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Global trends in ICT-based extension and advisory services in agriculture: a bibliometric analysis

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Utilizing Information and Communication Technology (ICT) to grant farmers direct access to information, while also developing models tailored to the specific contexts of both public and private agricultural extension sectors, stands as a pivotal endeavor in modern agriculture. This study uses bibliometric analysis to identify key research areas in ICT-based extension and advisory services (EAS) and to understand patterns and trends within this domain. The Scopus database served as the primary tool for accessing publications, yielding a corpus of 525 articles spanning from 1999 onwards, subsequently analyzed through VOSviewer and R software. The findings unveil that the Sustainability journal claims the highest number of published articles, while the Agricultural Economics journal garners the most citations within this realm. Notably, Aker emerges as the most globally cited author with 405 citations, while China Agricultural University emerges as the institution with the highest publication count concerning ICT-based EAS. India emerges as a frontrunner with 446 publications, while publications originating from the USA receive the highest number of citations, reflecting the nation's substantial endeavors and investments in harnessing ICT for agricultural extension purposes. The co-occurrence analysis of all keywords emphasizes the primary focus of publications on e-agriculture and e-extension. Furthermore, the outcomes of co-citation analysis highlight The Journal of Agricultural Education and Extension as the most referenced journal, with 22 citations and a cumulative link strength of 266, indicative of its profound influence and recurrent citation alongside other scholarly journals. This study uncovers an escalating interest in this field, emphasizing its paramount importance in contemporary agricultural practices. Accordingly, these findings offer crucial insights for guiding future research and shaping evidence-based policies, thereby aiding researchers, policymakers, and practitioners in improving ICT-based EAS in agriculture.

KEYWORDS

bibliometric analysis, co-citation, co-occurrence, e-extension, Scopus, VOSviewer

1 Introduction

Agriculture is frequently influenced by global forces and evolving factors such as technological advancements, demographic shifts, socio-economic changes, alterations in consumption patterns, and increased interdependence in global markets (Suvedi and Kaplowitz, 2016). In response to these dynamics, the emphasis on generating and applying agricultural knowledge is growing, particularly for small and marginal farmers who require pertinent information to enhance and sustain their farming enterprises (Glendenning and Ficarelli, 2012). Nevertheless, the agricultural sector is experiencing sluggish and stagnant growth, primarily due to the lack of improvement and innovativeness among the stakeholders involved. Agricultural extension and advisory service providers are crucial among these stakeholders, and they should embrace a more dynamic, innovative, and vibrant approach to fostering agricultural development, meeting the needs of farmers, and attaining the targeted growth rate (Saravanan, 2012).

The terms extension and advisory services (EAS) are frequently used interchangeably to form a framework that encompasses four paradigms outlined by Swanson (2009). First, technology transfer, which involves a persuasive and paternalistic top-down approach concentrated on enhancing food production by convincing farmers to adopt cost-effective new technologies. Second, advisory services, which employ a persuasive and participatory approach, and often use a pluralistic method involving both public and private extension agents. Farmers are encouraged to adopt specific practices or technologies based on research-validated solutions to address identified problems and constraints. Third, non-formal education, which adopts an educational and paternalistic approach, focuses on training farmers to utilize specific management skills and technical knowledge for enhanced production efficiency. Lastly, facilitation extension, which embraces an educational and participatory approach, aiming to assist farmers in defining their problems and developing suitable solutions. The extension service plays a crucial role in delivering information, suggestions, knowledge, and advice to farmers. However, a significant challenge lies in ensuring its relevance amid changing circumstances. To address this, there is a need for specialized strategies in effectively managing as well as disseminating knowledge and information packages to farmers. The philosophy and rationale of extension services have evolved, shifting from a top-down approach to participatory development and an extension-plus approach, combining EAS (Oladele, 2015). Extension-plus is particularly pertinent when it comes to reorganizing public extension programmes in emerging nations like India, where the extension system is facing difficulties in projecting its relevance and finding a meaningful role in addressing the current issues in rural and agricultural development.

However, the challenge in providing effective EAS is to determine how much of a role the government should have in executing the services. With an emphasis on the experiences of underdeveloped nations, they pinpoint common obstacles that make organizing expansion challenging. The size of the undertaking, dependency on broader agency operations and policies, difficulties determining the cause and effect required to allow accountability and secure funding and political support, liability for public service duties other than imparting information and expertise about agriculture, financial stability, and insufficient communication with those who generate knowledge are some of the notable challenges (Feder et al., 2013). Farmers view the quality of information supplied by public extension personnel as a critical problem since the flow of information is supply-driven rather than needs-based or area-specific [Raabe, 2008; NSSO (National Sample Survey Organisation), 2005]. This is because the organization is rigid and unchanging, with a top-down hierarchical structure that persists (Hall et al., 2000; Raabe, 2008). Just over 0.1 of the 1.3–1.5 million extension workers that are needed were employed in 2007 (Working Group on Agricultural Extension, 2007). According to a review of the public extension system's (PES) workforce availability, which includes Agriculture Technology Management Agency (ATMA) employees throughout all states, the ratio of extension service providers (ESP) to operational farm holdings is around 1:1,156. Several line departments at the state level have come under fire for their isolated operations, shaky connections, and infrequent collaborations (Sulaiman et al., 2005), which restricts the flow of information. Thus, the availability of these services remains insufficient, notwithstanding the resurgence of interest in and funding for agricultural extension in India. In this context, the scope of non-profit extension programmes, cooperatives, national agricultural research system extension services, and government extension programmes is extremely constrained [NSSO (National Sample Survey Organisation), 2005].

