Mapping the Research Landscape of Agricultural Extension, Sustainability, and Development: A Bibliometric Analysis

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DOI: https://doi.org/10.51244/IJRSI.2026.1307000390

Received: 07 August 2026; Accepted: 13 August 2026; Published: 20 August 2026

ABSTRACT

Agricultural extension plays a central role in sustainable agriculture, rural development, and climate resilience. As extension systems increasingly integrate environmental management, digital technologies, and participatory approaches, a systematic understanding of the field's research structure is needed. This study maps the global research landscape of agricultural extension, sustainability, and development using bibliometric analysis of 5,514 Scopus-indexed English-language publications. Keyword co-occurrence, country co-authorship, and overlay analyses were conducted using VOSviewer. Agriculture and agricultural extension emerged as central themes linked with sustainable development, ecosystem services, climate resilience, soil health, and organic farming. More recent themes included artificial intelligence, digital agriculture, biotechnology, nanotechnology, and remote sensing, indicating a shift toward technology-enabled extension and agricultural innovation. Country collaboration patterns showed strong contributions from the United States and China, with increasing participation from India, Brazil, Indonesia, Pakistan, Kenya, and the Philippines. Overall, the field is becoming more multidisciplinary, collaborative, sustainability-oriented, and digitally enabled. The study identifies future priorities in digital extension, climate adaptation, and inclusive agricultural innovation systems while providing a clearer and more reproducible description of the bibliometric corpus and analytical approach.

Keywords: Agricultural Extension, Sustainable Development, Bibliometric Analysis, Climate Resilience, Digital Agriculture, Rural Development.

INTRODUCTION

Agricultural extension is a key mechanism for linking research, technology, institutions, and farming communities. Traditionally, extension systems emphasized the transfer of knowledge and technologies to farmers to improve productivity and farm management (Anderson & Feder, 2007). Contemporary agricultural challenges, however, require a broader role. Climate change, food insecurity, environmental degradation, resource constraints, and rural inequality have increased the demand for extension approaches that combine technical advice with facilitation, participation, innovation, and community capacity building (Davis et al., 2012; Klerkx et al., 2012).

Sustainability has consequently become a central concern in agricultural research and development. Sustainable agriculture seeks to balance environmental protection, economic viability, and social equity (Pretty, 2008). Extension programs contribute to this objective by promoting practices such as soil conservation, crop diversification, organic farming, climate-smart agriculture, ecosystem management, and resource-efficient production. In this sense, agricultural extension is not only a channel for disseminating farm technologies but also an institutional mechanism for strengthening the adaptive capacity of rural communities.

Digital transformation has further expanded the scope of extension. Artificial intelligence, remote sensing, digital agriculture, precision farming, mobile advisory services, and data-driven decision support are increasingly used to improve farm management and information delivery. Wolfert et al. (2017) emphasized the growing role of big data in smart farming, while more recent bibliometric evidence shows that digitalization, smart agriculture, and farmer adoption have become prominent themes in sustainable agriculture research (Xu et al., 2024). A bibliometric study focused specifically on ICT-based extension and advisory services similarly identified e-agriculture, e-extension, mobile technologies, climate-smart agriculture, and digital agriculture as major thematic areas (Mukherjee et al., 2025).

Despite the expanding literature, broad evidence on how agricultural extension intersects with sustainability and development remains fragmented. Existing studies often examine a specific technology, geographical setting, sustainability practice, or extension modality. As a result, there is a need to map the field at a wider scale, identify influential research constituents, examine collaboration patterns, and trace the emergence of new themes. Bibliometric analysis is appropriate for this purpose because it combines performance analysis with science mapping to assess productivity, influence, conceptual structure, and collaboration within a large body of literature (Donthu et al., 2021).

Accordingly, this study aims to analyze the global research landscape of agricultural extension, sustainability, and development using bibliometric methods. Specifically, it seeks to: (1) identify major research themes and publication trends; (2) determine emerging topics and technological innovations associated with agricultural extension; (3) examine collaborative patterns among countries; and (4) analyze the evolution of research interests over time. The findings are intended to support researchers, policymakers, extension practitioners, and academic institutions in identifying research priorities and designing sustainable, climate-responsive, and inclusive agricultural extension programs.

