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A bibliometric analysis on artificial intelligence-based irrigation modeling techniques over the period of 1997-2023

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Abstract:
A bibliometric analysis was performed over the period 1997–2023, to pinpoint important trends, emphasis, and geographic distribution of international irrigation modeling research using new intelligence-based approaches. We mined the data for this study from the databases of the online version of the Web of Science. The data was analyzed using the Excel program, and the bibliometric mapping was performed using the VOSviewer software. A total of 1627 articles met the required criteria. The findings indicated that the number of articles had increased rapidly over the past five years and that English was the prevalent language (≈100%). Researchers in 99 countries have published in this field of research. China ranked first with 401 articles (24.7%), followed by the United States of America with 276 articles (17.0%). Egypt and Saudi Arabia are two of the top 10 countries in the world for research on the use of artificial intelligence in irrigation modeling. These articles were published in 423 journals; Agricultural Water Management was the most productive journal (86 articles, 5.3%), followed by Computers and Electronics in Agriculture (82, 5.0%). The most productive author is Kisi Ozgur from Turkey (43 articles, 2.6%). Taking into account all the institutions working on irrigation modeling (2026 institutions), Egyptian Knowledge Bank was ranked first (75 articles, 4.6%), followed by Northwest A&F University (China) (69 articles, 4.2%). Artificial neural networks and machine learning were the most commonly used intelligence-based techniques for irrigation modeling. Reinforcement learning was the least popular technique for irrigation modeling, which could be due to its complexity and data requirements.

Keywords: Web of Science, Bibliometric analysis, Irrigation modeling, Artificial intelligence

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1. Introduction

Seventy per cent (70%) of all freshwater withdrawals around the world are consumed by agricultural irrigation activities [1]. Therefore, optimal irrigation management has become an urgent necessity for addressing the insufficiency of water resources [2]. Thus, with the goal to use more efficiently water resources farmers need to be vulgarized by agricultural experts and updated on technological innovations [3]. To help accomplish this goal, experts have focused on modeling irrigation water use efficiency [4]. Although these models are very useful, they are little used for irrigation programming at the farm scale, yet they give a fairly reliable seasonal evaluation of water consumption [5].

Seventy percent (70%) of all freshwater withdrawals around the world are consumed by agricultural irrigation activities [1]. Therefore, optimal irrigation management has become an urgent necessity for addressing the insufficiency of water resources [2]. Thus, with the goal of using water resources more efficiently, farmers need to be vulgarized by agricultural experts and updated on technological innovations [3]. To help accomplish this

goal, experts have focused on modeling irrigation water use efficiency [4]. Although these models provide a fairly reliable seasonal evaluation of water consumption, they are rarely utilized for irrigation programming at the farm scale [5].

During the first decades of irrigation modeling, ballistic models were the most used software within the scientific community. The theory used in this modeling approach has been published for many years [13]. The major problem with the parameterization of ballistic models is that model calibration is currently required for all technical components of irrigation systems [7, 14]. At the present time, new intelligence-based approaches such as artificial neural networks, machine learning, deep learning, support vector machines, and reinforcement learning are becoming more required by irrigation modelers. The author [15] used an artificial neural network to provide new suggestions for irrigation schedules at the farm level. The author [16] carried out a bibliometric analysis of the scientific research work regarding the integration of different machine learning models that can provide adequate farm-scale irrigation steering.

Bibliometric analysis is a statistical tool for analyzing articles, books, and other publications [17]. Researchers can exploit many bibliometric techniques to analyze scientific publications in any research field. The bibliometric study is a very interesting tool that helps researchers assess current trends in research activities and take advantage of international collaboration opportunities [18]. It is a quantitative approach to monitoring advances in scientific publications [19]. A qualitative approach could also be used to assess trends in narrative scientific literature reviews. This technique of analysis could be subject to bias on the part of the researcher [19]. Bibliometric assessment approaches are the relevant tools to describe and draw temporal tendencies and upgrades in relation to the WoS categories, journals, and international collaborations among authors, as well as the geographical distribution of publications in terms of author affiliation and their citations [20].

