

Artificial intelligence for water management under climate change: a bibliometric and patent analysis

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Abstract: The world is facing significant issues in managing water resources due to water shortage and climate change. Artificial intelligence (AI) is in turn being used more to tackle these problems. This paper will provide a bibliometric and patent survey of AI use in water and climate between 2015 and 2025. Scopus (592 documents) and Web of Science (699 documents) were used to gather scientific data and WIPO (689 patents) and Espacenet (4,373 patents) to gather patent data. The findings indicate that both publications and patents have been rising strongly, with the highest point of 2024. Web of Science has a higher number of journal and conference papers, whereas Scopus has a more even distribution of disciplines. China, United States, and India are the most prolific countries in scientific production, and China also predominates on institutional production with the Chinese Academy of Sciences. Analysis of funding indicates a high level of concentration of Chinese agency support towards Web of Science but Scopus has a wider range of international funding. WIPO in the patent arena represents globally oriented applications by the United States, and Espacenet emphasizes regional activity, especially by China and Europe. All in all, the results indicate the rise of scientific research and technological advancement in this field.

Keywords: Artificial Intelligence, Water Management, Climate Change, Bibliometric Analysis, Patent Analysis, Scopus, Web of Science, WIPO, Espacenet, Research Trends.

1. Introduction:

One of the most important problems of this century is the climate change[1]. It has a great influence on water systems as it changes the rainfall and temperature distributions resulting in low water availability and water quality [2] . As a result, water shortages are experienced by one to two billion people, especially in arid areas where supply is less than demand [3]. Simultaneously, more extreme events like floods and droughts are occurring, complicating water systems to predict and manage, despite the recent development of forecasting methods

[3]. Rapid urbanization and economic development also contribute to the pressure on water resources and exacerbate the use of groundwater resources and pose long-term threats to water security [4]. All these issues emphasize the necessity of more sustainable and efficient practices of water management with the help of technological innovation, adaptation policy, and global collaboration [5]. In this case, artificial intelligence (AI) has become a popular way to improve how water is managed. AI techniques can look at large amounts of data, find complicated patterns, and make predictions more accurate. They can be used to forecast rain, monitor water quality, find pollution, predict floods, and optimize water systems [6]. Even though there is more research going on, there is still no clear global picture of how research and innovation using artificial intelligence in water management are evolving. The current research has a tendency to focus on databases only, and it offers only partial insights and makes it hard to see the overall trends, the most influential factors and the interconnection between scientific research and technological innovation.

To fill this gap, the current research conducts a comparative analysis of four large databases (Scopus, Web of Science, WIPO and Espacenet) to examine the productivity of research, trends in innovations, the top countries and institutions in this area, and the relationship between the level of scientific activity and the advancement of technologies in this field.

2. Materials and Methods:

In order to perform this bibliometric analysis, two major scientific databases, Scopus and Web of Science Core Collection, were selected because of their wide coverage and strong citation indexing [5], [7]. The search used the keywords Artificial Intelligence, Water, and Climate Impact for the period 2015–2025. The search retrieved 592 documents from Scopus and 699 from Web of Science, mainly in environmental sciences, engineering, and computer science. To examine technological development, patent data were collected from WIPO and Espacenet using the same keywords and time period, obtaining 689 records from WIPO and 4,373 from Espacenet. After removing duplicates and filtering irrelevant records, the datasets were analyzed using Excel for patent data and VOSviewer for scientific publications to explore trends, keyword relationships, collaboration networks, and citation patterns [8]. The main methodological steps are summarized in Figure 1.