METHODOLOGY

Data Source and Search Strategy

The bibliographic data were retrieved from the Scopus database because it provides standardized bibliographic metadata suitable for citation, co-authorship, and keyword analyses. The search was conducted within article titles, abstracts, and keywords using the following Scopus query:

TITLE-ABS-KEY("agricultural extension" OR "agricultural sustainability" OR "agricultural development")

The search was conducted on May 21, 2026. As shown in Figure 1, the query returned 5,514 documents. The documented search does not indicate a publication-year restriction or a document-type restriction to know the entire research landscape; therefore, all years and all Scopus document types returned by the query were treated as eligible. The original manuscript states that the analysis was limited to English-language documents. No manual title/abstract screening or subsequent exclusion stage was described. Accordingly, the 5,514 records shown in the Scopus results page were treated as the final bibliometric corpus.

Table 1. Search strategy and dataset description

Dataset element	Specification	Reproducibility note
Database	Scopus	Single bibliographic database used in the manuscript.
Search field	Article title, Abstract, Keywords	Equivalent to TITLE-ABS-KEY in Scopus.

Exact query	TITLE-ABS-KEY("agricultural extension" OR "agricultural sustainability" OR "agricultural development")	Exact search expression documented in the manuscript.
Search date	May 21, 2026	To be completed by the authors because Scopus coverage and citation counts change over time.
Publication period	All years indexed in Scopus at the search date	No publication-year restriction is documented in the search strategy.
Language	English	Supported by the limitation statement in the original manuscript.
Document types	All Scopus document types returned by the query	No document-type restriction is documented in the search strategy or Figure 1.
Records initially retrieved	5,514	Visible in the Scopus result shown in Figure 1.
Screening/exclusion process	No separate manual screening or post-retrieval exclusion stage documented	The manuscript proceeds directly from the Scopus retrieval to VOSviewer analysis.
Final publications analyzed	5,514	The retrieved records were treated as the final corpus because no later exclusions are documented.
Analysis software	VOSviewer 1.6.20	Used for country co-authorship, keyword co-occurrence, and overlay visualization.

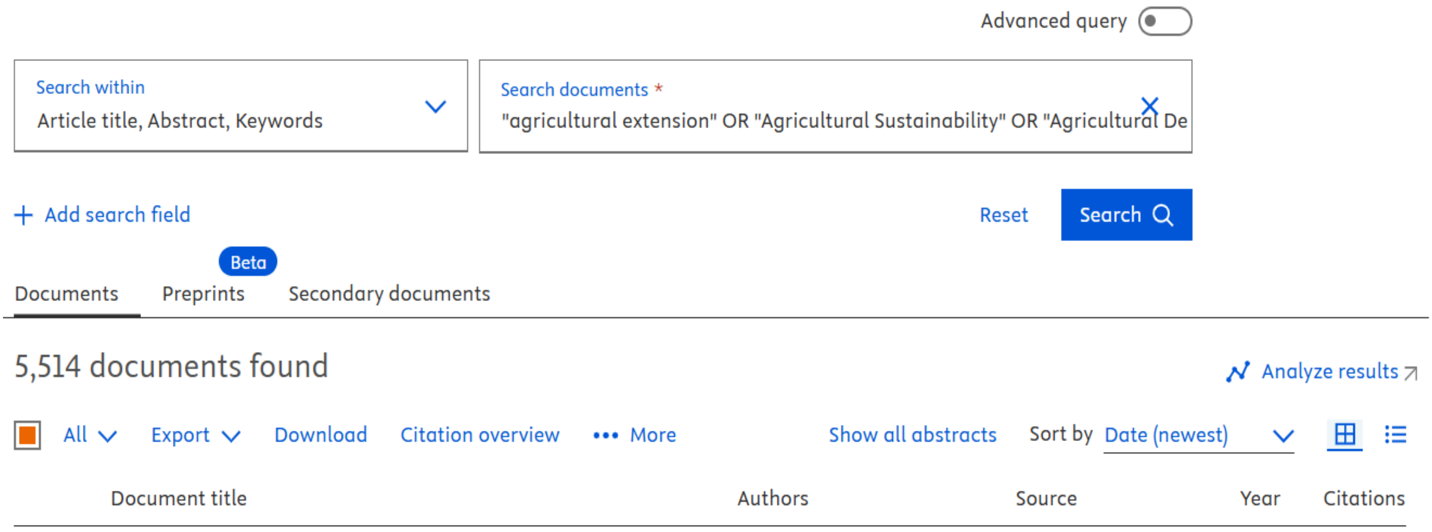

Figure 1. Scopus keyword-based search query and initial retrieval result.