According to a 2003 National Sample Survey Organization (NSSO) poll, 60% of farmers reported that they had not used any source of knowledge about contemporary technology to support their agricultural methods in the previous year. Out of those who had obtained information, 16% got it from input merchants and other progressive farmers. The practical relevance of the advice was deemed to be the main issue with extension services among farmers who had access to information [NSSO (National Sample Survey Organisation), 2005]. This raises concerns about the scope and applicability of the information supplied to farmers via the agricultural extension system. While this can be partially attributable to the services' insufficient communication—they must reach a sizable and intricate farming community—inappropriate or subpar information might also be a key hindrance to farmers' use of extension services. Scientists have little experience in field reality, while farmers and extension agents are passive participants (Reddy et al., 2006). Despite the dearth of actual studies on the topic, private extension is reported to have varying degrees of efficacy. However, private extension is allegedly limited to a selected few crops and locations where revenues are assured; it frequently focuses its services on areas with sufficient resources (Sulaiman and van den Ban, 2003). Also, since the private sector collaborates with individual farmers to advance corporate objectives, social capital is not produced. Additionally, challenges faced by public extension systems include limited reach due to financial constraints and sparse populations. Robust public extension services directly engage with ∼10% of the farmer population, a figure that further decreases in the presence of limited operating funds (Bell, 2015). Public extension services also struggle with providing non-recurring and regularly updated information, hindering adoption by farmers, especially without local facilitators (FAO, 2015). Thus, in the era of rapidly evolving and modernizing farming systems, public extension services delivered in developing nations are occasionally viewed as outdated. Government extension agencies, often bureaucratic, may lack the capacity to reach all smallholder farmers and provide timely, customized information (Bell, 2015). Addressing the challenges of accessibility and availability of extension personnel, information and communication technology (ICT)-based agro-advisory services emerge as a solution by offering cost-effective advisory services to farmers through tools like radio, television, call centers, mobile applications, etc., as needed (Paudel et al., 2018).

ICTs enable the capture, processing, transmission, storage, retrieval, and display of various forms of information, including text, images, video, graphics, animations, etc. This implies a significant enhancement in addressing almost all information requirements within the realms of agriculture and development processes. ICTs serve as crucial facilitators of globalization, ensuring the cost-effective and efficient flow of information, products, people, and capital globally (Oladele, 2015). The application of ICTs holds the potential to benefit agriculture, particularly in transforming the socio-economic conditions of the rural poor (Singh et al., 2015). ICTs have proven to be significant catalysts for development across various sectors, including agriculture, where they contribute to improved agricultural production through the introduction of farm technologies (Das, 2016). The incorporation of ICTs into agriculture development policies and programmes is crucial for the effective implementation of e-extension services. Recent research has demonstrated the positive outcomes of integrating ICTs into agriculture policies and programs. For instance, a study by Kumawat et al. (2020) in Ghana highlighted that mobile-based ICTs in agriculture led to increased yields and improved food security. Similarly, a study by Maja and Ayano (2021) in Malawi showed that web-based ICTs in agriculture led to greater adoption of improved practices and enhanced yields. Likewise, in India, Reddy and Ankaiah (2005) reported that implementing the e-Sagu prototype not only increased farmers' income by INR 3,075 (63 USD) per hectare but also reduced pesticide usage. Their initial economic estimate suggested that deploying the e-Sagu prototype for 1,000 farmers could result in an overall net benefit of INR 100 million (USD 204,800). Saravanan (2008) compared the cost and time indicators between the traditional extension system and the e-Arik (e-agriculture) project, revealing a 16-fold and three-fold reduction in time required for clientele availing and extension systems delivering extension services, respectively. Furthermore, a 3.4-fold economic benefit was reported compared to the expenditure of deploying the e-agriculture prototype. Cecchini and Raina's (2002) study on the Warana Wired Village project demonstrated how ICT could positively impact rural development, particularly by optimizing sugar cane operations and assisting small farmers and cooperatives. Key learnings from this case emphasized the importance of understanding community needs, maintaining ongoing community engagement, and ensuring equitable access for marginalized groups. Through empowering local operators and utilizing available IT resources, the project showcased how ICT could enhance effectiveness, transparency, and economic opportunities in rural areas, highlighting its potential for transformative development. De Silva and Ratnadiwakara (2010) proposed that the use of ICT could substantially decrease transaction costs by reducing the expenses associated with searching for information. This cost reduction could encourage more farmers to engage in commercial agriculture, providing an alternative to subsistence farming, which often kept many farmers in developing countries trapped in poverty.

The National e-Governance Plan in India has delineated key services within the Agriculture Mission Mode Projects (MMP) with the goal of providing farmers access to information regarding seeds, fertilizers, pesticides, government schemes, soil recommendations, crop management, weather forecasts, and agricultural produce marketing. Several state-specific initiatives such as KISSAN and e-Krishi in Kerala (Masiero, 2012), Gyandoot in Madhya Pradesh (Parmar et al., 2015), ASHA in Assam, Warana Wired Village Project in Maharashtra, and Krishi Maratha Vahini in Karnataka (Rohila et al., 2017) have been introduced by the Department of Agriculture and Cooperation (DoA&C), Government of India. To facilitate the implementation of MMP in agriculture, DoA&C has adopted a dual strategy utilizing AGRISNET along with two portals: AGMARKNET and DACNET (Mathur et al., 2009). The Indian government, in partnership with public-private collaborations, is actively developing and implementing innovative networked solutions as part of the Digital India initiative to improve agricultural services at the farm level. This includes initiatives such as the National e-Governance Plan in Agriculture (NeGP-A), deployment of mobile apps, establishment of Knowledge Management Portals, the Krishi Vigyan Kendra (KVK) Portal, Touch Screen Kiosks, Kisan Call Centers, AgriClinics, Common Service Centers, mKisan, Kisan TV, and the recently launched Kisan Sarathi by ICAR.

Private sector entities, including mobile network operators and ICT companies, also contribute significantly to e-extension services. Efforts include digital agriculture startups like CropInfo, ITC's e-Choupal (Singh, 2004), mobile apps such as FarmRise by Monsanto, weather systems like Skymet, and Reuters Market Light (Chahal et al., 2012), and digital traceability solutions like SourceTrace (Chemeltorit et al., 2018). In Kenya, Safaricom, a mobile network operator, partners with the government to provide farmers access to agricultural information and advisory services through mobile-based platforms. In Tanzania, Esri Eastern Africa, an ICT company, has developed a web-based platform that grants farmers access to agricultural information, including weather forecasts and market prices. Non-governmental organizations (NGOs) are also vital in implementing e-extension services, as seen in Ghana, where the International Institute of Tropical Agriculture (IITA) collaborates with the Ministry of Food and Agriculture to provide farmers with access to extension services through mobile-based platforms. Similarly, in Uganda, the National Agricultural Advisory Services (NAADS) program partners with NGOs to deliver extension services to farmers, leveraging ICTs (Rwamigisa et al., 2018).

