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Water-Energy-Food Nexus in Arid Regions: A Bibliometric Review of Integrated Resource Management in Agriculture

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ABSTRACT

This study conducts a bibliometric review of Water–Energy–Food (WEF) nexus research in arid and semi-arid agricultural systems from 2020 to 2025. Using data from Scopus and Web of Science, analyzed with VOSviewer and R-bibliometrix, 463 publications were mapped to identify key themes, collaborations, and research trends. Results show a rapid expansion of interdisciplinary studies focusing on sustainability, optimization, and climate resilience. Early research emphasized water management, while recent studies highlight renewable energy, agricultural productivity, carbon footprint reduction, and socio-economic governance. Leading contributors include Texas A&M University, University of KwaZulu-Natal, IHE Delft, and Hohai University, indicating strong transregional collaboration across Africa, Asia, and Europe. Thematically, the field is shifting toward integrated frameworks such as the WEFE nexus and circular bioeconomy approaches. The study concludes that the WEF nexus has become a crucial framework for achieving resource efficiency, climate adaptation, and food security in water-scarce environments. It offers theoretical advancement by linking systems governance with sustainability transitions and practical guidance for policymakers developing integrated resource strategies aligned with the SDGs.

Keywords: *Water–Energy–Food Nexus, Arid Regions, Sustainable Agriculture, Climate Change, Bibliometric Analysis.*

1. INTRODUCTION

Some of the most resource-poor places on Earth are arid and semi-arid regions. Rising temperatures, unpredictable rainfall, and growing populations put more demand on water, energy, and food systems. These places, which include sections of Sub-Saharan Africa, Central Asia, North Africa, and the Middle East, rely extensively on irrigation and groundwater extraction. This puts more stress on the ecosystem and requires more energy. The FAO State of the World's Land and Water Resources for Food and Agriculture 2021 report says that about 40% of the world's irrigated lands are in danger because of a lack of water and damage [1]. More current [2] data show that to make sure people have enough food in areas where the weather is unpredictable, land, water, and energy flows must be managed in a way that takes everything into account. These developments show how important it is to have an integrated resource-management approach that connects agricultural productivity, renewable energy, and water efficiency within the same policy and analytical framework.

The Water–Energy–Food (WEF) nexus has so emerged as a fundamental conceptual instrument for tackling interrelated concerns in sustainable development. The WEF nexus, which became popular at the 2011 Bonn Conference, encourages policymakers and researchers to think about how different resource sectors may work together and find ways to avoid trade-offs. This framework is very important for dry areas since it helps to balance the limited amount of freshwater with the rising costs of irrigation, desalination, and food processing. Recent studies underscore that the WEF nexus method can bolster resilience by integrating renewable energy with effective water utilization, hence enhancing both resource production and livelihood outcomes [3], [4]. For instance,

adding solar power to groundwater pumping systems or desalination plants has been demonstrated to lower carbon intensity while keeping crop yields the same. This shows how cross-sectoral optimization could work [5].

The literature has progressed towards broadening the framework to encompass ecosystems and greenhouse gas (GHG) issues, frequently referred to as the WEFE nexus. This change shows that more and more people understand that agriculture in dry areas can't rely only on technical efficiency, it also needs to protect biodiversity and ecological services. [6] showed that adding GHG emissions and ecosystem indicators to the nexus makes it a better measure of sustainability, especially when climate change is putting stress on the system. Such comprehensive models are essential for arid environments where vegetation restoration, soil moisture retention, and water harvesting technologies can provide significant co-benefits across the nexus components [7].

Empirical studies in arid and semi-arid environments validate the practical utility of the nexus [4] discovered that multi-criteria assessments of climate-resilient innovations in Moroccan dryland agriculture—such as deficit irrigation, renewable energy utilization, and soil conservation techniques—yield concurrent enhancements in food, water, and energy production. [8] also talked about how WEF-based models help distribute limited water resources more fairly while using less energy. These examples show that integrated management in places with low water availability supports long-term sustainability and is in line with SDG 2 (Zero Hunger), SDG 6 (Clean Water and Sanitation), and SDG 7 (Affordable and Clean Energy).

However, technology alone cannot guarantee success, governance and institutional coordination are still crucial. It is often hard to execute nexus since ministries are split apart and have different policy goals. The United Nations Office for South-South Cooperation [9] says that working together across sectors, exchanging data, and collaborative finance are all important for putting ideas into action. In dry areas where the government doesn't have a lot of money or power, new ways of doing things, such green bonds, blended finance, or community-based water-energy cooperatives, are very important for expanding integrated projects [10]. Furthermore, digital technologies, such as remote sensing and artificial intelligence, are progressively used to oversee and enhance resource interconnections, hence improving transparency and adaptive administration [11].