In the field of irrigation research, [21] conducted a bibliometric analysis between 1991 and 2014 based on the Web of Science database to pinpoint important trends, priorities, and international wastewater irrigation localities. The analysis carried out revealed that international research on wastewater irrigation would benefit from a broadening of scientific exchange on this subject, as well as from continued long-term studies and the sustainable integration of research on wastewater irrigation and wastewater management concepts. However, researchers have not yet conducted a bibliometric analysis focused on irrigation modeling.

Accordingly, the objective of this study is to carry out a bibliometric analysis to diagnose the actual research domains in the field of irrigation modeling using new intelligence-based approaches over the period 1997–2023, thereby revealing current research gaps and opening up the point to potential future research opportunities.

2. Material and methods

2.1. Data collection

The bibliometric analysis of artificial intelligence (AI) irrigation modeling techniques was performed using the Web of Science (WoS) database published online. We mined the data in this article in January 2024. We made the query on the WoS using the following keywords from research (TS): TS = (Irrigation modeling artificial neural networks OR Irrigation modeling machine learning OR Irrigation modeling deep learning OR Irrigation modeling support vector machines OR Irrigation modeling reinforcement learning). We then manually checked the results for accuracy and relevance to the topic search. We set the period for this study between 1997 and 2023. We conducted the bibliometric study using only the Science Citation Index Expanded (SCI-EXPANDED) and the Emerging Sources Citation Index (ESCI) citation databases.

2.2. Bibliometric analysis

The obtained results of the query regarding AI-based irrigation modeling techniques were analyzed with respect to document types and language, categories, country, evolution over the years, most productive authors and institutions, sources and references, terms, and keywords. We generated a geographic database of irrigation modeling publications using ArcGis software. Furthermore, VOSviewer software was utilized for data visualization to generate reference, keyword, and term graphs for bibliometric mapping [22]. VOSviewer uses bibliometric database files to build a scientific network of the elements mentioned above. Mathematical algorithms are used to cluster and graphically map the elements [20].

3. Results and discussion

3.1. Publication trend over time

Over the 27-year study period (from 1997 to 2023), researchers obtained a total of 1627 articles. English was the dominant language in WoS documents. SCIE (Science Citation Index Expanded) and ESCI (Emerging Sources

Citation Index) were the main publication venues for most of the articles. Most of the articles were published in the Water Resources (556 articles, 34.8%) and Environmental Science (441 articles, 27.1%) WoS categories. Figure 1 displays the evolution of the number of papers on irrigation modeling using intelligence-based techniques. This figure indicates that research on irrigation modeling is an old field of research that started nearly three decades ago. Indeed, the first publication in this research field was published in 1997. During the first ten years, the number of articles published did not exceed 10 per year. The publication rate increased significantly in 2019, with the number of articles published per year exceeding 100 for the first time. This trend has continued, with the number of articles published reaching 349 in 2023. The number of articles per year displayed exponential growth, as shown in Figure 1 (R^2 = 0.93). Nearly 67.2% of articles were published in the last five years of the study period (2019–2023, 1092 articles), and 88.6% of articles were published in the last ten years (2014–2023, 1440 articles). This exponential growth in the number of published articles over the years confirms the increasing interest in this field of research. Indeed, between 2021 and 2023, an increase in the number of articles of 43% was observed, reaching 349 articles in 2023 vs. 237 articles in 2021.

