficient water use in the face of climate change has led to a significant expansion of research in irrigation and agriculture. In this regard, bibliometric analysis has become a reliable and systematic approach to assessing the structure and evolution of scientific knowledge in this field. By using exclusively data from Scopus, one of the largest and most comprehensive abstract and citation databases, researchers can provide high-quality and standardized datasets for analysis. Scopus-based bibliometric studies enable quantitative evaluation of publication output, citation indicators, and international scientific collaborations, as well as identifying influential authors, leading institutions, and emerging research topics, such as deficit irrigation and climate-resilient agricultural practices. Thus, a bibliometric approach based on Scopus data provides a reliable basis for mapping research trends and identifying critical knowledge gaps in irrigation and agriculture in a changing climate.

2 METHODS

The aim of this study was to analyze global trends in research related to irrigation and agricultures using bibliometric methods. Bibliographic data was obtained from the Scopus database, recognized as one of the largest sources of peer-reviewed scientific publications.

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Data collection took place in February 2026. Relevant publications were identified using specific keywords related to irrigation and agricultures research. The search query was applied to the TITLE-ABS-KEY field in Scopus to ensure that the retrieved publications were closely related to the research topic. The selected period for analysis covered 2021 to 2025.

A total of 256 publications were retrieved and exported from the Scopus database in CSV format. The exported records contained information such as authors, publication year, source title, affiliations, countries, citations, and keywords. The methodological framework included several analytical tools. Microsoft Excel was used for data organization, cleaning, and descriptive statistical analysis. VOSviewer (version 1.6.20) was used to construct and visualize bibliometric networks, including co-authorship relationships and keyword co-occurrence patterns. Additionally, MapChart was used to illustrate the geographic distribution of publications across different countries.

2.1 Reviewing articles and determining compliance with requirements

The search was conducted using a combination of keywords and Boolean operators in the Scopus database. The search query was applied to the TITLE-ABS-KEY field to ensure a precise search of relevant literature.

The search string used in this study was formulated as follows:

TITLE-ABS-KEY ("irrigation" AND "agriculture") AND (LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2022) OR LIMIT-TO (PUBYEAR, 2023) OR LIMIT-TO (PUBYEAR, 2024) OR LIMIT-TO (PUBYEAR, 2025)) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re")) AND (LIMIT-TO (LANGUAGE, "English"))

Inclusion criteria required publications to be written in English and classified as articles or review papers. These document types were chosen because they provide comprehensive, peer-reviewed scientific information. To enhance the reliability of the dataset, several exclusion criteria were also applied. Publications lacking complete bibliographic information were excluded from the analysis. Furthermore, studies that only briefly mentioned irrigation or agricultural concepts, without addressing them as a primary focus of research, were excluded. After applying these criteria, the final dataset consisted of 256 publications

2.2 Data extraction and processing

The selected publications were analyzed using bibliometric methods to identify research trends and collaboration patterns. Bibliographic data extracted from the Scopus database included publication year, authors, affiliations, countries, journals, citations, and author keywords. Microsoft Excel was used to organize and preprocess the dataset and conduct descriptive statistical analysis. VOSviewer (version 1.6.20) was used to

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create network visualization maps showing the relationships between authors, keywords, and research collaborations. These network maps helped identify the most influential research topics and collaboration structures in this field. Additionally, MapChart was used to create geographic maps illustrating the global distribution of scientific publications related to irrigation and agriculture research. This approach provided a clearer understanding of the spatial patterns of research activity across different regions.

Fig. 1. Flowchart of the methodology.

3. RESULTS

3.1. Trend of publications on irrigation and agriculture

An analysis of scientific publications on irrigation and agriculture reveals a general trend of increasing research output between 2021 and 2025 (Figure 2). In 2021, 34 publications were registered in the database. This number increased significantly in 2022, reaching 59 publications, demonstrating growing scientific interest in irrigation management and sustainable agricultural

Latin American Journal of Education
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development. However, in 2023, the number of publications decreased slightly to 44, which may reflect temporary fluctuations in research productivity or changes in research priorities. Despite this decline, the number of publications increased again in subsequent years. In 2024, the number of publications increased to 53, demonstrating renewed interest in this topic.

The highest number of publications during the analyzed period was recorded in 2025-66 publications, highlighting the growing global attention to irrigation practices and their role in sustainable agricultural management. Overall, the results indicate that research in irrigation and agriculture has significantly intensified in recent years, reflecting the growing importance of water management, agricultural sustainability, and climate change adaptation in scientific discourse. Furthermore, an analysis of document types reveals that the majority of publications were research articles. Of the total number of documents analyzed, 86% were research articles, and 14% were review papers (Figure 3). This indicates that most research in irrigation and agriculture focuses on presenting original research results and experimental data. The relatively smaller proportion of review papers suggests that, although some studies aim to synthesize and generalize existing knowledge, this field remains largely defined by empirical and applied research.

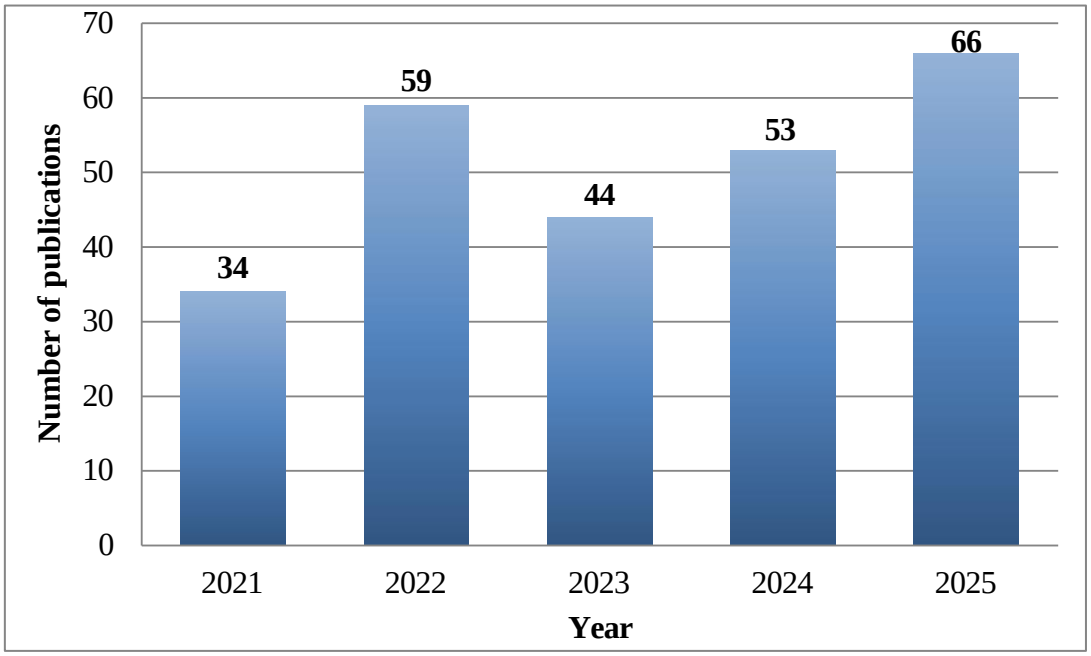

Fig. 2. Number of papers on irrigation and agriculture by the year of publication issues in the world.