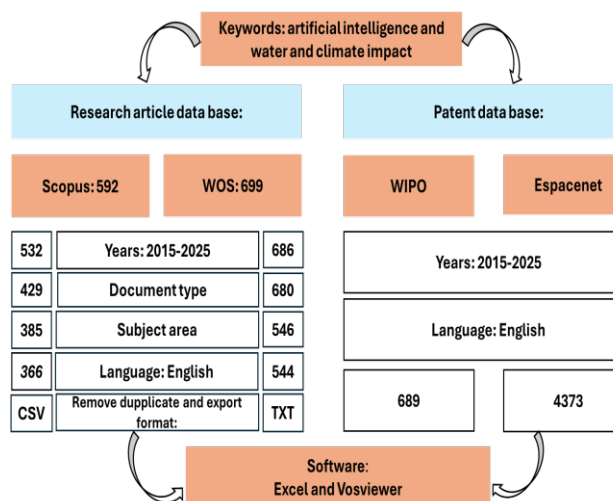


Fig 1. Framework of the bibliometric and patent analysis

3. Results:

3.1. Scientific Production Trends (2015–2025)

3.1.1. Trends in Number of Publications

Figure 2 illustrates how the topic of artificial intelligence to water and climate impact has evolved in Scopus and Web of Science over the years 2015-2025. The activity was low between the year 2015 and 2017, which suggests a developing field of research. Since 2018, the number of publications has been rising steadily, but with a sharp rise after 2020. The maximum is in 2024 when the most publications and citations are registered in both databases. It has a decline in 2025, primarily due to the fact that the year is in progress. In general, the findings indicate that the sphere of this research is developing rather quickly with Web of Science reporting a greater number of publications than Scopus, and both of the databases being on a similar increasing pattern.

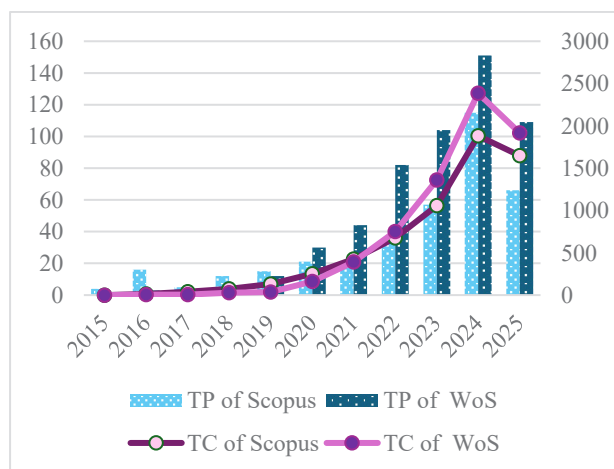
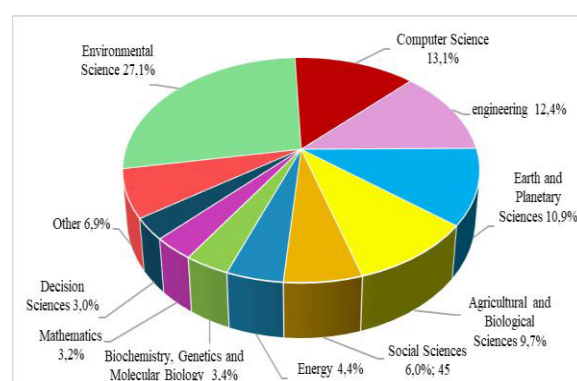


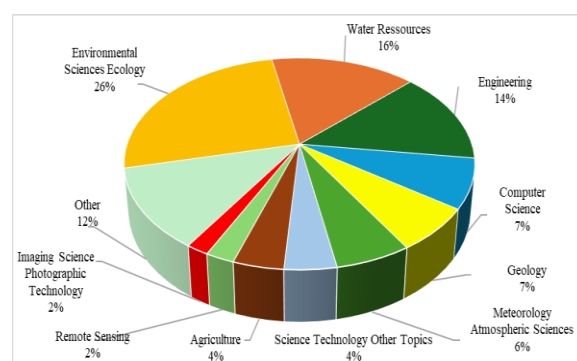
Fig 2. Annual Trends in Publications (Scopus vs WoS).