Agricultural advisory systems, particularly public extension services, have evolved over the last two decades, shifting from exclusive, expensive, and energy-intensive equipment accessible to a select few, toward the widespread adoption of dynamic and ever-evolving mobile, wireless, and internet technologies for the general population, enabling farmers in accessing information from diverse ICT sources (Barber et al., 2016). Increasing investment is now being made in India in recognition of the significance that agricultural extension plays in enhancing agricultural growth. The agricultural sector has embraced this trend with hopes that ICT can address the gaps left by public extension, especially in resource-poor farms with insufficient extension workers (Bell, 2015). The proliferation of ICT in developing nations enables users, particularly those in remote locations, to communicate and obtain crucial information (Aker, 2011). However, the effectiveness depends on the affordability of ICT and the provision of information tailored to specific conditions, given the highly localized nature of agriculture (McNamara et al., 2011; Bell, 2015). The 10th and 11th 5-year plans for India highlight the need to strengthen agricultural extension in the country because they see it as a means of boosting agricultural growth by closing the yield gap in farmer fields (Planning Commission, 2001, 2005, 2006). Despite the rapid advancements in ICTs, their utility hinges on their ability to facilitate the creation, collection, processing, storage, and dissemination of people-oriented content (Aregu et al., 2008). To fully leverage the potential of ICTs, it is crucial to adopt a process that considers the contributions and local needs of all segments of global society.

Thus, information and knowledge stand as pivotal elements in food security and sustainable agricultural development (Munyua, 2007; FAO/WB, 2000). Recognizing this, it is acknowledged that integrating ICTs into EAS is essential. Despite extensive research on ICT-based extension services, existing studies lack a structured analysis of bibliometric trends, leading to fragmented understanding of the field. Moreover, the absence of a comprehensive and current overview limits the ability to identify influential studies, authors, and organizations, which are crucial for guiding future research and policy decisions. Thus, the present study was undertaken to conduct a bibliometric analysis to systematically analyze and compile the body of available literature in order to close this gap. Bibliometric analysis places substantial emphasis on extensive and objective data, such as sizable datasets containing hundreds or even thousands of entries, encompassing metrics like number of citations, publications, and occurrences of keywords and topics. Despite the inherent objectivity of the data, the interpretation of bibliometric findings often combines both objective elements, like performance analysis, and subjective components, such as thematic analysis, achieved through well-informed techniques and procedures. Essentially, bibliometric analysis serves as a valuable tool for unraveling and visualizing the collective scientific knowledge and evolutionary intricacies within well-established fields, skillfully extracting meaningful insights from vast amounts of unstructured data. Consequently, well-executed bibliometric studies can establish robust foundations for advancing a field in innovative ways, providing scholars with the ability to (i) obtain a one-stop overview, (ii) identify gaps in knowledge, (iii) generate fresh ideas for investigation, and (iv) strategically position their contributions within the academic landscape (Donthu et al., 2021a). Such an approach can assist in determining the leading research efforts and knowledge gaps by finding the most cited studies, authors, and journals. Further, it helps build a more coherent and up-to-date understanding of ICT-based agricultural EAS, thereby directing future policy initiatives and research directions in this area. Hence, the present study was undertaken to provide answers to the following research questions:

i. What is the nature and evolution of research on ICT-based agricultural EAS?
ii. Who are the prominent authors, journals, and institutions contributing to this field?
iii. Which countries are most actively involved in ICT-based agricultural extension research?
iv. What are the prevailing research trends, and which areas require further investigation in both academic studies and policy frameworks?

2 Methodology

Scholars employ bibliometric analysis for several purposes, such as to identify emerging trends in the performance of articles and journals, patterns of collaboration, and research components and to investigate the intellectual framework of a particular domain within the body of existing literature (Verma and Gustafsson, 2020; Donthu et al., 2020, 2021b). To achieve these objectives in the present study, a detailed flow diagram has been provided in Figure 1, outlining the steps followed. These steps, adapted from Donthu et al. (2021a), are elaborated hereunder to systematically map the research landscape of ICT-based EAS in agriculture.

2.1 Defining the aim and scope of the study

In conducting bibliometric analysis, the initial step involves defining the aims and scope of the study before selecting analysis techniques and gathering data. This is crucial as inappropriate aims and scope can render the analysis futile, wasting resources. Aims typically involve retrospectively evaluating the performance and science of a research field, examining prolific constituents like authors, institutions, countries, and journals. The scope should be sufficiently large to justify bibliometric analysis capable of handling substantial data volumes (Ramos-Rodrígue and Ruíz-Navarro, 2004). Scholars can assess adequacy by reviewing the number of papers in the intended research field; if it reaches considerable numbers (e.g., 500 or more), bibliometric analysis is warranted, whereas smaller fields may benefit more from alternative review methods like meta-analysis or systematic literature reviews. The present study aims toward exploring the research trends in ICT-based agricultural EAS, focusing on evaluating key research contributions and collaboration patterns.

2.2 Choosing the bibliometric analysis technique

In the second step of conducting bibliometric analysis, the focus is on designing the study by selecting appropriate techniques aligned with the aims and scope defined in the initial step. Scholars face the challenge of deciding whether to choose techniques based on the desired bibliometric data or to select techniques first and then prepare the data accordingly. Donthu et al. (2021a) have

