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Bibliometric Analysis of Climate-Resilient Agricultural Technologies for Water-Secure Farming

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HIGHLIGHTS

- Agricultural technology has become interdisciplinary, with climate-resilient technologies emerging as a rapidly growing research field.
- Research increasingly focused on climate adaptation, water management, and AI-driven precision agriculture between 2021 and 2026.
- Publications grew annually by 26.14%, peaking in 2025, with India, China, and the United States leading.

ARTICLE INFO

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ABSTRACT

Agriculture in rainfed and water stressed regions is highly vulnerable to climate change due to a number of reasons. The study examined the global development of climate-resilient agricultural technology research from 2021 to 2026, focusing on water security, water-use efficiency, drought alleviation, soil moisture management, and water–food linkages. A bibliometric approach was used in the Scopus database. After applying the filters on year, language and keywords, 1233 documents in English language were excluded in the final set of data. The findings revealed that the number of publications has increased significantly over the years with a rate of 26.14% and a sharp increase in research output since 2023, with the peak year being 2025. The top contributing countries were India, China and the United States while top journals were found to be Science of the Total Environment, Journal of Environmental Management and Agricultural Water Management. Dominant research themes included climate change, food security, drought, irrigation, water scarcity, remote sensing, artificial intelligence, and smart irrigation. The findings provide evidence for guiding research priorities, fostering international collaboration, and supporting evidence-based policies that strengthen climate adaptation, water resource management, and sustainable agricultural development worldwide.

INTRODUCTION

Agriculture in rainfed and water-stressed regions is especially vulnerable because farmers often have limited access to irrigation, climate information, credit, insurance, storage, and technical support. Recent studies report that climate variability affects crop growth, soil fertility, water availability, and food security, thereby making adaptation-oriented agricultural research a central scientific and policy concern (Karri & Nalluri, 2024; Mehra et al., 2024; Nam et al., 2026; Roy et al., 2025; Singh et al., 2026). Ground water depletion, erratic and scanty rainfall, increase in water demand, low water use efficiency, high cost technologies, lack of awareness, training and infrastructure are the major problems in the water secure farming and technologies (Dhaarna & Kashyap, 2025; Qi et al., 2024; Hussen et al., 2026).

There is a growing volume of literature for climate-resilient agriculture in agricultural science, environmental management, water resources, sustainability science and digital technology. Research

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in remote sensing, artificial intelligence, machine learning, smart irrigation, and precision agriculture reflects a growing transition from traditional adaptation approaches to technology-driven, resource-efficient water management practices in agriculture. Concurrently, the adoption of these technologies is uneven, due to the high upfront costs for technology, poor extension service, lack of digital connectivity for many smallholder farmers, and inadequate institutional coordination. The mismatch between technological development and field-level application indicates the need to better understand research structures globally and where future research should be focused (Javed et al., 2025; Ma et al., 2024; Wonneberger et al., 2025; Lekha et al., 2026).

Policy-wise, knowledge of the global research landscape in climate-resilient agricultural technologies is needed to design appropriate adaptation strategies. Bibliometric evidence can help to inform policy decisions on priority areas, including water-efficient irrigation, digital agriculture, climate-smart agriculture, and capacity building. The outputs and results of the global research networks can help guide strategic investments, enhance the linkages between research institutes and agricultural agencies, and enable the transfer of scientific advances to the farm level. Thus, knowledge of the research development timeline in this area can be relevant for structuring technological development and fitting it to the water security and sustainable agricultural policies (Dhawi & Aleidan, 2024; Miller et al., 2024; Oswald-Spring & Jaramillo-Monroy, 2025).