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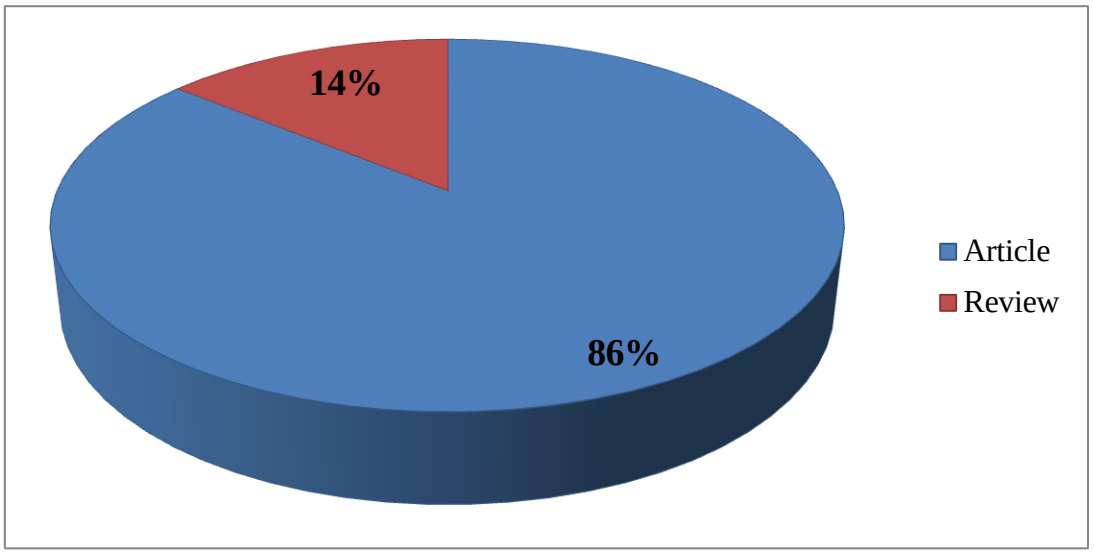

Fig. 3. Publication type on irrigation and agriculture issues in the world.

3.2. Journals on irrigation and agriculture research

To publish research related to irrigation and agriculture, researchers used a wide range of scientific journals from different parts of the world. An analysis of publication sources reveals that research results are distributed across numerous international journals specializing in environmental sciences, water resources management, and sustainable agriculture (Table 1). Among the analyzed sources, several journals made a significant contribution to the dissemination of research in this field. The journal Science of the Total Environment published the largest number of articles-54, followed by Agricultural Water Management with 28 publications and the Journal of Environmental Management with 27 publications. These journals play a crucial role in publishing research related to environmental impacts, water resources management, and sustainable agricultural practices. Other important journals include Water Supply with 13 publications, Environmental Monitoring and Assessment with 11 publications, and Water (Switzerland) with 10 publications. In addition, journals such as Chemosphere, Water Resources Management, Environmental Science and Pollution Research, Resources, Conservation and Recycling, Water, Air, and Soil Pollution, and Water Environment Research have also contributed to the development of this research area.

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Table 1. List of the journals on irrigation and agriculture by the year of publication issues in the world

Sources	Number	Sources	Number
Science of the Total Environment	54	Water Air and Soil Pollution	5
Agricultural Water Management	28	Water Environment Research	5
Journal of Environmental Management	27	Environmental Research	4
Water Supply	13	International Journal of Environmental Research and Public Health	4
Environmental Monitoring and Assessment	11	Environmental Pollution	3
Water Switzerland	10	Environmental Research Letters	3
Chemosphere	7	Irriga	3
Water Resources Management	6	Journal of Hydrology	3
Environmental Science and Pollution Research	5	Sustainable Water Resources Management	3
Resources Conservation and Recycling	5	Water Science and Technology	3

3.3. Authors and institutions in irrigation and agriculture research

The bibliometric analysis reveals a diverse global collaboration in irrigation and agriculture research, involving researchers from different countries and institutions. The leading authors, as shown in Figure 4, demonstrate significant contributions to the field. Zhao, J.[12] leads with 3 publications, followed by Wu, M.[13] (3), Singh, A. [14](3), Li, M. (3), Guo, S. (3), Guo, P. (3), Chu, C. (3), Cao, S. (3), and Cui, S. (3). Other notable authors include Chen, M. (2), Binger, R.L. (2), and Bernstein, N. (2). This distribution highlights the interdisciplinary nature of the research, with authors focusing on topics such as water resources management, soil health, and sustainable irrigation practices.

As shown in Figure 5, institutions play a key role in stimulating scientific research. China Agricultural University ranks first with 17 publications, highlighting China's dominance in this field. It is followed by the Chinese Academy of Sciences with 13 publications and Hohai University with 8. Other leading institutions include the Joint Research Centre of the European Commission (6), the Ministry of Agriculture of the People's Republic of China (6), the University of the Chinese Academy of Sciences (6), the Ministry of Education of the People's Republic of China (6), the Xinjiang Institute of Ecology and Geography (5), the Center for Agricultural Research, Education and Extension (5), and the Punjab Agricultural University (5). These institutions, mainly from China, with contributions from Europe, the United States, and India, account for a significant portion of the global research output, highlighting collaborative efforts in environmental sciences and sustainable agriculture. Overall, the concentration of publications at these leading institutions indicates the presence of strong research centers focused on addressing water scarcity, ecosystem resilience, and sustainable agricultural development.