Bibliometric analysis has emerged as a significant methodology for tracking the development of this interdisciplinary study domain. [12] analyzed more than 1,300 articles published from 2007 to 2022, identifying five principal research clusters: water management optimization, energy efficiency, food security, governance and policy, and climate resilience. The data showed that the number of publications grew quickly after 2015, which was around the time when the Paris Agreement and the SDGs were put into action. [13] also looked at research from South Africa from 2011 to 2024 and concluded that there was more coordination between hydrology, agricultural economics, and environmental governance. However, despite this growth, bibliometric syntheses concentrating exclusively on dry agriculture are still few. Most current studies operate on a global or national scale and fail to distinguish dryland production systems—such as irrigation, aquifer depletion, or desalination agriculture—from more extensive resource-management dialogues. This lack of evidence makes it hard for scholars and policymakers to learn from drought-prone areas in a way that is specific to those areas.

The WEF nexus approach has gained traction, but significant research and implementation gaps remain in arid agricultural settings. The literature is still divided amongst fields, which makes it hard to compare cases and leads to methodological discrepancies [12]. Regional studies frequently

overlook the social, financial, and governance factors that influence project scalability and long-term viability [9]. Moreover, scant bibliometric reviews distinctly delineate post-2020 research paths in arid and semi-arid environments, where climatic stress is most pronounced. As a result, the lack of a unified, evidence-based synthesis makes it harder to put nexus theory into practice for managing resources in dryland agriculture. To fix this problem, we need a full bibliometric review that includes subject clusters, key authors, institutional networks, and new policy ideas that are relevant to dry regions.

This study aims to conduct a comprehensive bibliometric review of the Water–Energy–Food (WEF) nexus literature from 2020 to 2025, with a particular focus on arid and semi-arid agricultural systems. It seeks to analyze publication dynamics, influential journals, and author collaboration networks to reveal the structural evolution of research within this domain. The study further identifies key themes such as optimization modeling, circular-bioeconomy integration, governance frameworks, and climate adaptation strategies that define current WEF nexus scholarship. By mapping regional hotspots and uncovering research voids across dryland territories, it aims to highlight geographical disparities and emerging centers of innovation. Additionally, the research synthesizes enabling conditions—technological, financial, and institutional—that support the practical implementation of WEF nexus approaches in resource-scarce agricultural contexts. Ultimately, this bibliometric synthesis establishes a foundational knowledge base to inform integrated resource management and promote resilient, sustainable agricultural systems in water-stressed environments worldwide.

2. METHODS

This study employs a bibliometric review methodology to comprehensively chart and examine the progression of research concerning the Water–Energy–Food (WEF) nexus in arid and semi-arid agricultural systems from 2020 to 2025. Bibliometric analysis offers a quantitative summary of scientific output, citation frameworks, and collaboration trends, facilitating the detection of topic clusters and nascent frontiers [14]. The research adheres to the PRISMA-based protocol for bibliometric reviews to guarantee methodological clarity and reproducibility [15]. We chose the Web of Science (WoS) Core Collection and Scopus databases as our main sources because they have a lot of peer-reviewed papers and good citation indexing. The search strategy utilized the Boolean query: ("water-energy-food nexus" OR "WEF nexus" OR "water-energy-food-ecosystem nexus") AND ("arid" OR "semi-arid" OR "dryland" OR "desert") AND ("agriculture" OR "farming" OR "food production"), restricted to publications from January 1, 2020, to September 2025. To keep the quality and comparability high, only English-language journal articles, reviews, and conference papers were included. Grey literature and preprints were not.

We used VOSviewer (version 1.6.20) and R-bibliometrix (version 4.2) to get rid of duplicates after exporting records from both databases. The final dataset had 463 different publications, such as journal articles, reviews, and proceedings about the WEF nexus in dry areas. Each entry was made the same by author, institution, country, keywords, and referenced sources. We calculated descriptive metrics like the annual publishing trend, the most productive authors, and the journals. Then we did performance and science-mapping studies. Using fractional counting methods in VOSviewer, we constructed networks for co-authorship, co-citation, and keyword co-occurrence. These networks let us see intellectual, social, and conceptual structures. Biblioshiny (R interface) was used to do thematic evolution and trend analysis to find changes in research focus, like optimization modeling, governance integration, and renewable energy applications in dryland agriculture.