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VII July 2026

Eligibility and Screening Process

The eligibility and screening process is summarized in Table 1 and illustrated in the PRISMA-style flow diagram (Figure 2). Because the study used a single Scopus search and the retained manuscript did not document a separate title/abstract screening stage, duplicate-removal stage, or additional exclusions after retrieval, the database-level search output was retained for bibliometric mapping. Thus, 5,514 records were included in the final corpus. This reconstruction follows the sequence documented in the manuscript, in which the Scopus retrieval is followed directly by VOSviewer analysis.

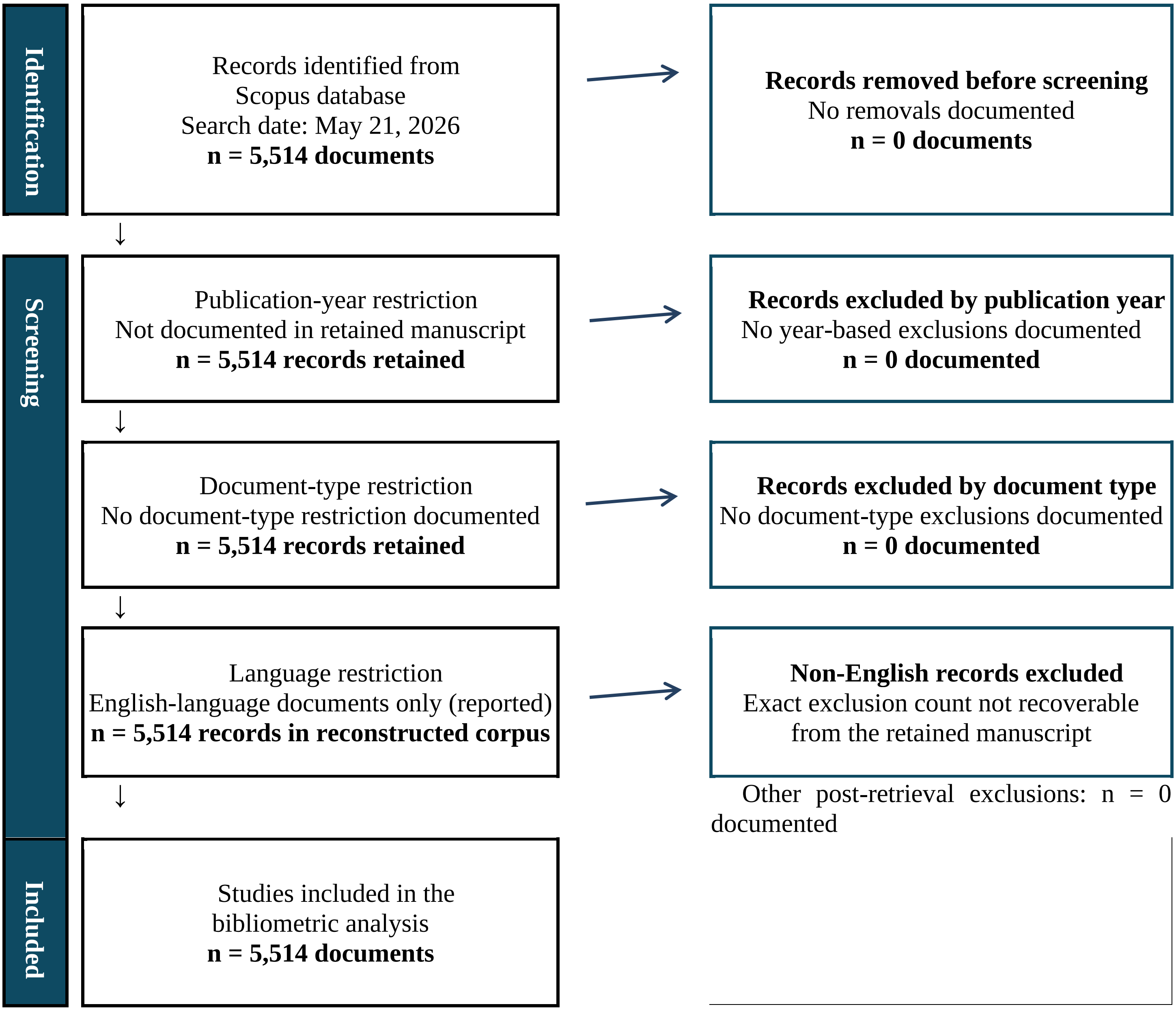

Figure 2. PRISMA-style flow diagram of the identification, screening, eligibility, and inclusion of publications for bibliometric analysis.

Bibliometric Indicators and Network Analysis

The analysis combined descriptive dataset profiling and science-mapping techniques following established bibliometric practice (Donthu et al., 2021). Science mapping included country co-authorship, keyword co-occurrence, and overlay visualization. Co-authorship analysis was used to examine international research collaboration, whereas keyword co-occurrence analysis was used to identify conceptual themes and emerging topics. Overlay visualization was used to interpret the temporal movement of research interests. The retained manuscript supports the corpus size, country prominence, keyword centrality, and temporal patterns shown in

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VII July 2026

Figures 1–4. Exact author-, institution-, journal-, citation-, total-link-strength (TLS), and cluster statistics were not preserved in the embedded manuscript output and therefore were not reconstructed from unsupported assumptions.

The bibliographic data were analyzed and visualized using VOSviewer version 1.6.20. In the country co-authorship map, larger nodes indicate greater publication presence, connecting lines represent collaboration, and overlay colors represent average publication year. In the keyword co-occurrence map, larger nodes indicate more frequently occurring terms, links represent co-occurrence relationships, and overlay colors show the temporal distribution of topics. Because the original VOSviewer map/network files and analysis logs were not retained within the manuscript, exact minimum thresholds, cluster counts, and TLS values cannot be reproduced reliably from the rendered figures alone.