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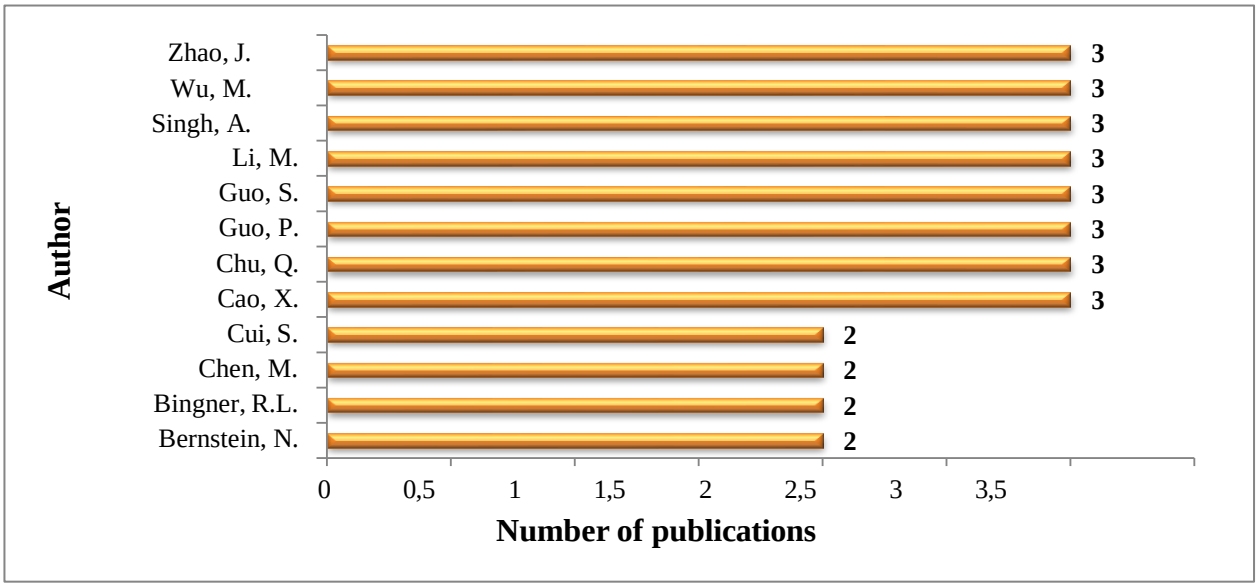

Fig. 4. List of top authors published on irrigation and agriculture issues in the world.

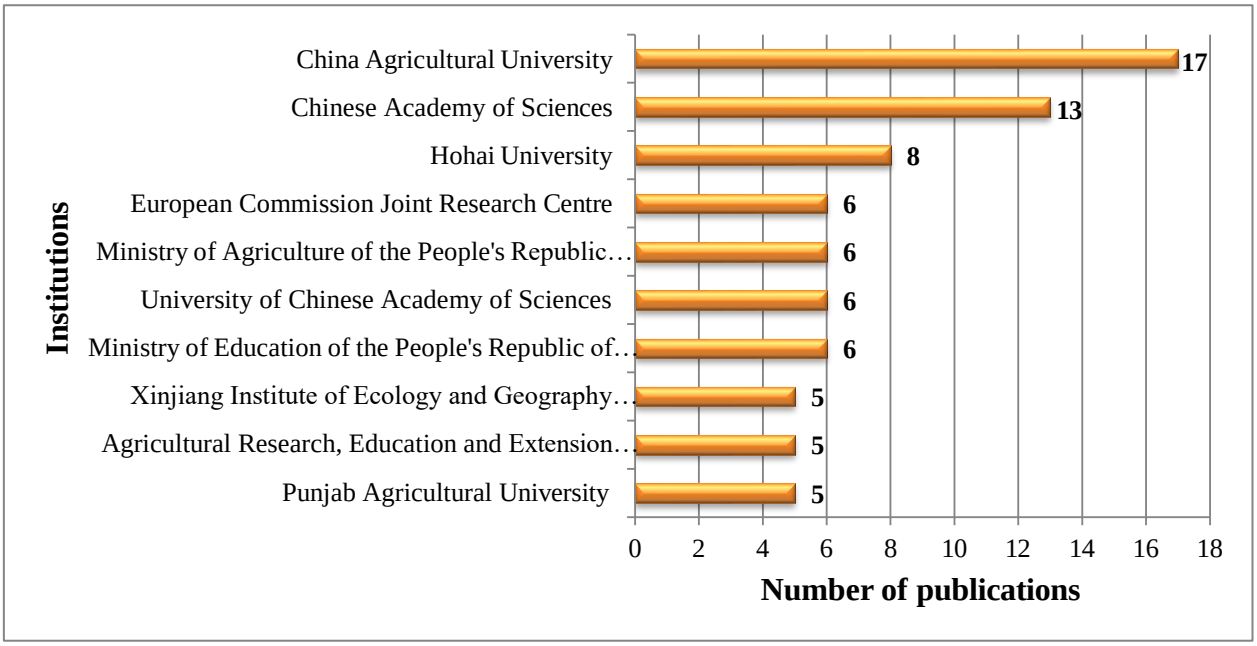

Fig. 5. List of top institutions on irrigation and agriculture issues in the world.

3.4. Top Countries in Irrigation and Agriculture Research

Research in the field of irrigation and agriculture has been published in many countries worldwide. The map in Figure 6 illustrates the distribution of publications, highlighting the most productive countries in this field. The leading countries account for a significant share of the global publication volume, reflecting their attention to water resources management, sustainable agricultural development, and environmental issues. China leads with 84 publications (approximately 30% of the total number of the top 10 countries), followed by the United States with 45 publications (16%), India with 37 (13%), Iran with 22 (8%), Italy with 19 (7%), the United Kingdom with 13 (5%), Australia

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with 11 (4%), Canada with 11 (4%), Spain with 11 (4%), and Egypt with 9 (3%). These 10 countries represent a significant share of research, with a particular focus on regions facing severe water shortages and agricultural pressures. The top-ranked countries include both developed and developing economies. Rapid economic growth and agricultural development in China, the United States, and India have led to increased research in ecology and agriculture, which in turn has increased the number of publications. This trend is likely explained by the fact that these countries are home to numerous highly ranked research centers and universities focused on water resource management and ecosystem resilience. Overall, the geographic distribution highlights the global relevance of irrigation practices in addressing climate change, food security, and resource conservation.