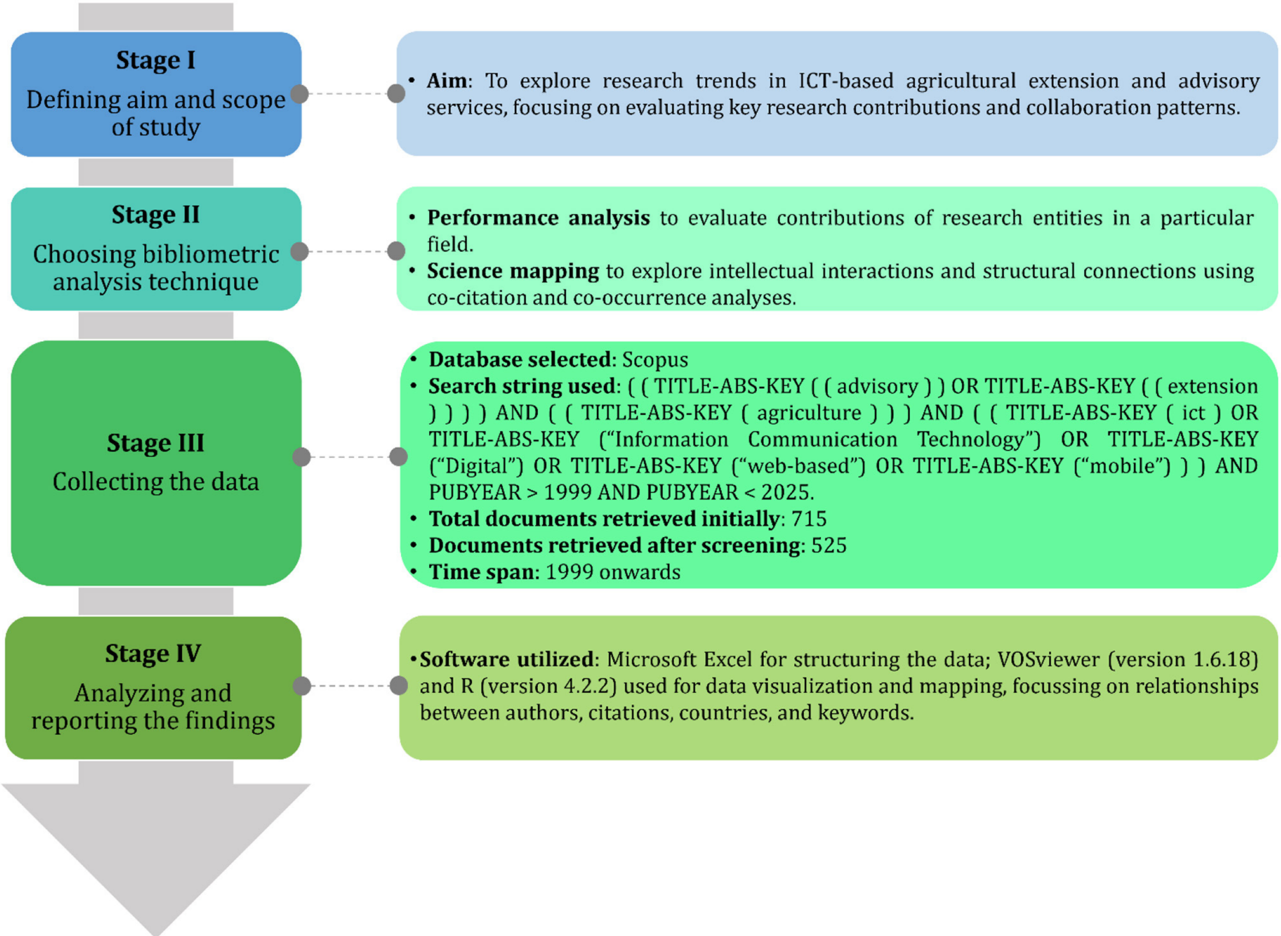

FIGURE 1
Flow diagram of the methodology used in the study.

suggested the latter approach, as it offers scholars a broader array of bibliometric analysis techniques. The choice of techniques should align with the study's objectives; for instance, a study aiming to review the past, present, and future of a research field with a sizeable bibliometric corpus may combine co-citation analysis (past), bibliographic coupling (present), and co-word analysis (future). On the other hand, if the study seeks to uncover themes over specific periods, co-word analysis can be used in conjunction with author keywords to enhance the analysis of co-citation and bibliographic coupling. In line with the analogy of performance analysis in bibliometric studies to the profile of participants in empirical studies, components such as total publications and citations should be selected now and analyzed and reported in a descriptive yet analytical manner later. Bibliometric analysis techniques can be categorized into two main groups: (a) Performance analysis- it focuses on evaluating the contributions of research entities within a specific field (Ramos-Rodrígue and Ruíz-Navarro, 2004; Cobo et al., 2011; Saini et al., 2023). The descriptive nature of the analysis stands as a defining characteristic of bibliometric studies (Donthu et al., 2021c). (b) Science mapping- it investigates the relationships among research entities (Ramos-Rodrígue and Ruíz-Navarro, 2004; Cobo et al., 2011; Baker et al., 2021; Saini et al., 2023). This analysis delves into the intellectual interactions and structural connections existing among these research entities.

2.3 Collecting the data

In the third step, researchers gather the necessary data for the chosen bibliometric analysis techniques outlined in the second step. This involves defining search terms to produce results substantial enough for bibliometric analysis while still maintaining focus within the dedicated research field or the specified scope of study established in the first step. The advent of scientific databases like Scopus and Web of Science has significantly simplified the process of obtaining extensive bibliometric data. In our study, Scopus served as the primary data source for the bibliometric analysis, chosen for its comprehensive and widely recognized status in academia. This database encompasses a diverse range of scholarly literature, including journals, conference proceedings, and various academic publications, making it an ideal choice for ensuring extensive coverage across multiple disciplines. The database's inclusion of bibliographic details, abstracts, citation information, and author affiliations provided valuable resources for bibliometric studies, enhancing the reliability and comprehensiveness of the analysis. The choice of Scopus as the data source contributed to a more holistic understanding of the research landscape, facilitating meaningful insights and interpretations in subsequent phases of the study. The search string employed for the present study, which resulted in an initial set of ∼715 records from the year 1999 onwards, is: ((TITLE-ABS-KEY ((advisory)) OR TITLE-ABS-KEY ((extension)))) AND ((TITLE-ABS-KEY (agriculture))) AND ((TITLE-ABS-KEY (ict) OR TITLE-ABS-KEY ("Information Communication Technology") OR TITLE-ABS-KEY ("Digital") OR TITLE-ABS-KEY ("web-based") OR TITLE-ABS-KEY ("mobile"))) AND PUBYEAR > 1999 AND PUBYEAR < 2025. Subsequently, a thorough screening process was conducted by reviewing the titles and abstracts of these publications, resulting in a careful elimination process, ultimately leading to the retention of 525 publications deemed pertinent to the research criteria. This meticulous approach ensures the inclusion of relevant and high-quality sources in the bibliometric analysis.

2.4 Analyzing and reporting the findings

The availability of user-friendly bibliometric software, including Gephi, Leximancer, and VOSviewer, has made the analysis of data efficient. As a result, there has been a notable surge in scholarly interest in bibliometric analysis in recent times (Donthu et al., 2021a). After performing the search, the dataset retrieved from the database was exported as a comma-separated values (CSV) file for subsequent analysis. Microsoft Excel was used to structure the data. At the same time, visualization and mapping of relationships among authors, publications, citations, countries, and keywords extracted from the documents were carried out using VOSviewer software (version 1.6.18) and R software (version 4.2.2).