RESULTS AND DISCUSSION

A. Dataset Profile and Bibliometric Performance Indicators

The final bibliometric corpus consisted of 5,514 Scopus-indexed English-language publications. No publication-year restriction was documented; accordingly, the corpus was treated as covering all years indexed in Scopus at the time of the search. Table 2 summarizes the dataset and network indicators that can be verified from the retained manuscript and figures.

Table 2. Dataset and network indicators supported by the retained Scopus/VOSviewer output

Indicator	Result	Interpretation/reporting basis
Final number of publications	5,514	Scopus result shown in Figure 1; no subsequent exclusion stage is documented.
Publication period	All years indexed in Scopus at the search date	No publication-year restriction is documented.
Language	English	Stated in the limitation of the original manuscript.
Most prominent country	United States	Largest visible country node in Figure 2; China is also a dominant contributor.
Second prominent country	China	Large, central, and highly connected node in Figure 2.
Emerging country participation	India, Brazil, Pakistan, Indonesia, Kenya, and the Philippines	Visible in the network and described as increasing participation in the manuscript.
Dominant keyword	Agriculture	Largest and most central keyword node in Figure 3.
Core extension keyword	Agricultural extension	Major highly interconnected keyword node in Figure 3.
Sustainability-oriented themes	Soil health, organic farming, crop rotation, groundwater management, ecosystem services	Dense group of sustainability-related terms linked with the central extension themes.
Recent technology-oriented themes	Artificial intelligence, deep learning, remote sensing, digital agriculture, biotechnology, nanotechnology	More recent overlay colors indicate growing attention to technology-enabled agriculture.

Climate/development themes	Climate change, climate resilience, food production, water quality, community development, stakeholder engagement, human capital	Shows the intersection of environmental resilience and participatory rural development.
Exact citation/TLS/cluster statistics	Not recoverable from the retained manuscript figures alone	Requires the original Scopus citation output and VOSviewer map/network files; unsupported numerical values were not fabricated.