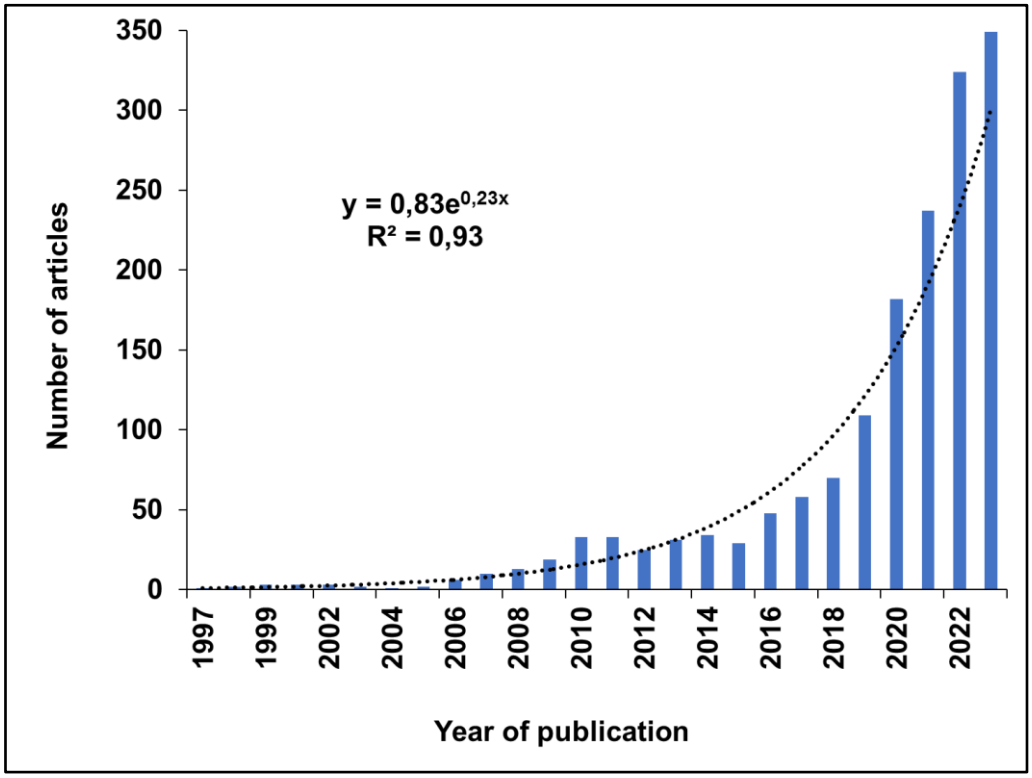

Figure 1. Number of articles published per year for the query over the period 1997-2023. (Web of Science search in January 2024).

3.2. Country analysis

The analysis showed that a total of 99 countries contributed to the elaboration of the 1627 articles in this bibliometric research study. Table 1 summarizes the top 10 most productive countries, publishing 97.6% of all publications (131.1%). Articles whose authors belong to different countries were counted as complete publications for each country rather than as fractional publications. Results presented in Table 1 revealed that studies conducted on irrigation modeling using intelligence-based techniques are mostly carried out by researchers originating from China (401 articles, 24.7%), followed by scientists from the USA (276 articles, 17.0%), Iran, India, and Spain (236, 202, and 88 articles, respectively; 14.5%, 12.4%, and 5.4%, respectively). These five countries together account for 62.9% of total publications produced.

Despite the scarcity of water resources in North African countries like Tunisia, the topic of irrigation modeling is not receiving enough attention, neither from the state nor from the research centers, which represents a huge gap. The scarcity of historical data related to irrigation in Tunisia could be a principal factor contributing to this situation. We can also say that there is an awareness of the importance of the role that modeling can play, but this is not yet taken into account in national water management strategies in countries such as Tunisia. In fact, climate change in the world, and particularly in North African countries, is accelerating efforts to deal with this problem, and modeling is one of the most effective solutions to measure the impact of measures to be set up.