In the present study, performance analysis of 525 extracted documents assessed key metrics like the number of publications and citations per year. Publications serve as a proxy for productivity, while citations gauge impact and influence. Other metrics, such as citation per publication and the h-index, integrate both citations and publications to assess the overall performance of research entities (Riaman et al., 2022). Despite the descriptive nature of this performance analysis, it acknowledges the significance of various constituents within a research field. Techniques employed for science mapping encompass citation analysis, co-citation analysis, co-occurrence analysis, etc. When integrated with network analysis, these techniques play a crucial role in illustrating both the bibliometric structure and intellectual framework of the research field (Tunger and Eulerich, 2018; Baker et al., 2020). Citation analysis measures the influence of publications and authors based on citation frequency, while co-citation analysis identifies links between publications frequently cited together (Saini et al., 2023). Co-occurrence analysis reveals closely related concepts based on their co-appearance, forming a thematic network that reflects the conceptual scope of the field (De Looze and Lemarié, 1997; Verma and Gustafsson, 2020). These techniques provide a comprehensive overview of the intellectual landscape surrounding ICT-based agricultural EAS.

3 Results

3.1 Trend in publication

The publications on ICT-based EAS exhibit a gradual increase over time, albeit with fluctuations, as indicated in Figure 2. The dataset commences with just two publications in 2000, followed by a few years of no publications in this domain. However, from 2005 onwards, there was a noticeable rise in the number of publications, starting with 5 in 2005 and reaching a peak of 72 in 2022. This trend suggests a growing interest and emphasis on ICT-based EAS in agriculture, likely propelled by technological advancements and an acknowledgment of ICT's significance in agriculture. Nevertheless, there is a slight decline in 2023, which may be attributed to various factors such as shifting research priorities or external events influencing research output. A substantial drop to only one publication in 2024 is because we have retrieved data from Scopus up to January 2024. Overall, the trend portrays a dynamic and evolving research landscape in ICT-based EAS in agriculture, underscored by sustained interest and contributions from researchers globally.

3.2 Top 10 journals

Journals serve as valuable resources for scholars and researchers to publish their research findings and to validate the publications of other authors by citing them in their work. The top 10 journals based on the number of articles published and citations received are shown in Table 1. Sustainability stands out as a leading journal with the highest number of published articles, contributing 14 publications, 148 citations, and an h-index of 7, demonstrating its considerable influence and impact in the field of ICT-based agricultural EAS. The journal's emphasis on sustainability is in line with the growing recognition of sustainable practices in agriculture, coupled with the incorporation of ICT tools. Meanwhile, Agricultural Economics stands out with 405 citations, making it the most cited journal within this domain. The journal Computers and Electronics in Agriculture has an h-index of 7, indicating its prominence in the field, and ranks highly in terms of citations (279) and articles (9). The journal is a valuable resource for scholars and practitioners interested in ICT-based agricultural extension because of its focus on technological developments in agriculture, especially in the application of computer and electronic technology. The journal Information Development, with 10 articles and 115 citations, demonstrates its relevance and impact in the field of ICT-based agricultural extension. The journal most likely covers topics related to the advancement and application of ICTs in agriculture.

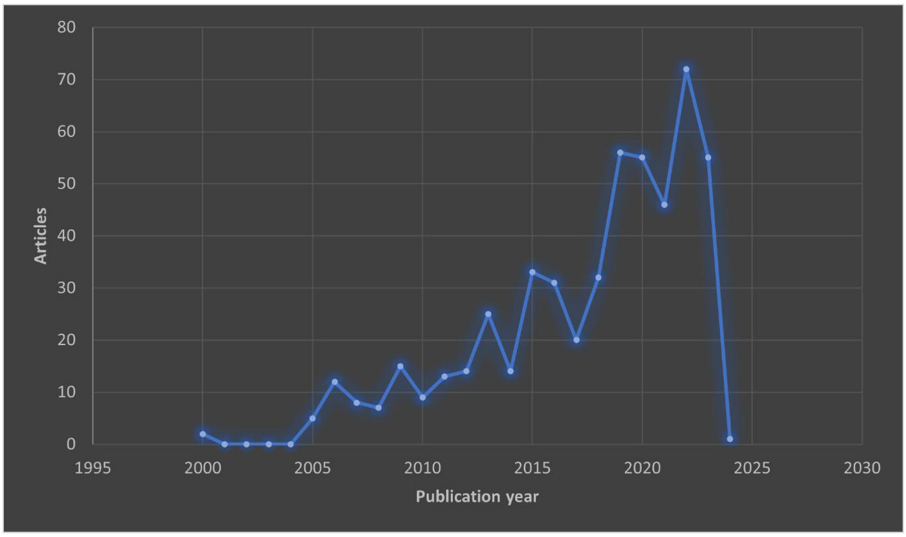

FIGURE 2
The publications on ICT-based EAS over the years.

TABLE 1 Top 10 journals based on number of articles published and based on citations they received.

Based on published articles			Based on citations		
Journals	Published articles	h-index	Journals	Total citations	h-index
Sustainability (Switzerland)	14	7	Agricultural Economics	405	1
Journal of Agricultural Extension	11	3	Computers and Electronics in Agriculture	279	7
Information Development	10	6	Electronic Journal of Information Systems in Developing Countries	199	7
Computers and Electronics in Agriculture	9	7	Agricultural Economics (United Kingdom)	153	1
The Journal of Agricultural Education and Extension	9	6	Sustainability (Switzerland)	148	7
Journal of Extension	9	2	Information Technology for Development	132	7
Electronic Journal of Information Systems in Developing Countries	8	7	Agricultural Systems	130	5
IFIP Advances in Information and Communication Technology	8	2	2007 International Conference on Information and Communication Technologies and Development, ICTD 2007	122	1
Computers in Agriculture and Natural Resources—Proceedings of the 4th World Congress; Information Technology for Development	7	3	Information Development	115	6
Information Technology for Development	7	1	NJAS—Wageningen Journal of Life Sciences; Science	109	2

3.3 Distribution of scientific productivity and literature references

In the context of ICT-based EAS in agriculture, it is vital to grasp the distribution of scientific productivity and literature references (Figure 3). Samuel C. Bradford's Law, formulated in 1934, offers a model for understanding this distribution, emphasizing the key sources that have a substantial influence on research and practical applications in this field. The law implies that the majority of citations will come from a small core of journals, followed by a bigger group of moderately cited journals and a vast number of journals that are rarely cited. Application of Bradford's Law to bibliometric analysis in ICT-based EAS in agriculture has helped to identify the core sources that have had a substantial