B. Country Co-authorship Network Visualization

Figure 3 presents the country co-authorship network in agricultural extension, sustainability, and development research. Node size represents relative publication presence within the network, connecting lines indicate co-authorship relationships, and overlay color represents the average publication year. The United States is the largest visible node and, together with China, occupies a prominent and highly connected position, indicating substantial contributions and broad international collaboration. The United States shows linkages with countries across Europe, Africa, Asia, and Latin America, while China is strongly connected with several Asian and Middle Eastern research partners.

The map also shows the increasing participation of developing and emerging economies, including India, Brazil, Pakistan, Indonesia, Kenya, and the Philippines. The more recent overlay colors associated with several Asian countries suggest that their contributions have expanded in later years. This pattern is consistent with the growing importance of sustainability, food security, digitalization, and climate resilience in countries where agriculture remains economically and socially significant.

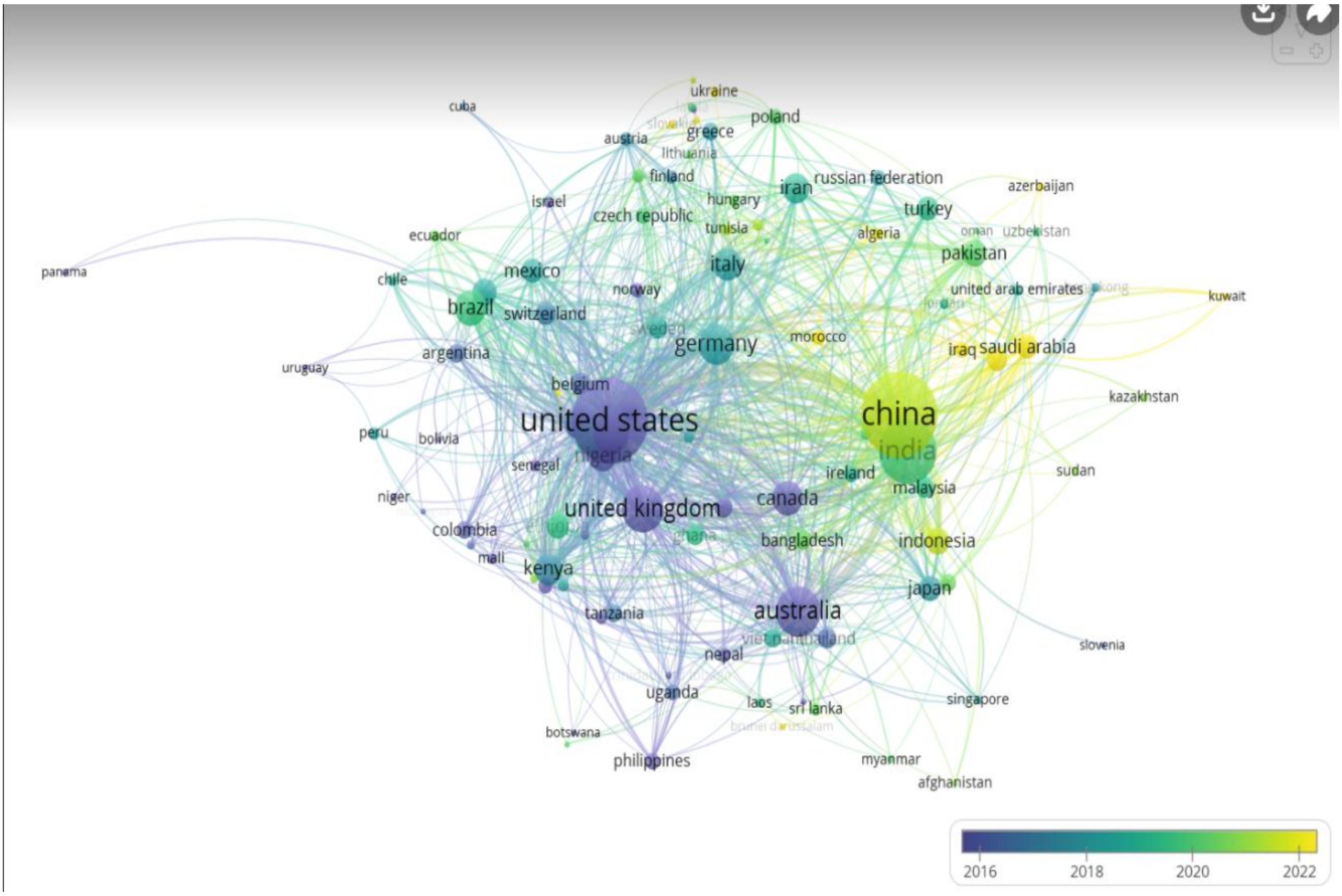

Figure 3. Country co-authorship network with overlay visualization.