Table 1. Number of articles published per country over the period 1997-2023

Rank	Country	Number of articles	Ratio of 1627 (%)
1	China	401	24.6
2	USA	276	17.0
3	Iran	236	14.5
4	India	202	12.4
5	Spain	88	5.4
6	Australia	84	5.2
7	Turkey	77	4.7
8	Egypt	75	4.6
9	Malaysia	75	4.6
10	Saudi Arabia	73	4.5

3.3. Most productive authors and institutions

The analysis of authors showed that a total of 5643 authors contributed to studies related to irrigation modeling using intelligence-based techniques and published 1627 articles. Consequently, we consider 0.29 articles (1627 publications by 5643 authors) per author. We set the minimum number of publications produced by an author at 5 for inclusion in this analysis. Regarding the authors' contribution to irrigation modeling research (Figure 2), the bibliometric analysis showed that Kisi Ozgur (Technical University of Lübeck, Germany) is the most productive author with 43 articles (2.6% of total publications). This analysis is very advantageous as it offers valuable information about irrigation modeling researchers around the world that gives us the opportunity to find potential scientific partners and institutions that are interested in making collaborations in this advantageous field of study.

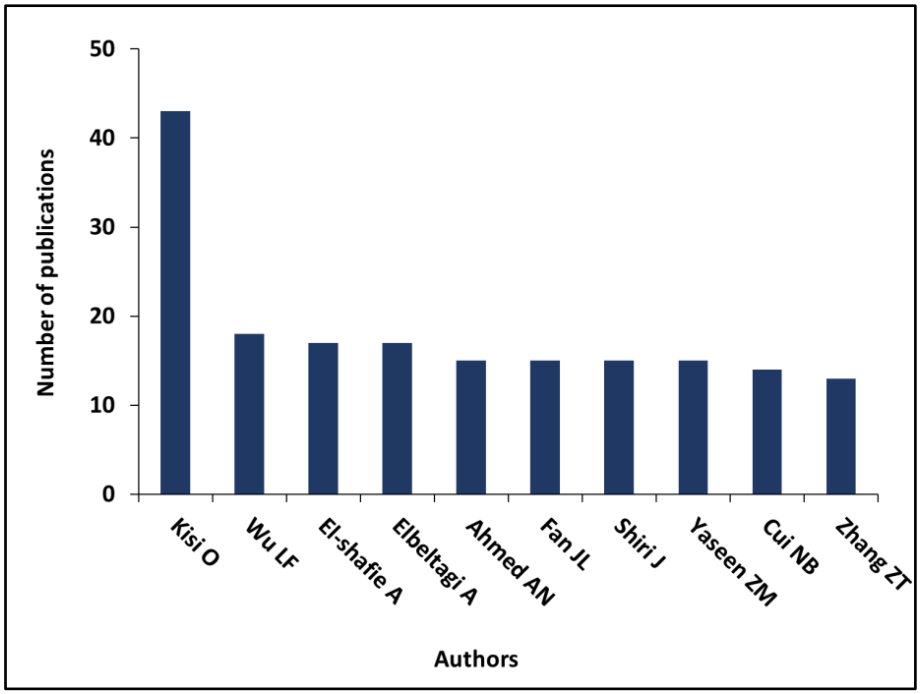

Figure 2. The top 10 most productive authors in terms of irrigation modeling for the period 1997-2023. (Web of Science search in January 2024).

Figure 3 illustrates the co-authorship network map, which reflects the high level of cooperation between authors within their field of research and between other fields. The thickness of the line indicates stronger collaboration between authors, meaning they have co-authored more publications together.