The quantitative mapping of publication growth, influential sources, productive countries, author and institutional cooperation, citation impact and evolution of keywords make the bibliometric approach well suited for further analysis and usage. The analysis may provide a means to deduce a major theme, new technologies, areas of research need, and collaboration trends from a vast pool of literature. It uncovers unique situations, providing researchers and stakeholders with valuable perspectives for future exploration and engagement in related fields (Roy et al., 2024). It also enables evidence-based planning by identifying the mismatch between the current research priorities and the preparedness for drought, irrigation efficiency, water conservation and climate adaptation. Therefore, the present study examines global research on climate-resilient agricultural technologies from 2021 to 2026, with emphasis on water security, irrigation efficiency, drought mitigation, soil-moisture management, smart irrigation, and the water-food nexus.

METHODOLOGY

A bibliometric research design was used to examine global publications on climate-resilient agricultural technologies during 2021 to 2026. The Scopus database was selected as the primary data source because of its extensive coverage of peer-reviewed articles, review papers, book chapters, conference proceedings, and interdisciplinary literature spanning agriculture, environmental science, water resources, climate science, and sustainability. The search query is : (TITLE-ABS-KEY ("Climate resilient" OR "Water security") AND TITLE-ABS-KEY ("agriculture")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (EXACTKEYWORD, "Agriculture") OR LIMIT-TO (EXACTKEYWORD, "Drought") OR LIMIT-TO (EXACTKEYWORD, "Water Security") OR LIMIT-TO (EXACTKEYWORD, "Irrigation") OR LIMIT-TO (EXACTKEYWORD, "Climate-resilient Agriculture") OR LIMIT-TO (EXACTKEYWORD, "Climate Resilient Agriculture") OR LIMIT-TO (EXACTKEYWORD, "Environmental Impact")) AND PUBYEAR > 2020 AND PUBYEAR < 2027. Once the year, language, keyword, and subject relevance filters were applied, 1,233 documents remained. Comma-separated values (CSV) files of the bibliographic records were obtained from Scopus. The exported file was subsequently verified for missing fields, duplicate records, inconsistent spelling of author keywords and names of countries, sources and institutions. Minor inconsistencies were fixed for better visualization and descriptive statistics of the network.

RESULTS

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework was employed to facilitate a transparent, systematic, and reproducible process for selecting relevant literature. In bibliometric research, the PRISMA flow diagram strengthens the reliability and transparency of the analysis by presenting a clear account of the records identified, screened, excluded, and ultimately included at different stages of the literature search and selection process.

The analysis process is demonstrated in Figure 1. Biblioshiny and VOSviewer software were used for analysing the dataset. Descriptive bibliometric statistics such as annual production growth, source productivity, document type distribution, authorship pattern, citation impact, co-authorship level, and international collaboration statistics were calculated using the reference processing software Biblioshiny. The keyword co-occurrence network, country