To guarantee robustness and interpretability, network-level variables, including total link strength, modularity, and cluster density, were analyzed to assess the connection of research

communities. We made overlay visuals to show how new subjects (such "circular bioeconomy," "climate adaptation," and "WEFE") started to appear after 2020. Qualitative interpretation enhanced quantitative findings to elucidate research focal points and prospective trajectories, in accordance with modern bibliometric standards [16] . Lastly, we made sure that the bibliometric trends matched up with real-world developments in the implementation of arid agricultural nexus by cross-referencing all the results with relevant systematic reviews and regional case studies.

3. RESULTS AND DISCUSSION

3.1 Network Visualization

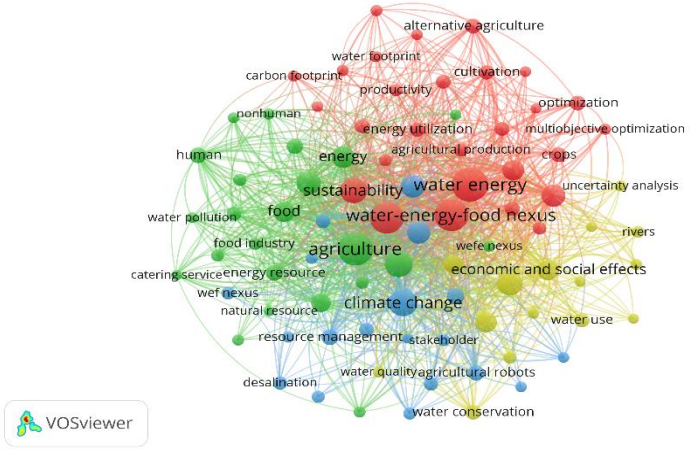

Figure 1. Network Visualization
Source: Data Analysis Result, 2025

The VOSviewer network visualization shows how the Water–Energy–Food (WEF) nexus research is organized in dry and semi-dry agricultural settings from 2020 to 2025. Each node stands for a keyword, and the size of the node shows how often it appears. The lines that connect the nodes (edges) show how strong the co-occurrence is across publications. Four main clusters may be seen: red, green, yellow, and blue. Each one stands for a different theme orientation. The terms "water-energy-food nexus," "agriculture," "sustainability," and "climate change" are all in the middle of the sentence, which shows that they are all conceptual anchors. This means that most studies agree on sustainability-driven frameworks that combine biophysical processes with social and policy perspectives.

The red cluster (top part) is all about optimizing, being productive, growing things, analyzing several goals, and using energy. This group includes technology and engineering methods used in WEF nexus research, especially those that use optimization models to make the most of limited resources in farming. To make irrigation more efficient, increase crop yields, and use less energy, these studies frequently use multi-objective optimization, linear programming, or systems modeling. The terms "carbon footprint" and "alternative agriculture" show that more people are interested in farming systems that don't emit carbon, irrigation driven by renewable energy, and farming practices that don't add carbon to the atmosphere. This group shows that quantitative, model-based studies that try to find ways to be more efficient in dry conditions are the most common.

In the green cluster (the left section), you can find words like "sustainability," "food industry," "natural resource," "water pollution," "human," and "energy resource." It shows a socio-environmental and systems-oriented point of view that focuses on sustainability transitions, environmental management, and the human aspects of the WEF nexus. This series of studies focuses on how industrial food systems, water pollution, and resource depletion are all connected. The repeated use of "WEF nexus," "food," and "resource management" suggests a holistic approach to

agricultural sustainability that includes life-cycle evaluation, resource circularity, and stakeholder engagement in dryland farming. This group sometimes overlaps with policy studies that look at problems with governance and how to use resources wisely in places where water is scarce.

The yellow cluster (bottom right) is made up of the words "economic and social effects," "water use," "stakeholder," "rivers," and "uncertainty analysis." This is the governance and policy research part of the nexus, which focuses on the social and economic trade-offs of managing resources. This research examines institutional coordination, stakeholder engagement, and risk management in the context of climatic unpredictability. Research within this cluster typically examines the influence of water scarcity and governance capability on agricultural adaptation and investment choices in dry nations. The mention of "economic and social effects" shows how nexus studies have changed recently from looking at physical resource flows to looking at equality, livelihoods, and socio-economic resilience. This is important for understanding the human side of integrated resource management.

The blue cluster (bottom part) includes "climate change," "water conservation," "water quality," "desalination," and "agricultural robots." This group focuses on ways to adapt technology and reduce climate change in dry farming. In this area, topics include precision irrigation, desalination technology, renewable energy integration, and digital tools for adaptive resource management. The link between "climate change" and "resource management" shows how research in dry areas is more and more combining new technologies with environmental sustainability. New phrases like "agricultural robots" show a shift toward smart farming and automation when resources are limited. This is part of a larger trend toward digital transformation in sustainable agriculture.