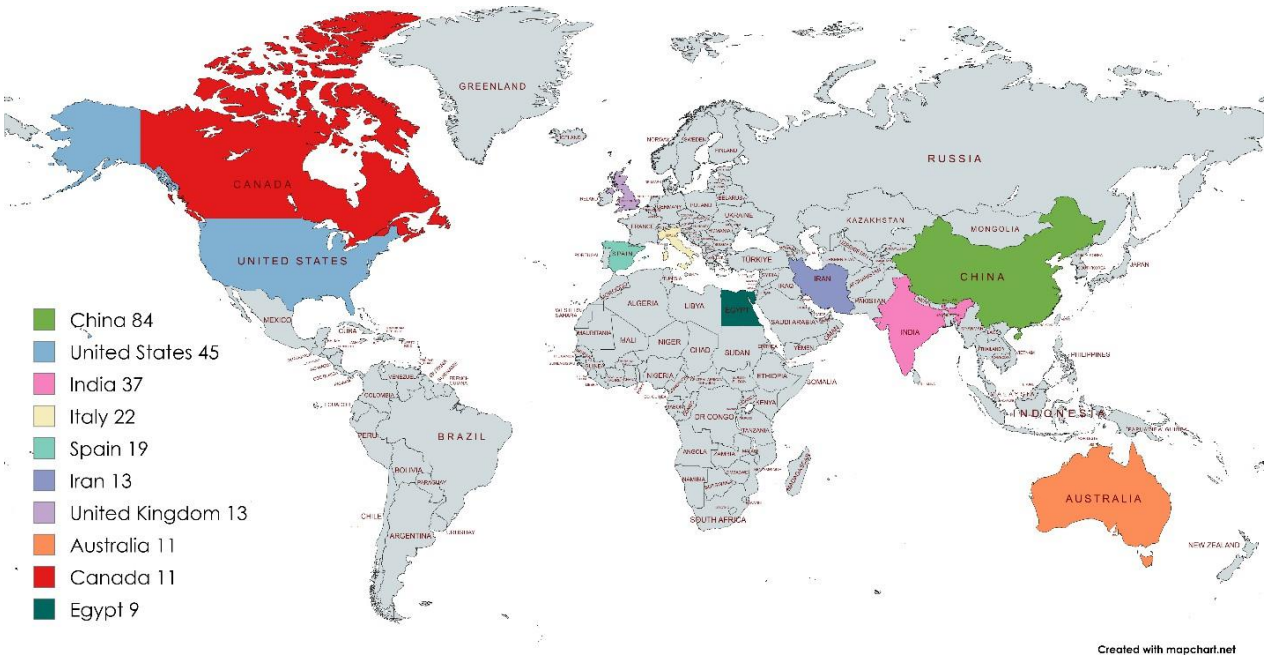

Fig. 6. List of top countries on irrigation and agriculture issues in the world.

3.5. Top cited papers in irrigation and agriculture research

A high number of citations indicates the quality and novelty of the research. The ten most cited papers in irrigation and agriculture are presented in Table 2. In total, these publications received 5,212 citations over the period 2021-2025. Almost 30% of citations in this field came from these 10 papers in the table. The top 10 cited papers include seven review articles and three research articles. In this list of the most cited papers, India is represented by two papers, China by two, Italy by two, and Pakistan, Iraq, Malaysia, and Iran by one each. As can be seen from this analysis, the majority of papers were published in peer-reviewed journals rather than conference proceedings. For example, of the sources that published at least three papers, the majority were highly ranked journals in

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the fields of environmental management and sustainable development, containing in-depth analyses with comprehensive justifications. These journal articles provide detailed information on environmental impacts, sustainable practices, and technological solutions. Thus, despite the smaller number of reviews, they were cited more often than conference papers due to their high importance and contribution to the field.

Table 2 List of top cited publications on irrigation and agriculture in the world.

Title	Journal	Corresponding author	PY	TC 2021-2025	Doc.type
Soil salinization management for sustainable development: A review	Journal of Environmental Management	Singh, A.	2021	433	Article
Nanobiotechnological advancements in agriculture and food industry: Applications, nanotoxicity, and future perspectives	Science of the Total Environment	Ali, S.S.	2021	211	Review
Adapting agriculture to climate change via sustainable irrigation: Biophysical potentials and feedbacks	Environmental Research Letters	Rosa, L.	2022	175	Review
Rice–wheat system in the northwest Indo-Gangetic plains of South Asia: issues and technological interventions for increasing productivity and sustainability	Paddy and Water Environment	Bhatt, R.	2021	168	Review
Integration of electrodialysis with renewable energy sources for sustainable freshwater production: A review	Journal of Environmental Management	Mir, N.	2021	140	Review
Optimizing sustainable agriculture: A comprehensive review of agronomic practices and their impacts on soil attributes	Journal of Environmental Management	Gatea, A.A.G.	2024	121	Review
Waste-derived nanobiochar: A new avenue towards sustainable agriculture, environment, and circular bioeconomy	Science of the Total Environment	Sani, M.N.H.	2023	115	Review
Towards a better understanding of atmospheric water harvesting (AWH) technology	Water Research	Wang, M.	2024	87	Review
Agricultural water and land resources allocation considering carbon sink/source and water scarcity/ degradation footprint	Science of the Total Environment	Wu, H.	2022	74	Article
An analytical framework to assess SDG targets within the context of WEFE nexus in the Mediterranean region	Resources, Conservation and Recycling	Malago, A.	2021	71	Article

***PY** - Published year, ***TC** - Total citation

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3.6. Top cited journals in irrigation and agriculture research

In this section, we analyzed the top journals that published the largest number of articles. Considering this factor, we decided to examine the journals with the highest number of citations in irrigation and agriculture. First, we sorted the source titles alphabetically from the Excel file containing the analyzed documents. Then, step by step, we summarized the total number of citations of articles for each journal. Interestingly, this resulted in an updated list of potential journal titles. The top 10 journals were selected, which are shown in Figure 7. Almost 75.15% (3916 citations) of the total citations came from articles published in these 10 journals. As a result, ranked first in terms of citation count with 1433 citations, becoming the best journal. Five journals: Science of the Total Environment, Journal of Environmental Management, Agricultural Water Management, Environmental Research Letters, and Environmental Pollution are among the journals with the highest number of citations. Four journals: Resources, Conservation and Recycling, Environmental Monitoring and Assessment, Water Resources Management and Water Research have more citations, despite having fewer articles on irrigation and agriculture issues worldwide.