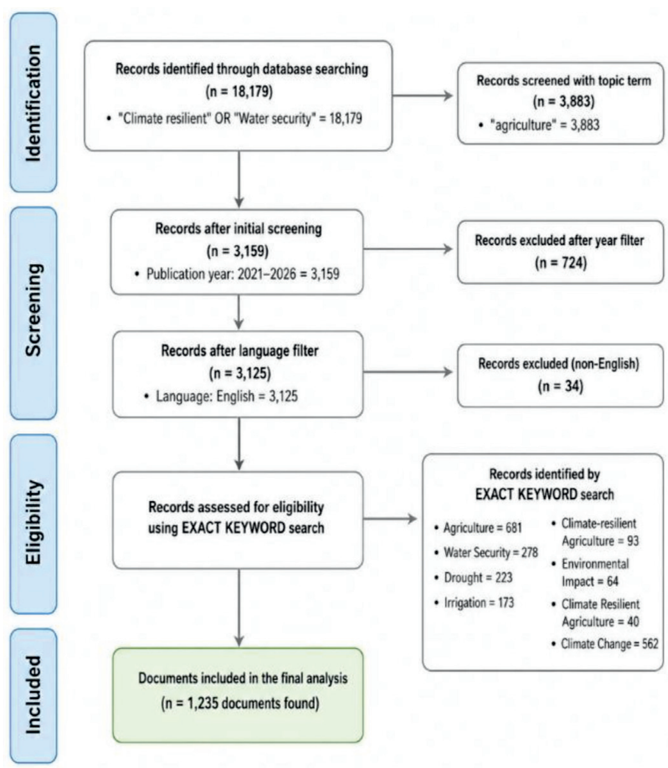

Figure 1. PRISMA

collaboration network, institutional collaboration network, author collaboration network and source-level network were created and visualised using VOSviewer (Vosviewer, 2026). Occurrence thresholds were scaled to the size of the network being considered to prevent the inclusion of meaningless, uninterpretable clusters. The findings were analyzed to detect patterns of publication, the leading countries, sources of influence, collaboration networks, key words, new research areas, and the direction of future research in the field of water-secure and climate-resilient agriculture.

A total of 1,233 documents published across 637 sources were included in the final dataset covering 2021–2026. The field recorded a growth rate of 26.14%, with an average document age of 1.69 years and an average of 11.39 citations per document. A total of 234,597 references, 7,326 Keywords Plus and 3,621 author keywords were included in the dataset. A total of 5,573 authors contributed to the research field, with an average of 5.31 co-authors per document. The collaborative nature of the field was reflected in a high rate of international co-authorship, at 37.79 per cent. The most common document types are articles, followed by reviews, book chapters and conference papers. The main bibliometric profile is presented in Table 1.

The trend of annual publications was evident and had increased throughout the study period. Publication output rose from 88 articles in 2021 to 107 in 2022 and 137 in 2023. It further increased to 185 articles in 2024 and reached the highest level of 435 articles in 2025. When the data were extracted there were 281 articles published in the year 2026. The trend showed that after 2023, research activity has greatly increased, reflecting a growing recognition of the importance of studies on climate adaptation, drought mitigation, irrigation efficiency, water-resource management, and sustainable agriculture. The annual output is given in Table 2.

Table 1. Dataset Bibliometric Profile

Indicator	Result
Timespan	2021 to 2026
Sources	637
Documents	1,233
Annual growth rate	26.14%
Average citations per document	11.39
References	234,597
Keywords Plus	7,326
Author keywords	3,621
Authors	5,573
Single-authored documents	72
Co-authors per document	5.31
International co-authorship	37.79%

Table 2. Annual Publication Output

Year	Articles
2021	88
2022	107
2023	137
2024	185
2025	435
2026	281

The country-wise results revealed that India had the largest number of publications with 245 articles, followed by China with 162 articles and the USA with 87 articles. India contributed 206 single-country publications and 39 multiple-country publications, whereas China recorded 93 single-country and 69 multiple-country publications. At the source level, *Science of the Total Environment* received the highest number of citations (706), followed by *Journal of Environmental Management* (645) and *Agricultural Water Management* (560). The results of the keyword analysis indicated that there was a focus on research themes related to climate change, food security, sustainable agriculture, drought, irrigation, water scarcity, remote sensing, artificial intelligence, machine learning, and smart irrigation. The summary of these results is shown in Table 3.

DISCUSSION

The results suggest that now agricultural technology research has become an interdisciplinary field, and climate-resilient agricultural technology is an emerging and fast-growing research field. The surge in publications since 2023 highlights the rising importance of climate adaptation, food security, and sustainable water management. The focus on drought stress, heat tolerance, soil-water conservation and climate-smart crop management by recent studies on agriculture align well with this trend (Antala et al., 2025; Sugumar et al., 2024; Teferi et al., 2025). The high frequency of water-related terms validates that water availability, water use for irrigation, groundwater conservation and water-food link are four important aspects of agricultural resilience.