The image shows that there is a lot of connectivity between clusters, which supports the idea that WEF nexus research in dry areas is multidisciplinary, combining engineering, environmental science, and socio-economics. The main nodes—"water-energy-food nexus," "agriculture," "sustainability," and "climate change"—serve as bridges that integrate research on technical optimization with research on governance, people, and adapting to climate change. The many connections between different parts of the subject show that it has grown into a coherent body of knowledge where people from different sectors are working together more and more. The comparatively smaller nodes on “desalination,” “stakeholder,” and “economic and social effects” suggest that socio-institutional and technical adaption dimensions are still not fully addressed as compared to modeling and optimization themes. Future study should focus on enhancing the empirical and governance-oriented aspects of nexus studies to attain genuine integrated resource management in arid and semi-arid agricultural systems.

3.2 Overlay Visualization

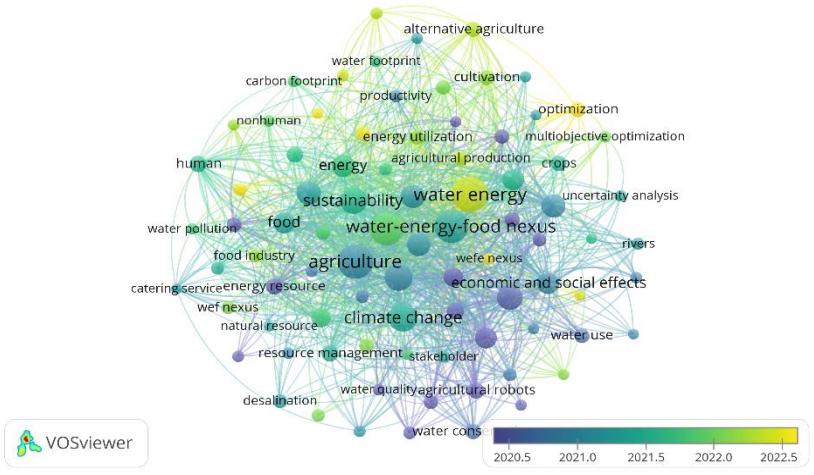

Figure 2. Overlay Visualization

Source: Data Analysis Result, 2025

The overlay visualization map shows how Water–Energy–Food (WEF) nexus research has changed over time in dry and semi-dry areas from 2020 to 2025. The color gradients, from dark blue (previous years) to brilliant yellow (recent years), show the average publication year of keywords. The darker blue nodes in the early research themes (2020–2021) show that the main issues were basic ones like "climate change," "resource management," "water conservation," "water quality," and "desalination." These issues represent the preliminary stage of post-2020 research, during which academics focused on hydrological equilibrium, energy use in irrigation, and drought adaptation. During this period, research predominantly examined the alleviation of water scarcity via technological solutions such as desalination and optimized irrigation systems, suggesting that initial WEF nexus literature in arid regions was primarily water-focused and concentrated on the biophysical management of resources.

Moving into the intermediate period (2021–2023), the network starts to focus on systems integration and optimization. This is shown by green nodes like "optimization," "multiobjective optimization," "energy utilization," "agricultural production," and "sustainability." At this point, study focus shifted from resource conservation to encompass economic efficiency, the use of renewable energy, and increased production. As part of the WEF nexus strategy for sustainable dryland farming, the use of renewable energy technology (such solar-powered irrigation and bioenergy recovery) became more and more important. Researchers also started using system-dynamics and multi-objective optimization models to find a balance between the trade-offs between water, energy, and food outcomes when the climate is unknown. This period signified a methodological shift from descriptive analysis to quantitative and model-driven techniques that integrate resource efficiency with sustainability objectives.

The most recent study phase (2023–2025), shown by bright yellow nodes, focuses on new and forward-looking themes such "alternative agriculture," "water footprint," "carbon footprint," "economic and social effects," and "WEFE nexus." These concepts signify an expansion of nexus thinking to include social equality, economic trade-offs, and climate neutrality in agricultural systems. The importance of "carbon footprint" and "alternative agriculture" indicates that contemporary WEF studies increasingly prioritize climate-smart and low-carbon agricultural practices, while the inclusion of "economic and social effects" reveals increased concern for governance and policy integration. In short, the overlay visualization shows a chronological progression—from resource-based management (2020–2021), to optimization and integration (2021–2023), and finally toward holistic, sustainability-oriented, and socio-environmental innovation (2023–2025)—marking the intellectual maturity of WEF nexus research in arid agriculture.