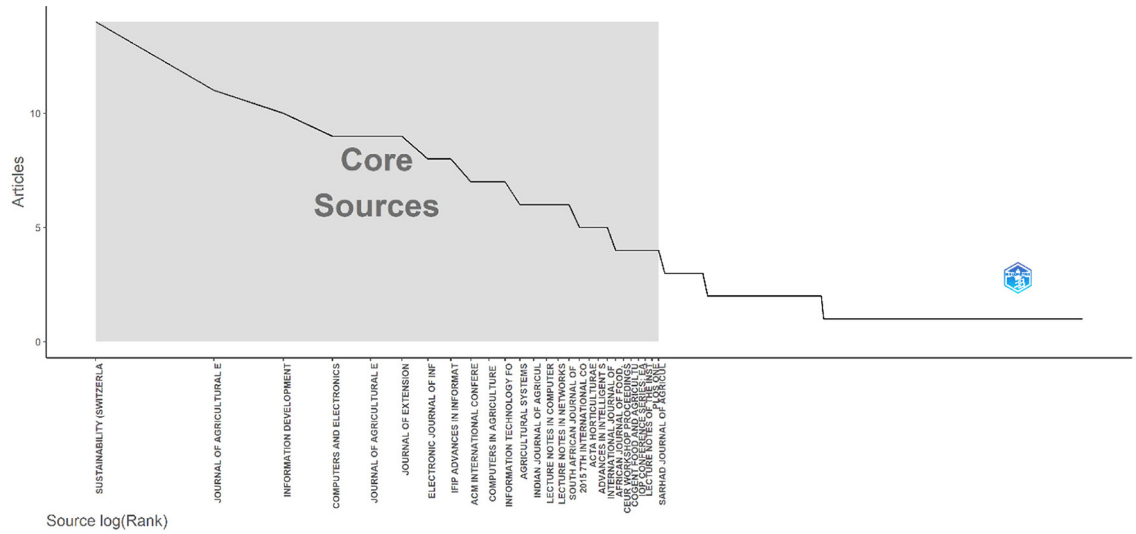

FIGURE 3
Distribution of scientific productivity and literature references according to Bradford's Law.

impact on research and practice in this field. In the realm of ICT-based EAS in agriculture, Sustainability, The Journal of Agricultural Education and Extension, and Information Development are the major sources that are found to be essential.

3.4 Top 10 global cited authors

The high citations and normalized citation count of the top 10 globally cited authors demonstrate their substantial contributions to the literature, as indicated in Table 2. With 405 total citations and a normalized citation score of 10.95, Aker (2011) tops the list, demonstrating the significant influence of his work in the field. He emphasized the role of mobile phone coverage in facilitating technology adoption. He also reported that leveraging ICT-based extension services in developing nations can revolutionize information access, enhance productivity, and drive sustainable agricultural development. Following closely with 153 total citations and an exceptionally high normalized citation score of 12.07, the work of Deichmann et al. (2016) appears to be highly influential in the field, which highlighted the substantial influence of mobile phones and the internet on agriculture, emphasizing their role in enhancing inclusion, efficiency, and innovation, while acknowledging that these digital technologies only partially address the challenges faced by farmers in rural areas of developing countries. Gandhi et al. (2007) and Fraisse et al. (2006) have also made noteworthy contributions, with 122 and 117 total citations, respectively. These authors have made significant contributions to the corpus of knowledge, and their work has been cited by researchers worldwide, as evidenced by their Google Scholar citation counts. Their research has likely influenced the evolution of theory, policy, and practice in these domains, highlighting their significance in the academic community.

3.5 Top 10 most relevant affiliations

The top 10 affiliations that are most pertinent, as determined by the number of articles published in the field of ICT-based agricultural EAS listed in Table 3, offer insightful information about the organizations that are actively engaged in this field of study. With 21 articles, China Agricultural University tops the list, demonstrating its important contribution to the advancement of agricultural extension knowledge. Following closely with 16 and 14 articles, respectively, the Sokoine University of Agriculture and Universiti Putra Malaysia demonstrate their substantial presence in this field. The University of Guelph and the International Maize and Wheat Improvement Center (CIMMYT) are also prominent contributors, with 14 and 13 articles, respectively. These organizations play a crucial role in shaping the discourse around agricultural EAS, contributing valuable research and insights. The University of Florida, Michigan State University, Cornell University, King Saud University, and the University of Hohenheim round out the top 10 list, each with 13–11 articles. These organizations highlight the global nature of research in agricultural EAS by representing a diverse range of geographic locations and academic strengths. Thus, the top 10 most relevant affiliations show the depth and scope of research being carried out in ICT-based agricultural EAS. These organizations are leading the way in innovation and advancing the field, which eventually helps farmers and agricultural communities worldwide.

3.6 Top 10 countries in terms of total scientific publications

The analysis of the top 10 countries in terms of total scientific publications (Figure 4) related to ICT-based EAS in agriculture provides valuable insights into the global landscape of research

TABLE 2 Top 10 globally cited authors with total and normalized citations.

Sl. No.	Authors	Journals	Total citations	Normalized citations	Citations from Google Scholar
1	Aker (2011)	Agricultural Economics	405	10.95	1,374
2	Deichmann et al. (2016)	Agricultural Economics	153	12.07	534
3	Gandhi et al. (2007)	International Conference on Information and Communication Technologies and Development, ICTD 2007	122	5.64	399
4	Fraisse et al. (2006)	Computers and Electronics in Agriculture	117	9.18	253
5	Fabregas et al. (2019)	Science	109	7.86	287
6	Norton and Alwang (2020)	Applied Economic Perspectives and Policy	99	10.72	227
7	Mittal and Mehar (2012)	Quarterly Journal of International Agriculture	69	5.78	229
8	Aldosari et al. (2019)	Journal of the Saudi Society of Agricultural Sciences	64	4.61	168
9	Minet et al. (2017)	Computers and Electronics in Agriculture	62	8.16	117
10	Ayre et al. (2019)	NJAS—Wageningen Journal of Life Sciences	62	4.47	110

TABLE 3 Top 10 most relevant affiliations determined by the number of articles published in the field of agricultural EAS.