The extensive inter-country connections indicate that agricultural extension and sustainability research increasingly relies on international collaboration to address transboundary challenges such as climate change, environmental degradation, food insecurity, and technological transformation. Earlier contributions in the overlay map are concentrated among established Western research systems, whereas newer activity is increasingly visible in Asian and other emerging economies. This shift suggests a broadening of the global knowledge base and may create opportunities for stronger South–South and North–South research partnerships.

C. Keyword Co-occurrence Network and Thematic Evolution

Figure 4 shows the keyword co-occurrence network and its temporal overlay. "Agriculture" and "agricultural extension" appear as central and highly connected themes, linking with farmers, sustainable development, ecosystem services, climate change, and related development concepts. These relationships indicate that agricultural extension is increasingly discussed as part of a broader sustainability and rural-development system rather than solely as a mechanism for technology transfer.

A dense sustainability-oriented theme is visible around soil health, organic farming, crop rotation, groundwater management, ecosystem services, and related ecological concepts. This pattern supports the continuing importance of agroecological and resource-conservation approaches in extension research. Altieri and Nicholls (2017) emphasized the role of sustainable farming systems in climate resilience, while Pretty (2008) framed sustainable agriculture as the integration of environmental, economic, and social objectives. The observed keyword structure reflects these interconnected dimensions.