3.1.2. Subject area

Figure 3 shows the most popular topic in Scopus and Web of Science on artificial intelligence related to water management in climate change. Environmental Science is the most prevalent in Scopus with 205 documents (27.1%) and Computer Science and Engineering (99 and 94 documents respectively) with an active role of Earth and Planetary Sciences (82 documents, 10.9%). Environmental Sciences and Ecology is also the leader in Web of Science (272 publications, 26%), Water Resources (170 documents, 16%) and Engineering (151 documents, 14) but with a lower share (80 publications, 7%). In general, the two databases indicate that environmental-related fields significantly prevail, yet Scopus demonstrates a more even representation of contributions made by computational-related fields, and Web of Science is more inclined towards hydrology and environmental engineering.



(a)



(b)

Fig 3. Documents by subject area **(a)** from Scopus and **(b)** from WoS.

3.1.3. Most relevant keywords:

The keyword analysis from Scopus and Web of Science, illustrated in Figure 4 (VOSviewer maps), shows that the most frequent terms are Artificial Intelligence, Climate Change, and Machine Learning, highlighting the growing use of artificial intelligence in water and climate studies. In Figure 4(a) (Scopus), the clusters are mainly associated with forecasting, machine learning, and prediction, indicating a strong focus on predictive modeling and analytical methods. In Figure 4(b) (Web of Science), the thematic structure highlights terms such as

remote sensing, optimization, and sustainability, reflecting a broader orientation toward monitoring technologies and sustainable water management. Overall, Scopus emphasizes predictive approaches, while Web of Science shows a wider range of technological and environmental themes.

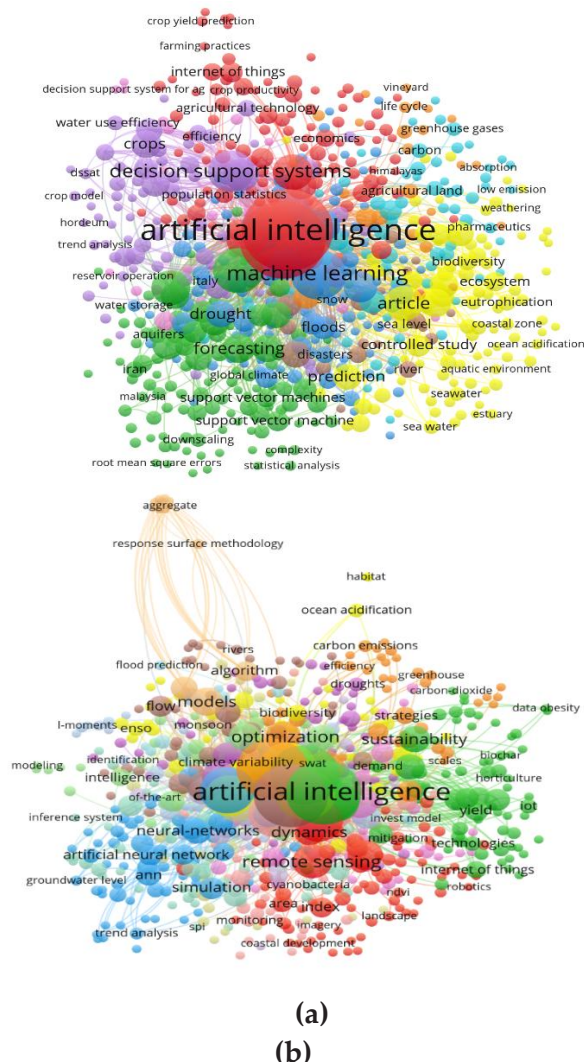


Fig 4. map of the most frequently used keywords (a) Scopus and (b) WoS.