3.3 Citation Analysis

Table 1. The Most Impactful Literatures

Citations	Authors and year	Title
475	Pan, S.-Y., Gao, M., Kim, H., ... Pei, S.-L., Chiang, P.-C. (2018)	Advances and challenges in sustainable tourism toward a green economy
239	Li, M., Fu, Q., Singh, V.P., ... Zhang, C., Li, T. (2019)	An optimal modelling approach for managing agricultural water-energy-food nexus under uncertainty
236	Pellegrini, P., Fernández, R.J. (2018)	Crop intensification, land use, and on-farm energy-use efficiency during the worldwide spread of the green revolution
234	Wichelns, D. (2017)	The water-energy-food nexus: Is the increasing attention warranted, from either a research or policy perspective?

Citations	Authors and year	Title
188	Scott, C.A., Kurian, M., Wescoat, J.L. (2015)	The Water-Energy-Food Nexus: Enhancing Adaptive Capacity to Complex Global Challenges
181	Daccache, A., Ciurana, J.S., Rodriguez Diaz, J.A., Knox, J.W. (2014)	Water and energy footprint of irrigated agriculture in the Mediterranean region
174	Rosa, L., Rulli, M.C., Davis, K.F., ... Passera, C., D'Odorico, P. (2018)	Closing the yield gap while ensuring water sustainability
169	Nhamo, L., Ndlela, B., Nhemachena, C., ... Mpandeli, S., Matchaya, G. (2018)	The water-energy-food nexus: Climate risks and opportunities in Southern Africa
149	De Strasser, L., Lipponen, A., Howells, M., Stec, S., Bréthaut, C. (2016)	A methodology to assess thewater energy food ecosystems nexus in transboundary river basins
146	Dayioğlu, M.A., Türker, U. (2021)	Digital transformation for sustainable future-agriculture 4.0: A review

Source: Scopus, 2025

The most important studies in the Water–Energy–Food (WEF) nexus literature show how research that connects sustainability, resource efficiency, and technological innovation has changed over time in many ways. Foundational works like Scott, Kurian, and Wescoat (2015) and Wichelns (2017) laid the conceptual and policy groundwork for the WEF nexus, highlighting its importance in increasing the ability to adapt to difficult global problems. Later studies, such as Daccache et al. (2014), measured the connections between water and energy consumption in Mediterranean agriculture. De Strasser et al. (2016) have suggested ways to measure WEF interactions in transboundary basins, which shows that integrated governance is becoming more important. Thematically, research like Li et al. (2019) improved optimization models in uncertain situations to make agricultural systems work better, while Rosa et al. (2018) looked at the important balance between narrowing yield gaps and making sure water is sustainable. Nhamo et al. (2018) conducted regional analyses that framed these concerns within the context of climate risks and possibilities in Southern Africa, demonstrating the policy significance of the nexus in vulnerable regions. Simultaneously, Pellegrini and Fernández (2018) associated land usage and energy efficiency with agricultural intensification during the Green Revolution, highlighting the historical origins of resource trade-offs. Recent studies, such as Dayioğlu and Türker (2021), have extended the nexus concept into the digital age, investigating Agriculture 4.0 as a driver for sustainable development. In addition, Pan et al. (2018) linked sustainability transitions to green economy goals, bringing together environmental and economic points of view. These high-impact studies show how the WEF nexus has changed from ideas to real-world models and digital innovations. This makes it clear that it is a key part of managing resources in a changing climate.