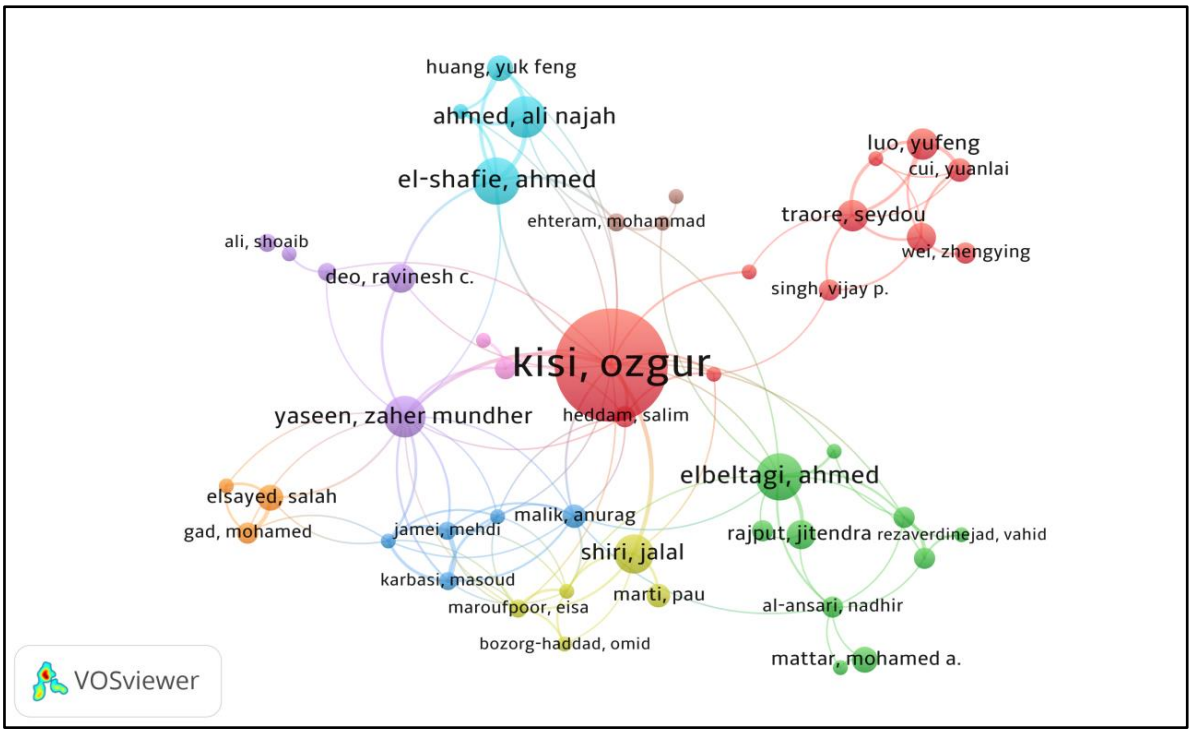

Figure 3. Co-authorship network of irrigation modeling researchers using intelligence-based techniques (Web of Science search in January 2024).

3.4. Analysis of sources and references

The bibliometric analysis revealed that 1627 articles related to irrigation modeling have been published in 423 journals over the period 1997–2023. Figure 4 represents the first 10 scientific journals that have published publications in relation to irrigation modeling. It can be seen that Agriculture Water Management (5.3%), Computers and Electronics in Agriculture (5.0%), Remote Sensing (4.5%), Hydrology (4.0%), and Journal of Water (4.0%) were the most productive journals.