3.1.4. The most relevant countries:

Table 1 provides a bibliometrical summary of country level contributions in Web of Science (WoS) and Scopus regarding the research on artificial intelligence, climate, and water. China is the top-ranked in terms of total publications in WoS and also performs well in terms of citation in both databases indicating its domination in this area. The United States ranks second in terms of publication and citation rates, continuing to have a very high rate of research output. India has a comparatively high amount of publications, however, with lower average citation, which means that the impact per publication is lower than in the leading countries. Contrarily, Germany, Canada and Malaysia have lower publications yet higher values of average citation, which indicates greater

influence of research, especially in Scopus. Other nations such as Saudi Arabia, Turkey, France have moderate productivity and lower citation impact which could also be more recent or less noticeable contributions. In general, China, the United States and India are more dominant regarding production, whereas, countries like Germany, Malaysia and Canada lead regarding research impact and Scopus typically rates higher citation averages than WoS of a number of countries. Table 4. the most leaders' countries in the field from Scopus and WoS.

Country	TP in WoS	TP in Scopus	TC in WoS	TC in SCOPUS	AC in WoS	AC in SCOPUS
China	138	45	2653	895	19,23	19,89
United States	112	64	1753	1190	15,65	18,59
India	61	52	835	419	13,69	8,06
Iran	47	15	735	215	15,64	14,33
England	45		812		18,04	
Saudi Arabia	45	9	564	81	12,53	9
Australia	43	17	843	253	19,6	14,88
Germany	43	15	814	529	18,98	35,27
Malaysia	33	8	1057	652	32,03	81,5
Spain	33	18	449	406	13,61	22,56
Italy	25	31	261	563	10,44	18,16
United Kingdom		22		486		22,09
Canada	27	19	569	992	21,07	52,21
Turkey	11	19	119	123	10,81	6,47
France	27	16	292	150	10,81	9,38

AC : average citation

3.2. Patent Activity and Technological Innovation (2015-2025)

3.2.1. Trends in Patent Publications

Figure 5 demonstrates the dynamics of patenting in WIPO and Espacenet during the years 2015 to 2025 in the area of artificial intelligence in relation to water and climate. All in all, the overall trend of both databases is upwards and this means that there is constant growth of technological innovation. The activity of the early years (2015-2018) is low and gradually improving, and the activity acute after 2019, indicating a growing interest in this field. The quantity of patents has been continuously growing, peaking in 2024, the most innovative period of the period under investigation. The values are high in 2025 but a little bit lower since the year is still current. Over the years, WIPO typically documents more patents compared to Espacenet, implying wider international scope and Espacenet exhibits the same trend at lower levels. In general, the findings suggest that the growth of patent activity is high and sustained and is in line with the growth of scientific publications.

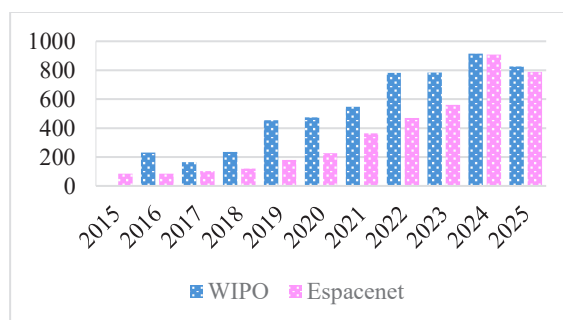


Fig 5. The patent publication by year in WIPO and Espacenet.

3.2.2. Geographical Distribution of Patent Activity

In Figure 6, the geographical distribution of patents in WIPO and Espacenet is presented, with various innovation strategies depending on countries. The US tops both databases, which is a confirmation of its high patenting activity worldwide. Canada and Australia are well balanced in their contribution to both systems and the European Patent Office more pronounced in Espacenet, which is indicative of high regional innovation. China has more patent records in Espacenet than in WIPO indicating that it emphasizes on regional filing. On the contrary, such countries as India, Italy, and the United Kingdom are more pronounced in WIPO, which means that they tend to use international patent protection more. Generally, WIPO indicates a more globally oriented patenting and Espacenet a more regionalized innovation pattern, and the trends in both are generally consistent with the scientific publication activity.