3.4 Density Visualization

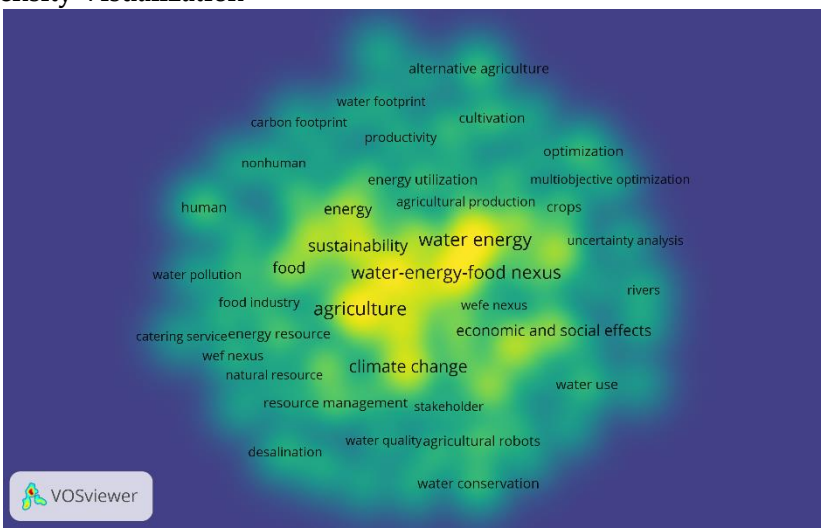

Figure 3. Density Visualization

Source: Data Analysis Result, 2025

The density visualization map shows how intense and concentrated research activity is in the Water–Energy–Food (WEF) nexus field in dry and semi-dry agricultural areas. The color gradient, which goes from dark blue (low density) to brilliant yellow (high density), shows how often keywords appear together. The bright yellow area in the middle shows the most important and often co-cited concepts, which are "water-energy-food nexus," "agriculture," "sustainability," "water energy," "food," and "climate change." This concentration reveals that these terms comprise the intellectual and thematic heart of the WEF nexus discourse, reflecting the transdisciplinary integration of agricultural systems, water management, and energy efficiency in sustainability research. The strong central clustering also shows that studies on climate adaptation, resource optimization, and integrated policy frameworks are highly cross-referenced. This suggests that the WEF nexus has become a well-established way of looking at things in environmental and agricultural sciences.

On the other hand, the periphery regions (green to blue areas) reveal new or specialized subfields including "desalination," "agricultural robots," "carbon footprint," "alternative agriculture," and "economic and social effects." Even while these subjects are currently less well-known areas of research, their increasing prominence shows that WEF nexus studies are becoming more diverse, focusing on technical innovation and socio-economic evaluation. The rise of terms like "water footprint" and "multiobjective optimization" shows a shift in methods toward quantification and efficiency modeling. On the other hand, "stakeholder" and "economic and social effects" show that there is more focus on governance, inclusivity, and justice in nexus implementation. The density map shows that the research landscape is growing up but still growing. It is centered on sustainability and agriculture, but it is also starting to explore new areas like climate-smart technology and socio-environmental integration for managing resources in dry areas.

3.5 Co-Authorship Network

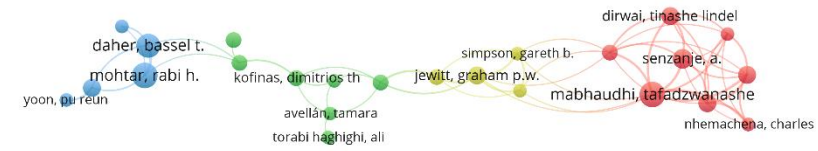

Figure 4. Author Visualization
Source: Data Analysis Result, 2025

Figure 4 shows the author co-authorship network visualization shows numerous distinct collaboration clusters that affect the intellectual landscape of Water–Energy–Food (WEF) nexus research in dry areas. The red cluster is a significant African research network that focuses mostly on agricultural water management, adapting to drought, and nexus policy in Southern Africa. It is led by Tafadzwanashe Mabhaudhi, A. Senzanje, and Charles Nhemachena. The blue cluster, which is led by Rabi H. Mohtar and Bassel T. Daher, focuses on the theoretical and modeling foundations of the WEF nexus. It looks at systems-based frameworks used in case studies from the Middle East and around the world. The green cluster, which includes Dimitrios Th. Kofinas, Tamara Avellán, and Ali Torabi Haghighi, connects environmental governance with integrated resource assessment throughout Europe and Central Asia. The yellow transitional nodes, like Graham P. W. Jewitt and Gareth B. Simpson, connect African and European research communities, which suggests that international collaboration is on the rise. The network topology shows that the research field is connected all over the world but focused on specific regions. Collaboration between African applied research and global system-modeling researchers helps the WEF nexus grow both conceptually and practically in arid and semi-arid agriculture.