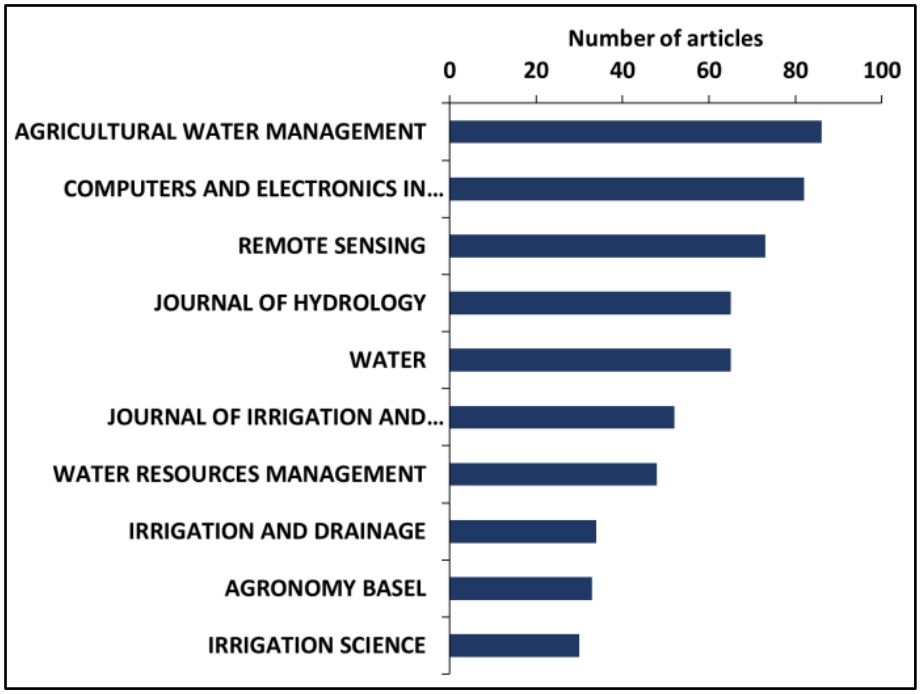

Figure 4. The top 10 journals that published articles related AI-based irrigation modeling techniques for the period 1997-2023 (Web of Science search in January 2024)

3.5. Analysis of terms

A profound analysis of titles and abstracts in the 1627 articles was performed using the VOSviewer software in order to extract the most used terms by scientists. In the software, the minimum number of occurrences of a term has been set to 10 times. This gave 63 terms out of 4501 that met the selection criteria. The co-occurrence map of the obtained terms is shown in Figure 5. The higher the number of co-occurrences of two terms, the closer they will be on the map. As it is exposed in figure 5, the most common term used by scientists is “estimation” with a number of occurrences of 124 occurences. The emergence of estimation as the most used term could be explicated by the fact that irrigation modeling heavily relies on estimating various parameters, including daily reference evapotranspiration (33 occurences), crop water requirements (47 occurences). AI-based modeling techniques are the best tool to make comparison (34 occurences) between irrigation techniques or between irrigation management scheduling scenarios. AI-based modeling techniques were also used to study the impact (24 occurences) or the effect (21 occurences) of climate change (16 occurences) on irrigation water management. AI-based modeling technique such as support vector machine (22 occurences) was used to model (57 occurences) groundwater (17 occurences) in relation to irrigation purposes.