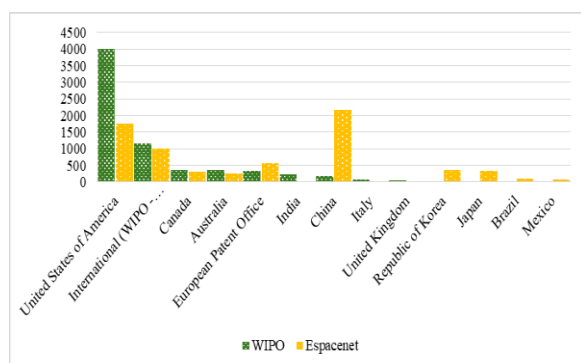
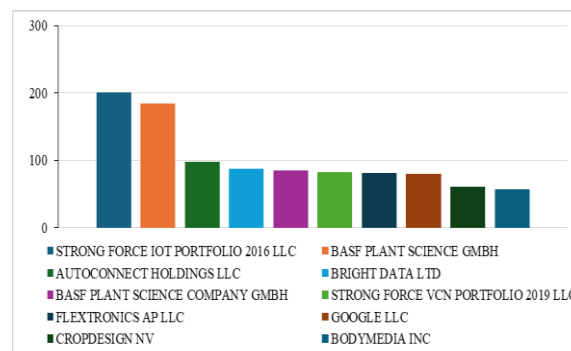


Fig. 6. The impactful countries in patent publication.

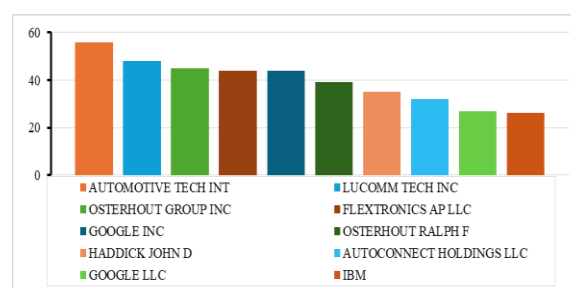
3.2.3. Top Patent Applicants and Innovation Leaders

Figure 7 shows the key patent applicants in WIPO and Espacenet, which are the key players in the innovation in this sphere. Large international companies rule the WIPO, with STRONG FORCE IOT PORTFOLIO 2016 LLC in the first place, then BASF PLANT SCIENCE GMBH and AUTOCONNECT HOLDINGS LLC, and other big companies like Google LLC and FLEXTRONICS AP LLC, which shows great strategies in protecting patents worldwide. Compared to Espacenet, which has a more heterogeneous structure, with AUTOMOTIVE TECH INT taking the lead, smaller companies and individual inventors of the region, such as LUCOMM TECH INC and OSTERHOUT GROUP IN are represented in a larger

proportion in WIPO, indicating varying degrees of innovation and filing strategies.



(a)



(b)

Fig. 7. Leading Patent Applicants in (a): WIPO and (b) Espacenet

Overall, WIPO shows companies that target global markets, while Espacenet reflects more local or regional activity. The fact that only a few applicants are present in both databases means that each one gives a different view of innovation in this field.

Discussion:

This study provides an integrated overview of global research and innovation trends on the application of artificial intelligence in water management under climate change. By combining bibliometric data from Scopus and Web of Science with patent analysis from WIPO and Espacenet, it highlights the evolution of scientific production, technological development, and international collaboration patterns. The results show a strong acceleration in both publications and patents after 2019, with a peak in 2024, indicating a close link between academic research and technological innovation in this field. Differences are observed between databases. Web of Science generally records more publications than Scopus, while Scopus covers a broader range of disciplines and includes more review articles. At the country level, China, the United States, and India dominate in both publications and patents, while countries such as Germany, Malaysia, and Canada show higher citation impact, indicating