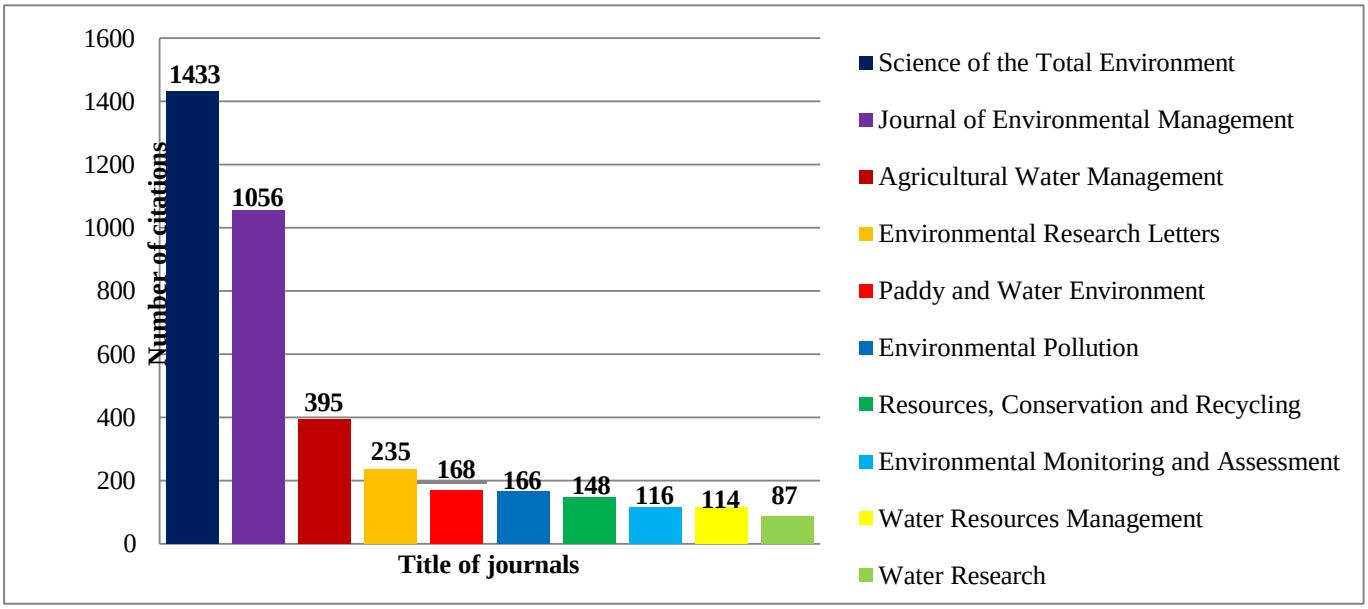

Fig. 7. Top cited journals on irrigation and agriculture issues in the world.

3.7. Top funding sponsors and subject areas in irrigation and agriculture research

There is a correlation between the prevalence of participating countries and the funding of major programs and projects. Between 2021 and 2025, 160

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different funders jointly published 256 articles on irrigation and agriculture worldwide. By analyzing the publications of the top 10 funders on irrigation and agriculture, we were able to identify the most influential and productive institutions in this field. As shown in Figure 8, of the 10 funders, five were from China, two from the United States, and the rest from European Union programs. Various subject cluster titles are available for the subject areas represented in the Scopus database. The majority of articles published on irrigation and agriculture worldwide belong to the main subject clusters shown in Figure 9. The Environmental Sciences cluster accounts for 57% of the total number of publications, agricultural and life sciences for 11%, Earth and planetary sciences for 9%, and the remaining share (including engineering, social sciences, energy, biochemistry/genetics/molecular biology, and others). These results confirm the interdisciplinary nature of irrigation and agricultural research, with a dominant focus on environmental aspects, supported primarily by major national funding programs in China.

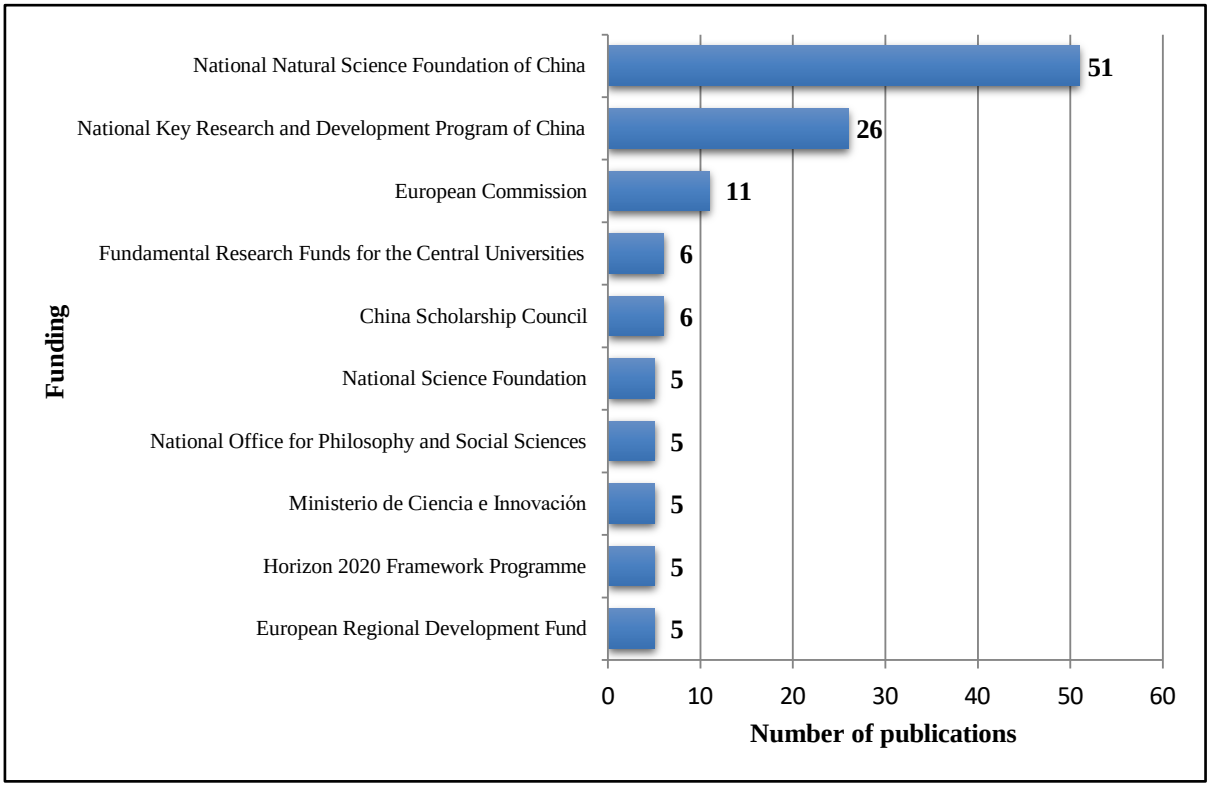

Fig. 8. List of top funding sponsors on irrigation and agriculture issues in the world.