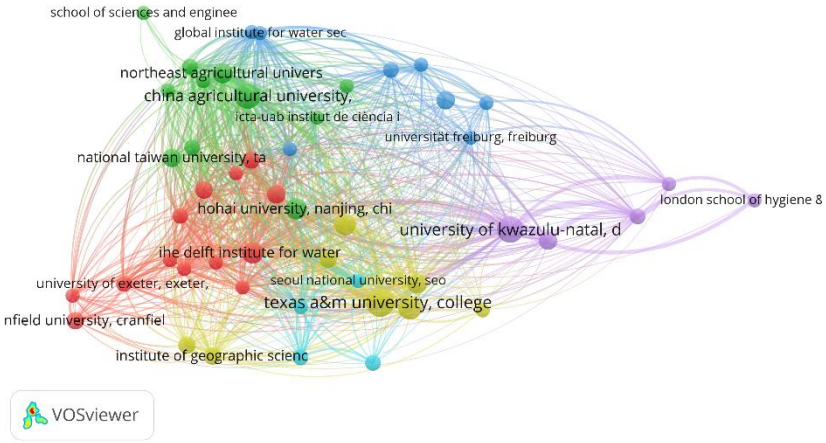

Figure 5. Affiliation Visualization
Source: Data Analysis Result, 2025

Figure 5 illustrates the institutional co-authorship network shows that research on the Water–Energy–Food (WEF) nexus in dry and semi-dry agricultural systems is done by people all over the world and works together a lot. The biggest nodes, such the University of KwaZulu-Natal, Texas A&M University, IHE Delft Institute for Water Education, Hohai University, and China Agricultural University, show that these are the top schools that are pushing research and cooperation across continents. The University of KwaZulu-Natal and the London School of Hygiene & Tropical Medicine lead the purple cluster. This is a significant partnership between Africa and Europe that focuses on water security, food systems, and sustainable development in dryland areas. Asian schools including Hohai University, Northeast Agricultural University, and China Agricultural University make up most of the red and green clusters. These clusters focus on hydrology, energy-water efficiency, and new ways to grow crops when resources are limited. Blue nodes like Universität Freiburg and the Global Institute for Water Security, on the other hand, show that Europe is a leader in environmental modeling and ecosystem management research. The clusters are closely linked to each other, which shows that the research community is becoming more integrated and interdisciplinary. Texas A&M University is a major transregional hub that connects these networks across Asia, Africa, and Europe, linking hydrological engineering, sustainability governance, and climate adaptation science.

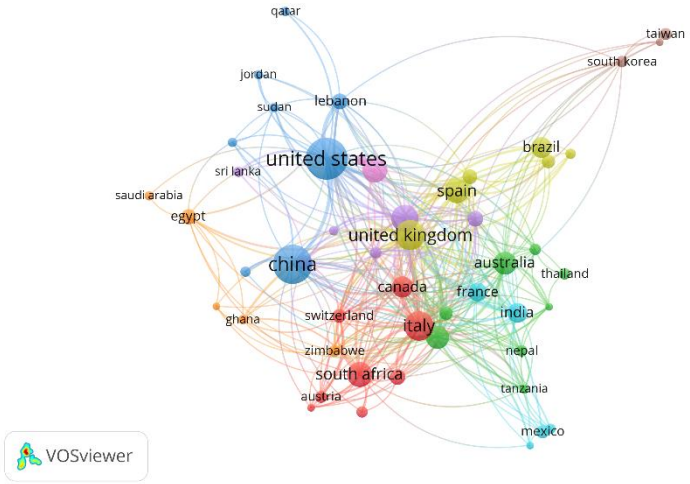

Figure 6. Country Visualization
Source: Data Analysis Result, 2025

Figure 6 illustrates the country collaboration network demonstrates that Water–Energy–Food (WEF) nexus research in arid and semi-arid agriculture is propelled by a highly interconnected global system, predominantly influenced by the United States, China, and the United Kingdom, which serve as primary hubs connecting other regional clusters. The big node sizes of these countries show that they publish a lot and work together a lot with other countries. The United States and the United Kingdom have strong ties to European countries including Italy, Spain, France, and Switzerland. This suggests that they are leaders in cross-disciplinary frameworks, modeling, and policy research. At the same time, China is forming close ties with Australia, India, and Thailand. This shows that collaboration is expanding in the Asia-Pacific region, with an emphasis on technical innovation and sustainable farming techniques in areas where water is scarce. South Africa, Zimbabwe, and Egypt are new African contributors who commonly work with European and American organizations on climate change adaptation and water management. Latin America and East Asia are becoming more involved, as shown by smaller but strategically connected nodes like Brazil, Mexico, and Taiwan. This map shows a pattern of worldwide collaboration with several hubs.

It shows that partnerships between North and South and networks between regions are important for promoting integrated WEF research that is relevant to the problems of dry and resource-limited areas.

Discussions

1. Practical Implications

This bibliometric review's results give policymakers, agricultural planners, and development groups that work in dry and semi-arid areas a lot of useful information. First, the fact that a lot of research is focused on words like "optimization," "climate change," "sustainability," and "agriculture" shows that future policy design should move away from sectoral approaches and toward integrated resource management frameworks that deal with water scarcity, energy efficiency, and food security all at once. The identification of key collaborative institutions—such as the University of KwaZulu-Natal, Texas A&M University, IHE Delft, and China Agricultural University—suggests strategic nodes for international partnerships, capacity building, and knowledge transfer in developing regions facing similar climatic stress. These insights can help governments and regional groups choose transdisciplinary programs that bring together research, innovation, and policy through cooperation across borders. Second, the network analysis shows how important it is to connect technological innovation (such irrigation based on renewable energy, desalination, and precision agriculture) with social equality and governance frameworks. New studies on "economic and social effects" and "stakeholder participation" show that sustainable solutions must include community involvement and access to financial services, especially in places with few resources. This paper advocates for practitioners to implement nexus-based project evaluation standards that consider economic viability, environmental sustainability, and social justice. Lastly, the fact that African, Asian, and European collaborations are the most common in the region means that WEF implementation strategies need to be tailored to the specific hydrological, cultural, and institutional conditions in arid agricultural zones. This will help connect global frameworks with local realities.