stronger research influence. Institutional analysis confirms the leading role of the Chinese Academy of Sciences, along with significant contributions from France, Italy, and the United States. Funding patterns also differ, with WoS dominated by Chinese national support, while Scopus shows more diversified international funding sources. Patent analysis reveals contrasting patterns between WIPO and Espacenet. WIPO reflects more internationally oriented filings, mainly led by the United States, while Espacenet captures stronger regional innovation, particularly from China and Europe. Major companies such as Google, BASF, and STRONG FORCE IOT PORTFOLIO dominate patent activity, alongside smaller firms and individual inventors, highlighting innovation at multiple scales. Overall, the findings confirm the growing importance of AI for addressing water and climate challenges, while also emphasizing the need for international collaboration and knowledge sharing [1] AI offers strong potential for prediction and management, but effective long-term solutions require cooperation and adaptation to local contexts. Further research is needed to better understand watershed vulnerability under climate change, which is essential for developing resilient water systems [9]. This study has some limitations. focuses only on English-language publications, and some 2025 data may still be incomplete. Future studies could include multilingual data, and more recent updates to provide a more complete understanding of AI applications in water systems under climate stress.

Conclusion:

This study provides an integrated overview of global research and innovation trends on the application of artificial intelligence in water management under climate change. By combining bibliometric data from Scopus and Web of Science with patent analysis from WIPO and Espacenet, it highlights the evolution of scientific production, technological development, and international collaboration patterns. The results show a strong acceleration in both publications and patents after 2019, with a peak in 2024, indicating a close link between academic research and technological innovation in this field. Differences are observed between databases. Web of Science generally records more publications than Scopus, while Scopus covers a broader range of disciplines and includes more review articles. At the country level, China, the United States, and India dominate in both publications and patents, while countries such as Germany, Malaysia, and Canada show higher citation impact, indicating stronger research influence.

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O.E.B.; resources, O.E.B ; data curation, O.E.B; writing—original draft preparation, O,E,B ; writing—review and editing: K.H., H.E.A, and K.E.A; visualization, H.B., and A.E.A; supervision, K.H; funding acquisition: K.H, All authors have read and agreed to the published version of the manuscript.

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References:

- [1] A. Srivastava et R. Maity, « Assessing the potential of AI-ML in urban climate change adaptation and sustainable development », *Sustainability*, vol. 15, n° 23, p. 16461, 2023.
- [2] Y. Nan, M. Bao-hui, et L. Chun-Kun, « Impact analysis of climate change on water resources », *Procedia Engineering*, vol. 24, p. 643-648, 2011.
- [3] F.-J. Chang, L.-C. Chang, et J.-F. Chen, « Artificial intelligence techniques in hydrology and water resources management », *Water*, vol. 15, n° 10, p. 1846, 2023.
- [4] H. Zhang, J. Yu, C. Du, J. Xia, et X. Wang, « Assessing risks from groundwater exploitation and utilization: Case study of the Shanghai megacity, China », *Water*, vol. 11, n° 9, p. 1775, 2019.
- [5] H. El Allaoui *et al.*, « Trends and insights in medicinal plant extract research: a ten-year bibliometric and visualization study », *Horticulturae*, vol. 10, n° 11, p. 1163, 2024.
- [6] M. Kumar, « AI for climate change: Predicting environmental impact and developing sustainable solutions », *ESP Journal of Engineering & Technology Advancements*, vol. 4, n° 3, p. 127-133, 2024.
- [7] L. Leydesdorff, P. Wouters, et L. Bornmann, « Professional and citizen bibliometrics: complementarities and ambivalences in the development and use of indicators—a state-of-the-art report », *Scientometrics*, vol. 109, n° 3, p. 2129-2150, 2016.
- [8] K. El Ahmadi *et al.*, « A bibliometric analysis of the supercritical CO₂ extraction of essential oils from aromatic and medicinal plants: trends and perspectives », *Horticulturae*, vol. 10, n° 11, p. 1185, 2024.
- [9] T. D. Mengistu, S. W. Chang, et I.-M. Chung, « Modeling and prediction of climate change impacts on water resources vulnerability: A

multi-model approach », *Journal of Environmental Management*, vol. 388, p. 126025, 2025.