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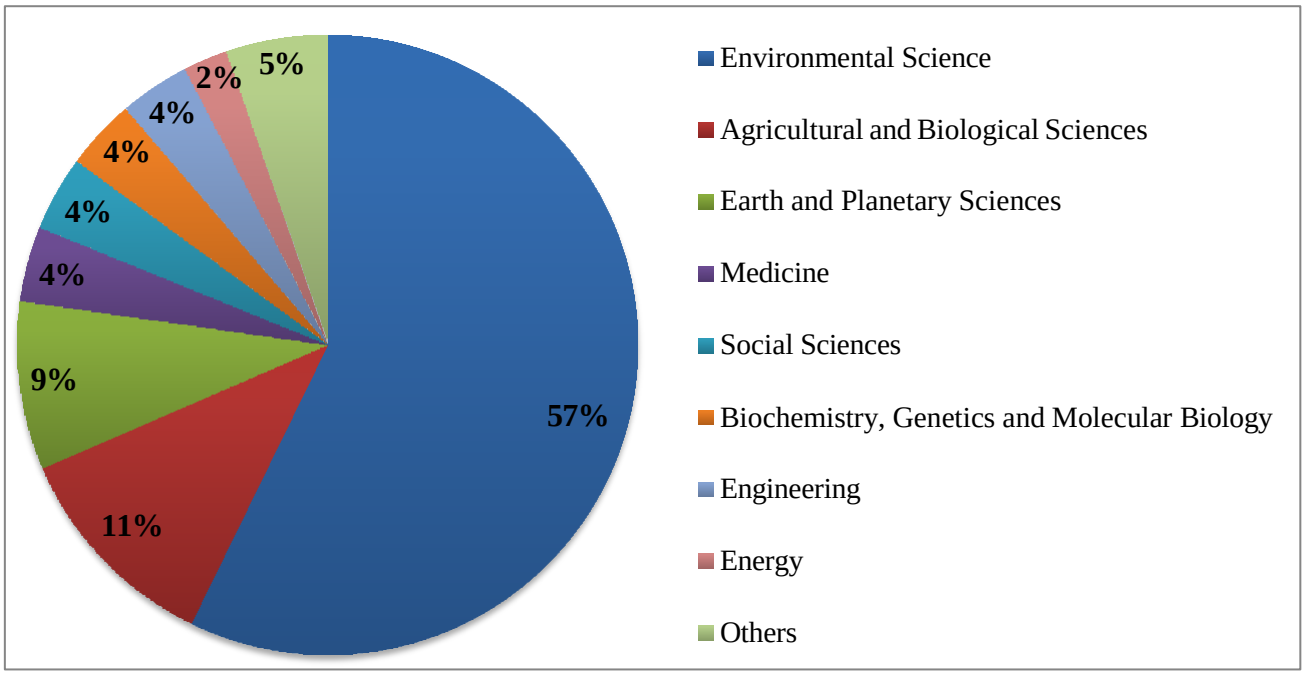

Fig. 9. Top topic cluster name on irrigation and agriculture issues in the world.

3.8. Top co-authorships and keywords on irrigation and agriculture

Using VOSviewer, it is possible to create co-authorship, keyword co-occurrence, citation, bibliographic relationship, and co-citation maps from bibliographic data. The supported file formats are .txt, .ris, and .csv from databases such as Scopus (Samir Kumar Jalal, 2022). The original file was imported into OSviewer, and the software was used to create a co-authorship and keyword co-occurrence map (shown in Figures 10 and 11). The co-authorship analysis yielded a network of 1161 authors. Only authors with at least 10 publications on the topic of irrigation and drainage systems were included in the network. There are a total of 30 elements distributed across seven clusters: Cluster 1 (6 elements), Cluster 2 (6 elements), Cluster 3 (6 elements), Cluster 4 (4 elements), Cluster 5 (3 elements), Cluster 6 (3 elements), Cluster 7 (2 elements).

The analysis yielded 4,132 keywords. After eliminating common keywords with low relevance scores and words with low frequency (by default, a minimum of 5 keyword occurrences is selected to strengthen co-occurrence results), 25 elements were identified. Based on the overall connection strength, each resulting keyword is mapped to a node, creating a network map of all keywords. Figure 11 shows the network map of keyword co-occurrence for the top 25 authors. Node size reflects the importance of the keyword.

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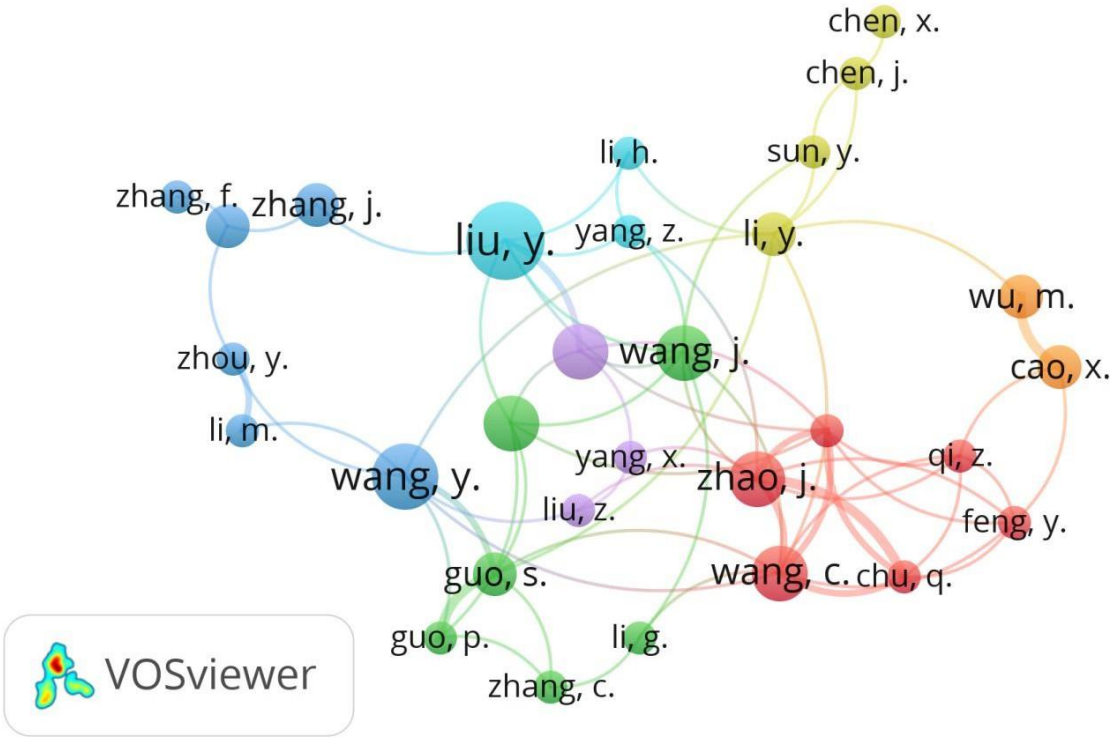

Fig. 10. Network map of top co-authorships based on the total link strength.