The impact of other journals of related interest to environmental management and agricultural water management also

Table 3. Key Findings

Indicator	Major result	Interpretation
Leading countries	India: 245; China: 162; United States: 87	Asian countries contributed prominently, with moderate international collaboration.
Influential sources	Science of the Total Environment: 706 citations; Journal of Environmental Management: 645; Agricultural Water Management: 560	High-impact studies appeared in environmental, water, and agriculture journals.
Dominant keywords	Climate change, food security, sustainable agriculture, drought, irrigation, water scarcity	Research concentrated on adaptation and water-resource challenges.
Emerging keywords	Remote sensing, precision agriculture, machine learning, artificial intelligence, smart irrigation	Digital tools became central to crop-water monitoring and decision support.
Collaboration pattern	37.79 percent international co-authorship; 5.31 co-authors per document	The field was collaborative but required stronger institutional integration.

reflects that water management is not limited to crop science but is also a component of water-resource planning and sustainability studies. The dominance of India, China, and the United States again indicates that research activity is limited to countries where large-scale agriculture is practiced, the developed scientific infrastructure is present, and the climate is largely exposed. But the outcomes of the collaboration also indicate that international cooperation is still unbalanced. The percentage of single country publications, particularly India, is relatively high and reflects the good productivity of the country but points to the need to build more extensive international research collaborations.

This is crucial because climate risks, drought preparedness and water scarcity are transboundary issues that are characterized by the need for sharing data, comparative field studies, and coordinated institutional networks. Research on water security and social organization also indicates that technical solutions work better when they are complemented by local governance, the participation of farmers, and coordination of policies (Dhawi & Aleidan, 2024; Miller et al., 2024; Oswald-Spring & Jaramillo-Monroy, 2025).

The composition of keywords brings out the transition from the previous days' adaptation from past to present, to the present and digital and data-driven agriculture. The terms used in this article suggest increased attention to real-time monitoring, crop water-stress assessment, irrigation planning and decision making support: remote sensing, machine learning, artificial intelligence, precision agriculture, and smart irrigation. In line with the findings of other studies done showing rising application of satellite data, predictive models and digital tools in agricultural modernization and water resource assessment (Arefin et al., 2026; Pandey et al., 2025; Qi et al., 2024). However, that has yet to become a reality in the real world. Smallholder farmers can be limited in access by high costs and limited connectivity, extension services, and lack of digital literacy. Therefore, future research should combine technological innovation with affordability, training, field validation, local adaptation, and policy support so that climate-resilient technologies can move from scientific development to farm-level implementation.

Integrated climate-resilient agricultural approach using artificial intelligence, remote sensing, Internet of Things (IoT)-based monitoring, precision irrigation, and socio-economic evaluations should be further explored in future studies. Developing inclusive innovation ecosystems that support smallholders, enhancing capacity-building and digital literacy initiatives is warranted (Barman et al., 2026) Particular efforts should be undertaken to create low-cost and farmer-friendly solutions that are applicable to smallholder farming systems. Emerging technologies must be tested for effectiveness, scalability, and sustainability through long-term field research, regional adaptation studies, and policy-oriented research.

CONCLUSION

The evidence shows that research is increasingly centered on water security, drought mitigation, irrigation efficiency, soil-moisture management, smart farming, and the water-food relationship. The strongest publication growth after 2023 confirms the rising global importance of resilient and water-secure agriculture. Scientific leadership is limited to a small number of countries, and there is still a need to increase cooperation between both regions and institutions, and disciplines. Future research needs to focus more on these farmers-level factors such as farmer-level adoption, affordable digital instruments, field validation, and policy supports to ensure the adoption of these technologies and transform them into resilient agricultural systems. Areas identified as emerging trends in the literature include: Artificial Intelligence, Machine Learning, Remote sensing, Precision agriculture, Smart irrigation systems and Digital decision-support tools. Researches on field-level validation, cost-effective technology improvement, farmer's behaviour on technology adoption, adaptation strategies in regional level and interdisciplinary studies for better results are required.

DECLARATIONS

Ethical statement/approval: This study used publicly available bibliographic records and did not involve human participants, animals, or confidential information.

Conflict of interest: The authors declare that there is no conflict of interest.

Data availability statement: As the data was fetched from publicly available records only analyzed data will be available upon request from the corresponding authors.

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