Sl. No.	Organization	Articles
1	China Agricultural University	21
2	Sokoine University of Agriculture	16
3	Universiti Putra Malaysia	14
4	University of Guelph	14
5	International Maize and Wheat Improvement Center (CIMMYT)	13
6	University of Florida	13
7	Michigan State University	12
8	Cornell University	11
9	King Saud University	11
10	University of Hohenheim	11

TABLE 4 Top 10 most cited countries in the area of ICT-based agricultural EAS.

Sl. No.	Country	Total citations	Average article citations
1	USA	1,101	31.50
2	India	477	8.10
3	China	223	8.60
4	Australia	173	10.80
5	Germany	171	12.20
6	Tanzania	138	13.80
7	Belgium	102	20.40
8	Saudi Arabia	87	29.00
9	United Kingdom	84	9.30
10	South Africa	81	6.20

in this field. India emerges as the leader with 446 publications, reflecting the country's significant efforts and investments in leveraging ICT for agricultural extension. The United States follows with 251 publications, showcasing its advanced research infrastructure and focus on innovation in agricultural technology. China ranks third with 119 publications, which underscores its growing role in adopting ICT for agricultural development. Australia, Kenya, Tanzania, Germany, Indonesia, Nigeria, and South Africa also feature prominently with 84, 80, 59, 57, 56, 55, and 50 publications, respectively, highlighting the diverse global contributions to the amalgamation of ICT and agricultural extension. These figures indicate a global recognition of the importance of ICT in enhancing agricultural productivity and sustainability, emphasizing the need for continued research and collaboration in this area to address the challenges faced by farmers worldwide.

3.7 Top 10 most cited countries

The top 10 most cited countries in the area of ICT-based agricultural EAS offer insightful information about the global impact of research in this area, as shown in Table 4. The USA tops the list with 1,101 total citations and an average article citation of 31.50, demonstrating the significant impact and influence of its research output. India and China come next with 477 and 223 total citations, respectively, reflecting their noteworthy contributions to the area. Other major contributors include Australia, Germany, and Tanzania, with 173, 171, and 138 total citations, respectively. With total citations ranging from 81 to 102, Belgium, Saudi Arabia, the United Kingdom, and South Africa complete the top 10. The intellectual prowess and geographical diversity of these countries highlight the global reach of research in the field of ICT-based agricultural EAS.

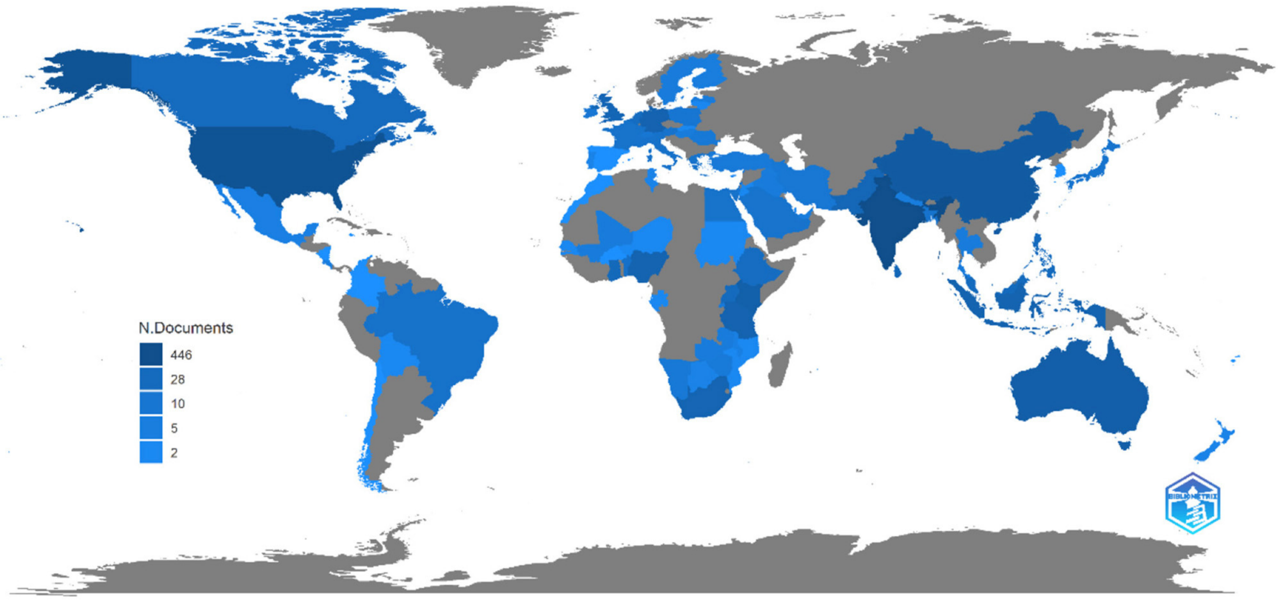

FIGURE 4
Country-wise scientific production indicating the number of documents produced related to ICT-based EAS in agriculture.

3.8 Co-occurrence analysis of all keywords

Co-occurrence analysis is a potent method that is utilized in bibliometric investigations to identify patterns of relationships between keywords in scientific literature. We deployed VOSviewer in this study with specific configurations, such as author keywords, fractional counting, a minimum of three occurrences per keyword, and weights by occurrence, resulting in the identification of a total of 94 items, categorized into 13 clusters based on their keyword co-occurrence patterns (Figure 5). Each of the 13 clusters is a unique thematic grouping of keywords that frequently show up together in the literature on ICT-based agricultural EAS. Most likely, each cluster reflects a specific sub-topic or facet of the broader field. Table 5 gives the list of items under each thematic cluster, wherein the number of items within each cluster indicates its size, providing information on the relative importance or prevalence of the corresponding thematic area in the literature. Smaller clusters reflect emerging or niche areas of research, whereas larger clusters indicate well-established or extensively researched topics.

3.9 Co-citation analysis of journals

Co-citation analysis of journals is a valuable technique in bibliometric analysis, providing insights into the interconnections and influence of academic publications within a particular field. This analysis helps pinpoint influential journals that significantly impact scholarly discourse. It involves evaluating the citation patterns of journals, particularly how frequently they are cited together in other's works. VOSviewer was used to carry out the co-citation analysis, with specific settings, like cited sources, and a minimum of five citations for inclusion, resulting in 19 journals meeting the threshold. The result of a network among them is shown in Figure 6.