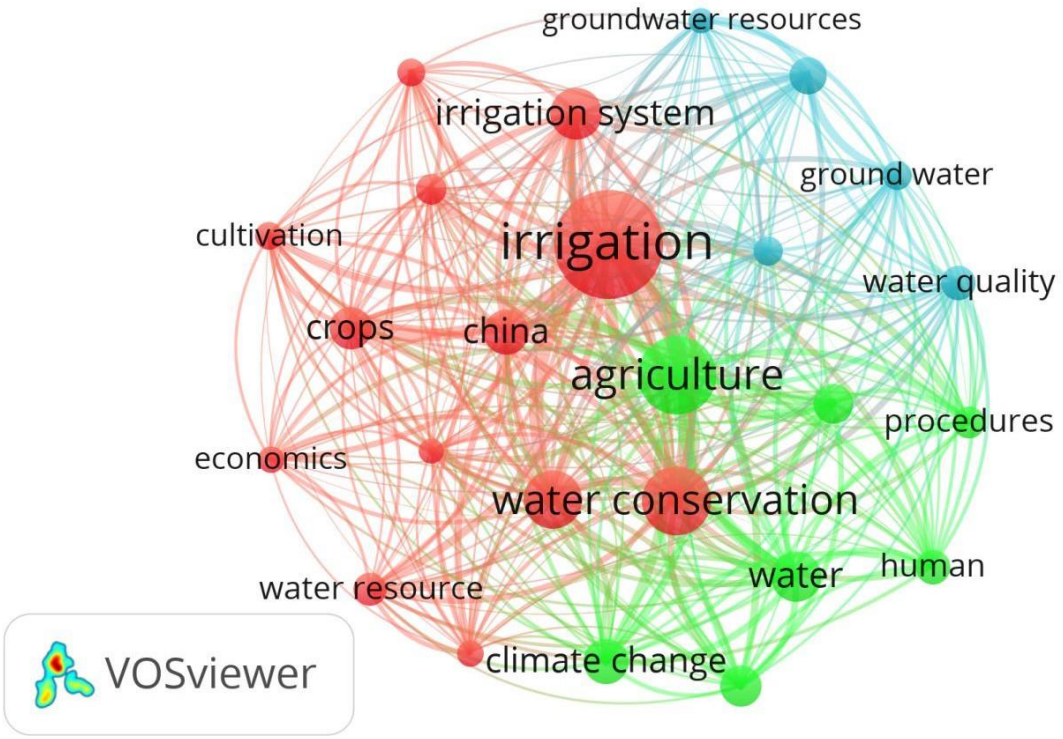

Fig. 11. Network map of top keywords based on the total link strength.

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4. DISCUSSION

4.1. Irrigation and agriculture

The bibliometric analysis conducted in this study provides a comprehensive overview of global research trends in irrigation and agriculture for the period 2021-2025. The results indicate a noticeable increase in the number of scientific publications in recent years, reflecting the growing attention of the international scientific community to issues related to water resources management and sustainable agricultural development. An analysis of annual publication trends reveals a general upward trend in scientific research output. Although a temporary decline in the number of publications was observed in 2023, the overall trend shows a steady increase, reaching its highest level in 2025. This pattern suggests that irrigation and sustainable agricultural development are becoming increasingly important research topics due to growing concerns about climate change, water scarcity, and the need for efficient resource management.

The distribution of document types shows that the majority of publications are original research articles, while review articles account for a smaller share of the total. This indicates that this research area is largely focused on empirical and applied research focusing on irrigation technologies, water use efficiency, and agricultural productivity. At the same time, review articles play an important role in synthesizing existing knowledge and identifying future research directions. An analysis of publication sources highlights the important role of high-ranking international journals in disseminating research related to irrigation and agriculture. Journals such as Science of the Total Environment, Agricultural Water Management, and Journal of Environmental Management account for a significant share of publications and citations. These journals focus on interdisciplinary research related to environmental sustainability, water resource management, and agricultural systems, further emphasizing the integrative nature of research in irrigation and agriculture. Furthermore, an analysis of co-authorship and keyword co-occurrence reveals strong collaborative networks between researchers and institutions. The presence of multiple author groups indicates active scientific collaboration between countries and research organizations. Similarly, the keyword network highlights key research topics such as irrigation management, water resources, environmental sustainability, and agricultural productivity. These results demonstrate that irrigation and agricultural research is increasingly characterized by interdisciplinary approaches and international collaboration.

4.2. Irrigation and agriculture issues worldwide

Irrigation plays a crucial role in global agricultural production, particularly in regions where rainfall is insufficient to sustain crop yields. As

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global population growth continues to drive demand for food, efficient irrigation systems have become essential to maintaining agricultural productivity and ensuring food security. This study's country-level analysis reveals that China, the United States, and India are leading contributors to irrigation and agricultural research. These countries possess large agricultural sectors and significant research capacity, enabling them to produce a significant share of global scientific output in this field. Their active participation reflects national priorities related to increasing agricultural productivity, optimizing water resource use, and addressing environmental issues.

Globally, irrigation systems face numerous challenges, including water scarcity, soil salinization, inefficient water distribution, and environmental degradation. In many regions, traditional irrigation methods result in significant water losses due to evaporation, leakage, and poor management practices. Consequently, improving irrigation efficiency has become a top research priority. Keyword analysis also reveals that recent research has increasingly focused on sustainable irrigation practices, climate change adaptation, and integrated water resources management. These research areas reflect a growing understanding that agricultural productivity must be balanced with environmental sustainability and long-term resource conservation. As a result, interdisciplinary research integrating agricultural science, environmental management, and engineering is becoming increasingly important in this field.

4.3. Current Central Asia in irrigation and agriculture issues

Central Asia is one of the regions where irrigation plays a crucial role in agricultural production due to its predominantly arid and semi-arid climate. Agriculture in this region relies heavily on irrigated water resources, particularly from large transboundary rivers such as the Amu Darya and Syr Darya. In recent years, Central Asian countries have increasingly focused on improving irrigation efficiency and promoting sustainable agricultural practices. Rapid population growth, climate variability, and growing water demand have increased pressure on regional water resources, making efficient irrigation management an urgent issue. Current research and development efforts in Central Asia are focused on introducing modern irrigation technologies, including drip irrigation systems, precision farming, and digital monitoring tools. These technologies are designed to reduce water loss, increase crop yields, and improve the resilience of agricultural systems.

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Climate change is also expected to have a significant impact on irrigation practices in the region. Rising temperatures, changing precipitation patterns, and increased drought frequency may impact water availability and agricultural productivity. Consequently, developing climate-resilient agricultural systems and adaptive water management strategies has become an important research area. Furthermore, regional cooperation is essential for effective water resource management in Central Asia. Since major river basins are shared by several countries, coordinated water management policies and joint research are essential to ensure sustainable and equitable water distribution in the region. Overall, improving irrigation efficiency and strengthening regional cooperation will be key factors in addressing future agricultural and environmental challenges in Central Asia.