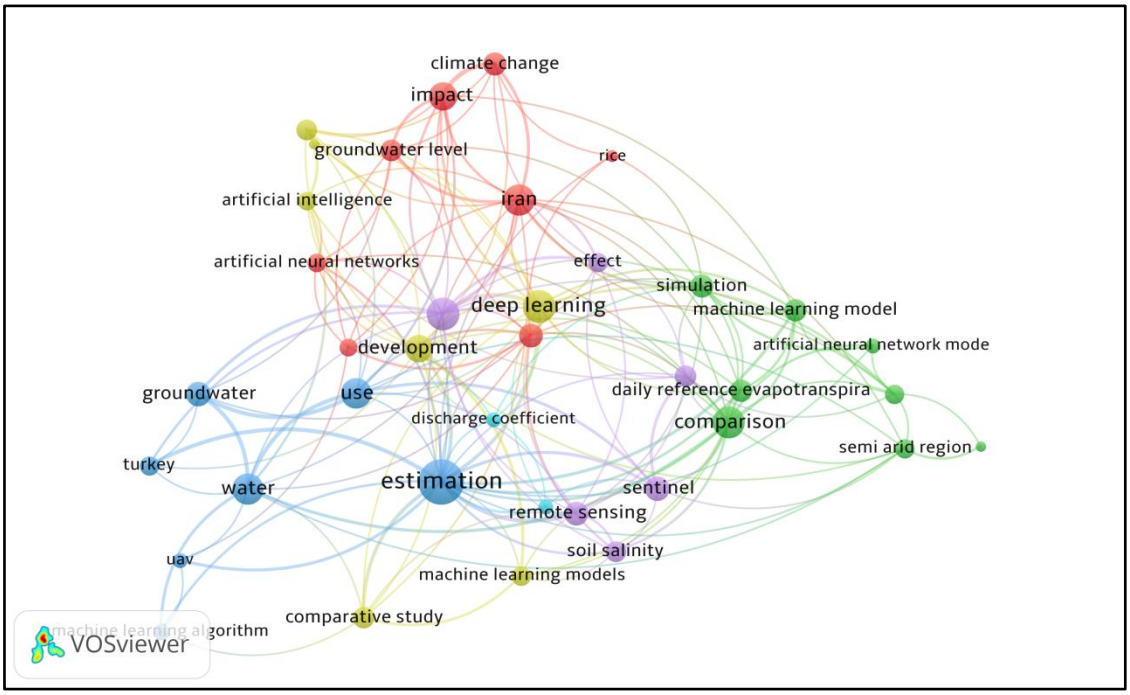

Figure 5. Terms map. Terms are located based on the co-occurrences in the titles and abstracts. (Web of Science search in January 2024).

3.6. Analysis of the most AI-based irrigation modeling techniques

Figure 6 represents the results of the analysis of the most commonly used AI-based irrigation modeling techniques. The results show that artificial neural networks (ANNs) are by far the most popular approach, accounting for 45.4% of the articles analyzed. Machine learning (ML) is the second most popular approach, with 40.9% of the articles. Deep learning (DL) is the third most popular approach, with 6.6% of the articles. Support vector machines (SVMs) and reinforcement learning (RL) are the least popular approaches, with 6.6% and 0.5% of the articles, respectively.

The dominance of ANN as an AI-based irrigation modeling technique could be explained by the fact that ANNs are powerful machine learning techniques that can learn complex relationships between input and output variables. This makes them well-suited for modeling the complex interactions between factors that affect irrigation, such as weather, soil, and crop growth. ML's popularity in AI-based irrigation modeling stems from its ability to solve a range of irrigation modeling problems, including estimating crop water requirements, optimizing irrigation scheduling, and predicting crop yields. However, DL techniques are typically more computationally expensive than other ML techniques, which may explain their relatively low popularity in AI-based irrigation modeling. The SVM technique is typically less flexible than other ML techniques, which may explain their relatively low popularity in AI-based irrigation modeling. Moreover, RL techniques are typically more complex than other ML techniques, which may explain their relatively low popularity in AI-based irrigation modeling.

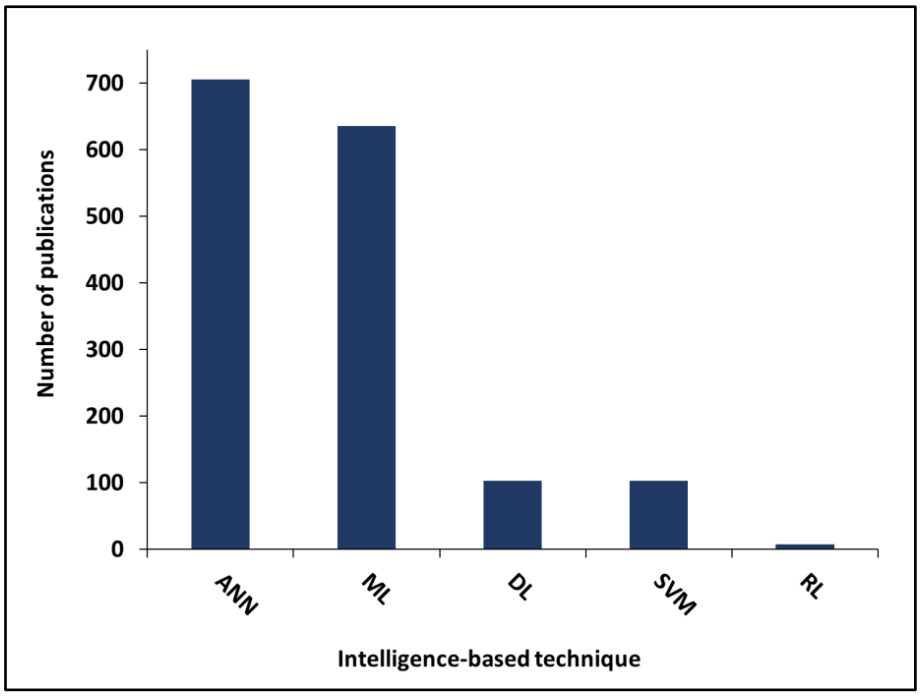

Figure 6. Distribution of AI-based irrigation modeling techniques. (Web of Science search in January 2024).