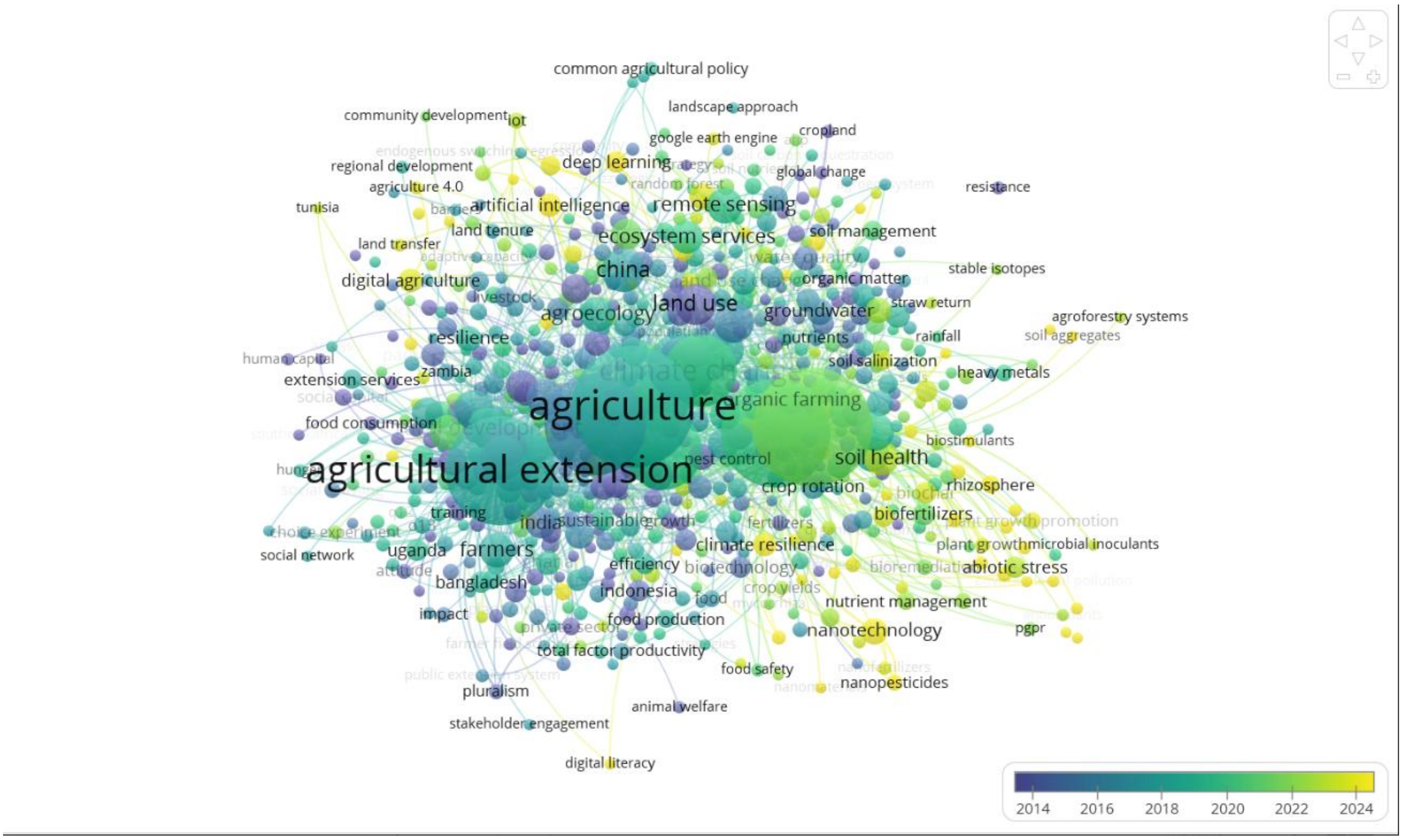

Figure 4. Keyword co-occurrence network with overlay visualization.

The overlay visualization also indicates a more recent concentration of technology-oriented keywords, including artificial intelligence, deep learning, remote sensing, digital agriculture, biotechnology, and nanotechnology. This transition points to the growing role of precision tools, digital platforms, and data-driven decision support in contemporary agricultural extension. Wolfert et al. (2017) described a similar transformation in smart farming through big data and digital decision-making. The presence of climate change, climate resilience, food production, and water quality further shows that digital innovation is increasingly intertwined with adaptation and sustainability objectives.

Participatory and developmental concepts, including community development, regional development, stakeholder engagement, extension services, and human capital remain connected to the technological and sustainability themes. This suggests that the future of extension is not purely technical: digital and climate innovations must still be translated through institutions, learning processes, and farmer-centered engagement. Because the retained figure is an overlay visualization rather than the underlying VOSviewer map file, exact threshold, cluster-size, and TLS values are not reported; interpretation is therefore limited to the relative node prominence, connectivity, and temporal patterns visible in the network.

D. Research Influence and Citation-Data Limitation

The original analytical plan referred to citation analysis; however, the retained manuscript does not contain a citation-ranking table, citation-network map, or Scopus/VOSviewer export from which exact document-, author-, institution-, or source-level citation counts can be reproduced. Citation values are also database- and date-sensitive. Reconstructing rankings from the embedded figures or substituting citation counts from another database would therefore not be methodologically equivalent to the original Scopus analysis. To avoid reporting unverifiable values, this revision does not fabricate citation counts or TLS values. Research influence is instead contextualized using field-defining works that support the identified themes, including Pretty (2008) for agricultural sustainability, Anderson and Feder (2007) for extension, Klerkx et al. (2012) for agricultural innovation systems, Aker (2011) for ICT-enabled extension, and Wolfert et al. (2017) for data-driven agriculture.

E. Comparison with Related Bibliometric Studies

The trends observed in this study are consistent with, but broader than, several recent bibliometric analyses in adjacent areas of agricultural research. Xu et al. (2024), in a bibliometric study of sustainable agriculture in the digital era, identified digitalization, smart agriculture, agricultural challenge management, and farmer adoption as important current and future research domains. The present network similarly shows a movement from conventional extension and sustainability themes toward artificial intelligence, remote sensing, digital agriculture, and related technologies. This convergence suggests that digital transformation is becoming a cross-cutting component of sustainable agricultural research rather than a separate technological niche.