2. Theoretical Contributions

Theoretically, this study enhances the comprehension of the Water–Energy–Food (WEF) nexus paradigm by situating it inside arid and semi-arid agricultural systems, a sector that has been inadequately represented in prior assessments. The bibliometric data shows that the field has grown from early studies that focused on water (2020–2021) to more integrated, systems-based, and socio-environmental approaches (2023–2025). This shows that the subject is becoming more mature in terms of theory. This trend shows that we are moving away from reductionist models of resource optimization and toward a more holistic nexus paradigm that includes views on governance, climate resilience, and the circular bioeconomy. The addition of new ideas like "carbon footprint" and "WEFE nexus" helps to expand theory even further by connecting resource management to global sustainability frameworks like the SDGs, planetary boundaries, and climate-neutral development.

This work enhances bibliometric methods in sustainability research by integrating science-mapping and temporal-overlay visualization, providing a dynamic perspective on conceptual evolution over five years. It places the WEF nexus not only as a technical framework but as an adaptive systems theory, highlighting the interconnections between natural resources, human institutions, and technological innovation. The identified author and institutional networks (e.g., Mabhaudhi–Mohtar collaboration paths) illustrate the influence of epistemic communities on the dissemination of theories across geographies. This review enhances the academic discourse by including network theory, resilience thinking, and systems governance into the overarching discussion of sustainable resource management in dry regions.

3. Limitations

This study, while extensive, possesses some flaws that subsequent research should rectify. The bibliometric analysis relied exclusively on Scopus and Web of Science databases, possibly excluding region-specific publications indexed in local repositories or non-English sources, which may inadequately reflect contributions from poor countries in North Africa or the Middle East. Second, bibliometric methods depend a lot on quantitative citation data, which may not show how case studies and field-based evaluations are important for policy or how deep they are qualitatively. Although co-occurrence and network visualizations proficiently delineate intellectual connections, they are inadequate for a comprehensive evaluation of the causal effects or implementation results of WEF nexus activities inside practical agricultural systems. Third, the time period (2020–2025) only covers the most recent wave of WEF nexus research, thus older theoretical origins and empirical milestones may not be completely shown. Furthermore, the keyword standardization procedure, albeit being meticulously vetted, may have inadvertently produced subtle biases in clustering conclusions, especially for nascent interdisciplinary themes that intersect with climate, governance, or economic modeling domains. Subsequent research may integrate bibliometric mapping with qualitative meta-synthesis and policy network analysis to enhance interpretive findings. Adding regional databases (like CNKI and African Journals Online) and grey literature to the dataset would help make it more representative. Even yet, the study gives us a strong empirical base for understanding how integrated WEF techniques are changing the philosophy and practice of sustainable agriculture in dry areas.

CONCLUSION

This bibliometric review demonstrates that research on the Water–Energy–Food (WEF) nexus in arid and semi-arid regions has evolved into a multidisciplinary and globally interconnected field that integrates environmental science, engineering, governance, and socio-economic perspectives. The analysis of 2020–2025 publications reveals a distinct shift from early water- and energy-focused studies toward systemic approaches emphasizing sustainability, optimization, and climate resilience in agricultural contexts. Central themes such as *sustainability*, *climate change*, and *agriculture* anchor the discourse, while emerging topics like *carbon footprint*, *alternative agriculture*, and *WEFE nexus* signal a deepening concern for low-carbon development and social inclusion. Collaborative patterns among leading scholars (e.g., Mabhaudhi, Mohtar, Daher) and institutions (e.g., University of KwaZulu-Natal, Texas A&M University, IHE Delft) indicate the formation of strong global research networks that connect Africa, Asia, and Europe. The study concludes that the WEF nexus provides a powerful conceptual and operational framework for addressing complex resource challenges in arid agriculture, offering pathways for integrated policy design, technological innovation, and equitable resource governance. Nonetheless, future studies should enhance regional representation and incorporate qualitative insights to bridge the gap between theoretical modeling and field-level implementation, ensuring that the nexus approach continues to inform resilient and sustainable agricultural transformation in water-stressed environments.

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