3.7. Analysis of AI-based irrigation modeling topics

This section analyzes in detail the main topics of irrigation modeling, highlighting their complexity and importance in modern agriculture. This study aims to provide a comprehensive understanding of the complexities and innovations in the field of irrigation modeling, from the precise management of irrigation water to the assessment of its far-reaching impacts to the introduction of cutting-edge precision techniques.

Irrigation water management

Irrigation water management requires a comprehensive understanding of water sources, distribution systems, and crop water requirements. The objective is to optimize the allocation and use of water resources for agricultural purposes. Key elements include assessing water quality, designing efficient irrigation systems (such as drip and pivot systems), and implementing water-saving techniques such as mulching and rainwater harvesting. Water availability and usage are often assessed using advanced modeling techniques, such as hydrological models and remote sensing.

Irrigation scheduling

An irrigation schedule is about deciding when and how much water to give your plants. We take into account a variety of factors, such as soil moisture content, weather forecasts, plant growth stages, and the specific water needs of different crops. Use models and algorithms to create accurate schedules that maximize crop yield while minimizing water waste. This includes integrating real-time data such as soil moisture sensors and weather monitoring to make informed irrigation timing and amount decisions.

Impacts of irrigation

Assessing irrigation impacts is important for understanding the broader impacts of irrigation practices. This includes ecological, economic, and social aspects. Researchers are assessing how irrigation impacts water resources, soil quality, and ecosystems, including potential problems such as salinization and flooding. Additionally, we analyze the economic feasibility of irrigation projects and their social impacts, including impacts on livelihoods and rural communities. Models and simulations can help predict and mitigate negative impacts.

Precision irrigation

Precision irrigation represents a technological advancement in the field of irrigation that leverages advances in sensors, automation, and data analysis to precisely adjust water delivery to the specific needs of individual plants or zones within a field. Soil moisture sensors, weather stations, and crop sensors provide real-time data to help make irrigation decisions. Algorithms and controls adjust irrigation schedules and flows accordingly to optimize water use efficiency and crop productivity. Precision irrigation also minimizes overwatering and reduces energy consumption, making it a sustainable option for modern agriculture.

Conclusion

We conducted an analysis of 1627 research articles on AI-based irrigation modeling techniques published on WoS for the period 1997–2023. Based on our analysis of 1627 research articles on AI-based irrigation modeling techniques published on WoS from 1997 to 2023, we can draw the following conclusions:

- During the last five years, researchers published most of the analyzed articles, producing a total of 1092 articles (67.2%);
- China was found to be the most productive country, with a total of 401 articles, followed by the USA with 276 articles;
- Kisi Ozgur from the Technical University of Lübeck (Germany) was the most productive author with 43 articles (2.6% of total publications);
- Agriculture Water Management (5.3%) followed by Computers and Electronics in Agriculture (5.0%) were found to be the most productive journals;
- As it was expected, "estimation" was the most used term among scientists in irrigation modeling purpose;
- Artificial neural networks and machine learning were the dominant AI-based techniques used to model irrigation problems;
- Topics such as irrigation water management, irrigation scheduling, irrigation impact, and precision irrigation were found to be relevant within irrigation modelers using AI-based techniques.

Finally, our bibliometric analysis proved to be a useful and powerful tool that allowed us to highlight research trends over time and space and suggest some potential new directions and opportunities in the field of research on irrigation modeling. The current study may be considered a baseline according to which future developments in this relatively old field of research will be compared and monitored.

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