The findings also complement the more focused analysis of ICT-based extension and advisory services by Mukherjee et al. (2025). Their study identified e-agriculture and e-extension as central themes and documented the growing importance of mobile technologies, digital agriculture, climate-smart agriculture, and information systems. In comparison, the present study has a wider conceptual scope because it combines agricultural extension with sustainability and development, allowing digital, environmental, and participatory themes to be interpreted within a single knowledge landscape.

The climate-oriented themes identified in Figure 4 are likewise consistent with the bibliometric review of climate-smart agriculture by Zhao et al. (2025), which documented rapid growth in climate-smart agriculture research and emphasized cross-disciplinary integration, collaborative approaches, and inclusive development. Taken together, these studies suggest that agricultural extension research is converging around three interconnected transitions: digital transformation, climate adaptation, and more inclusive innovation systems. The distinctive contribution of the present study is to show how these transitions intersect within the broader agricultural-extension knowledge landscape.

F. Future Research Directions

First, digital extension research should move beyond technology availability toward evidence on effectiveness, accessibility, and responsible use. Future studies should examine how artificial intelligence, remote sensing, mobile platforms, and decision-support tools improve farmer decisions under real field conditions; how extension organizations develop digital competencies; how agricultural data are governed and shared; and how digital systems can remain interoperable, affordable, and usable in low-connectivity environments. Particular attention is needed to the risk that digital transformation may widen rather than reduce inequalities when farmers differ in connectivity, literacy, language, gender, income, or access to devices.

Second, climate-adaptation research should more explicitly connect extension processes with measurable resilience outcomes. Priorities include localized climate advisories, early-warning systems, drought and flood preparedness, climate-smart soil and water management, and long-term evaluation of whether extension-supported practices improve productivity stability, livelihood security, and adaptive capacity. Research should also examine how scientific climate information can be translated into locally understandable and actionable advice through participatory extension.

Third, inclusive agricultural innovation systems require greater attention. Future research should analyze the participation of women, youth, Indigenous peoples, smallholders, remote communities, and other groups that may be underrepresented in technology and extension systems. Studies should examine co-design, farmer-to-farmer learning, pluralistic public-private extension arrangements, institutional linkages, and the role of local knowledge. Inclusion should be assessed not only by participation rates but also by who influences decisions, who receives benefits, and whose knowledge is incorporated into innovation processes.

Finally, future bibliometric work can strengthen the evidence base by combining Scopus with additional databases, using transparent search and screening protocols, publishing the cleaned bibliographic dataset and VOSviewer settings when permitted, and integrating bibliometric mapping with qualitative content analysis. Such mixed approaches can help explain why particular themes or collaborations emerge, rather than only describing their frequency and network position.

CONCLUSION

This bibliometric analysis maps the evolving research landscape of agricultural extension, sustainability, and development. The study shows that agricultural extension remains closely connected with sustainable agriculture, rural development, climate resilience, ecosystem management, and farmer-centered development. At the same time, the keyword overlay indicates an ongoing transition toward digitally enabled research involving artificial intelligence, remote sensing, digital agriculture, biotechnology, and other data-intensive technologies.

The country collaboration network demonstrates the global character of the field, with established leadership from major research-producing countries and increasing participation from developing and emerging economies. This expansion is important because many of the most urgent extension challenges—food security, climate vulnerability, resource degradation, and unequal access to innovation—are concentrated in agricultural regions where locally relevant knowledge and international collaboration are both needed.

The study also identifies three priorities for future scholarship and practice: effective and equitable digital extension, extension-supported climate adaptation, and inclusive agricultural innovation systems. Strengthening these areas will require research that connects technological innovation with farmer capabilities, institutional capacity, local knowledge, and measurable livelihood and sustainability outcomes.

The study is limited by its reliance on the Scopus database and English-language documents, which may exclude relevant publications indexed elsewhere or published in other languages. Bibliometric results are also affected by database coverage, author and affiliation name variations, keyword standardization decisions, citation-age effects, and the thresholds selected for network analysis. A further limitation of the retained project record is that the original VOSviewer map/network files and citation-ranking outputs were not preserved with the manuscript, preventing retrospective reporting of exact TLS, cluster, and citation-rank values. Future studies should archive these outputs, use transparent data-cleaning procedures, conduct sensitivity analyses using alternative thresholds, and consider complementary databases and qualitative review methods.

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