4.4. Methodological overlap in irrigation and agriculture research

A bibliometric analysis reveals a clear methodological distribution and thematic overlap in irrigation and agriculture research. As shown in Figure 12, the Venn diagram identifies three main categories: traditional methods, modern methods, and combined (hybrid) approaches. Traditional methods continue to play a fundamental role, including methods such as surface irrigation, flood irrigation, and gravity-fed systems. These methods are characterized by simplicity, low implementation costs, and widespread adoption in regions with limited technological infrastructure. Despite their age, traditional approaches remain highly relevant due to their practicality and established application.

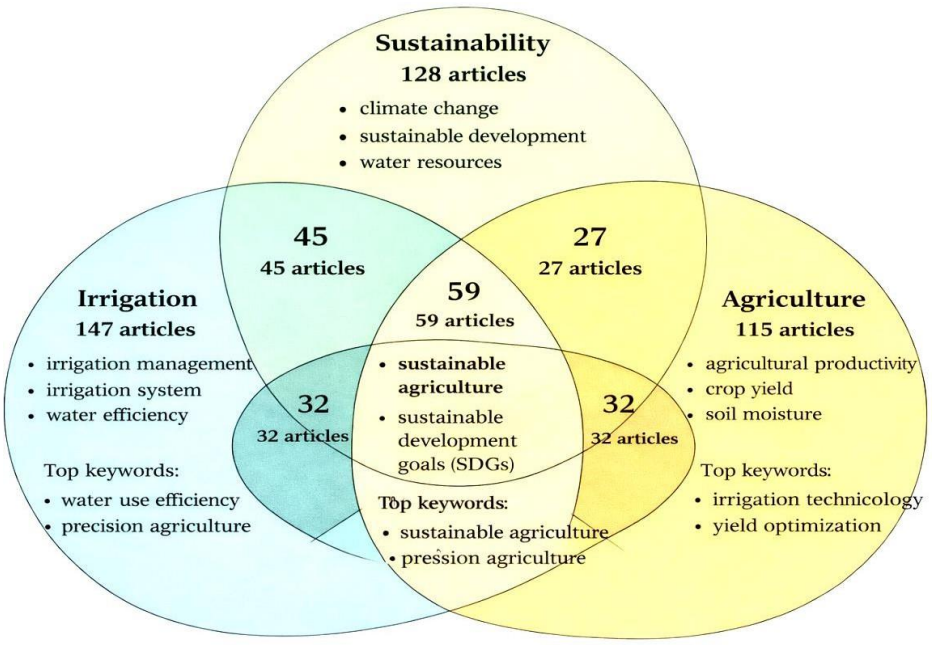

Fig. 12. Distribution and overlap of irrigation research methods based on bibliometric analysis, highlighting traditional, modern, and combined (hybrid) approaches.

Latin American Journal of Education
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In recent years, modern methods have attracted considerable attention, especially in technologically advanced regions. Methods such as drip irrigation, sprinkler systems, and smart irrigation using IoT technologies and sensors are associated with increased efficiency, precision, and environmental friendliness. The growing number of publications on modern methods demonstrates a global trend toward optimizing water consumption and increasing agricultural yields through innovation. The intersectional field, representing combined or hybrid approaches, combines the strengths of both traditional and modern methods. Research in this segment focuses on integrated irrigation systems, optimization models, and precision farming combinations. This convergence allows researchers to improve resource efficiency, enhance productivity, and support environmental sustainability. The intersectional field highlights the growing emphasis on interdisciplinary research that combines engineering, agronomic, and data-driven approaches. Overall, the Venn diagram demonstrates that research in irrigation and agriculture is evolving beyond isolated methodologies and toward a more integrated and hybrid framework. This trend reflects the scientific community's desire to balance feasibility, technological advancement, and sustainable development goals. Such integrated approaches are particularly relevant for addressing global water scarcity, increasing agricultural productivity, and shaping policies and management strategies in various regions, including Central Asia

5. CONCLUSIONS

The aim of this study was to examine global trends in irrigation and agriculture research through a bibliometric analysis of scientific publications indexed in Scopus for the period 2021–2025. The motivation for focusing on this topic was growing global concern over water scarcity, climate change, and the increasing demand for sustainable food production. Irrigation remains one of the most important components of agricultural systems, particularly in water-limited regions. Therefore, understanding the evolution of research in this area is essential for identifying key research directions and emerging challenges. The results of the analysis reveal a steady increase in the number of publications related to irrigation and agriculture, demonstrating growing scientific attention to water management and sustainable agricultural practices. The predominance of scientific articles indicates that this field is largely driven by empirical and applied research aimed at improving irrigation efficiency, crop yields, and environmental sustainability.

The study also identified leading journals, countries, and institutions contributing to research in this field. Countries such as China, the United States, and India play a dominant role in the development of irrigation and agriculture research due to their large

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agricultural sectors and significant investments in scientific development. The presence of high-ranking journals publishing irrigation research further highlights the interdisciplinary nature of this field, linking agriculture, ecology, and water resources management. Overall, the results indicate that irrigation and agriculture research has become an increasingly important scientific field in addressing global environmental and food security challenges. The data obtained from this bibliometric analysis can help researchers and policymakers better understand current research trends and support the development of more sustainable irrigation strategies in the future.

6. LIMITATIONS

This study has several limitations that should be acknowledged when interpreting the results. First, the bibliometric data were obtained exclusively from the Scopus database, which, although comprehensive, may not cover all relevant publications indexed in other databases such as Web of Science or Google Scholar. As a result, some important studies might have been omitted. Second, the analysis was based on a predefined set of keywords, primarily “irrigation” and “agriculture.” While these keywords capture the core focus of the study, they may have excluded relevant publications that use alternative or more specific terminology related to water management, agroecosystems, or climate adaptation strategies. Third, the study relies solely on bibliometric techniques derived from the CSV dataset, including publication counts, keyword co-occurrence, and trend analysis. This approach does not incorporate qualitative assessments or field-based validation, which could provide deeper insights into the practical implications of irrigation strategies. Furthermore, the time span of the dataset may limit the representation of very recent developments in the field, particularly emerging technologies and innovative irrigation practices. Additionally, regional disparities in publication output, especially in Central Asia, may influence the overall findings due to underrepresentation in global scientific databases. Finally, citation-based indicators used in this study may be affected by time-dependent biases, where older publications tend to accumulate more citations than recent ones, potentially influencing the interpretation of research impact.

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