The outcome of the co-citation analysis reveals that The Journal of Agricultural Education and Extension stands out as the most referenced journal, with 22 citations and a total link strength of 266, indicating its strong influence and frequent citation alongside other journals. Additionally, Agricultural Economics, Information Technology for Development, and World Development are noteworthy, with total link strength of 216, 158, and 155, respectively. These figures indicate their significance in the scholarly discussions regarding ICT-based EAS in agriculture, suggesting that they are pivotal in disseminating and advancing knowledge in this domain.

4 Discussion

The analysis of publications on ICT-based EAS reveals a gradual increase over time, with a notable rise starting in 2005 and peaking at 72 publications in 2022. The peak in 2022 indicates a particularly heightened interest or advancement in this field. As technology continues to advance, researchers and practitioners might have been focusing on developing and implementing innovative solutions in this domain, leading to a surge in publications. A few decades ago, television and radio were primary tools for disseminating agricultural technologies. However, the landscape has evolved, and in contemporary times, the internet and mobile-based smart ICTs, including social media, digital photography, video platforms, and digital information repositories, are extensively utilized to disseminate agriculture-related information and technologies to rural communities (Balaji et al., 2007). Research indicates that modern ICT tools like mobile phones enable farmers to access timely information

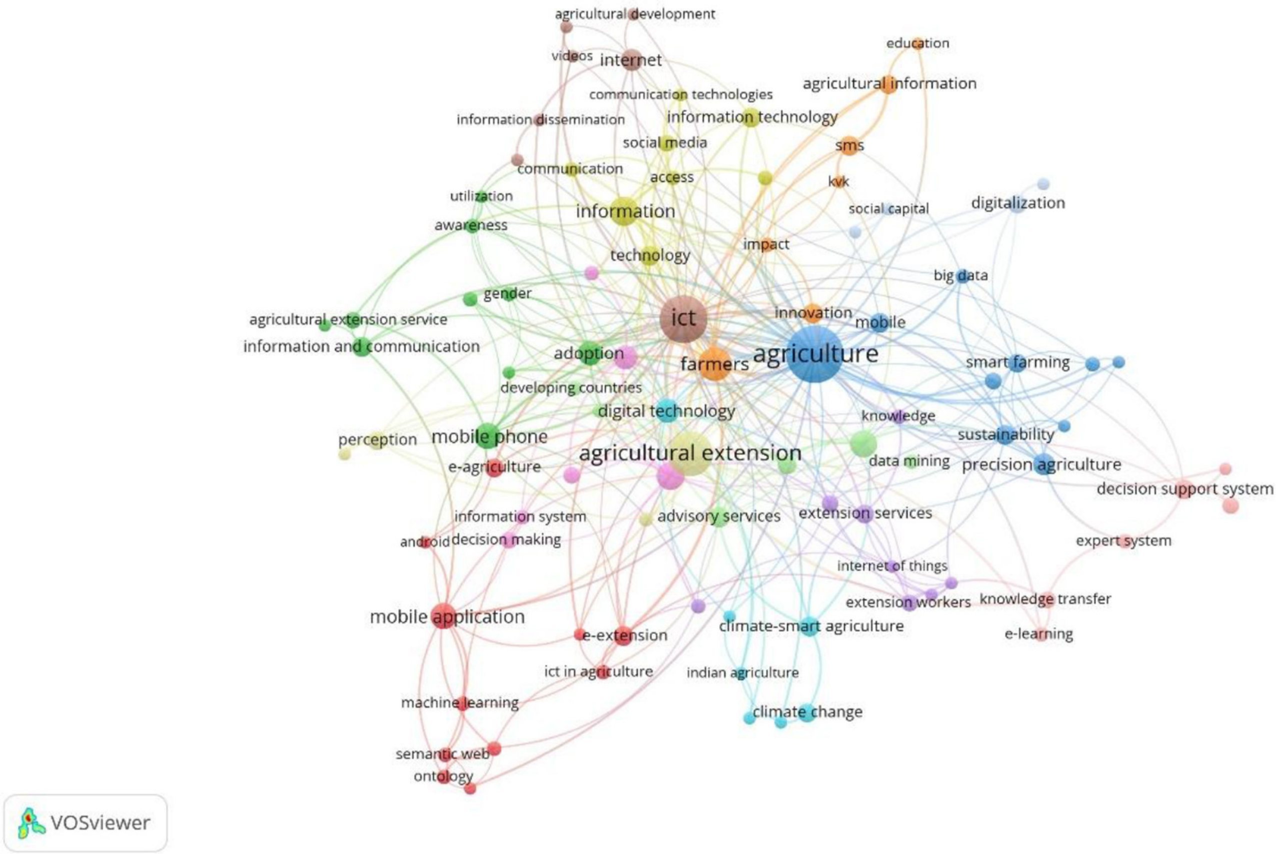

FIGURE 5
Co-occurrence analysis network map showing unique clusters of thematic grouping of keywords that frequently showed up together in the literature [each node indicates a word, each line indicates link between words; thickness indicates their co-occurrence; color of the cluster reflects themes, encompassing topics (words) and their relationships (links) within thematic clusters].

on agricultural technologies, increasing farm income through optimized resource utilization (Ogutu et al., 2014; Emeana et al., 2020). Globally, mobile phone-based initiatives have been successful in disseminating agricultural information, empowering farmers to make informed decisions (Ali and Kumar, 2011; Larochelle et al., 2019). In India, mobile-based advisory services have helped farmers manage crop pests and diseases effectively (Tadesse and Bahiigwa, 2015). Similarly, in Kenya, advisory services through voice and text messages have connected farmers with local markets and traders, leading to improved profitability (Ogutu et al., 2014). In Ethiopia, mobile services have empowered farmers to negotiate better prices with commission agents and traders, reducing transportation costs and facilitating easier marketing of farm products (Tadesse and Bahiigwa, 2015). Furthermore, the use of mobile phones among farmers has led to reduced transportation costs and facilitated easier marketing of farm products (Khan et al., 2019). Aker (2008) discovered that cell phones decreased the disparity in grain prices across markets by at least 6.4% and lessened the intra-annual price fluctuation by 12%. Casaburi et al. (2014) discovered that delivering agricultural guidance to smallholder farmers through SMS messages led to an 11.5% rise in yields compared to a control group that did not receive messages.

Apart from mobile phones, ICT-based tools in agriculture encompass various technologies including web portals, telecentres, and hybrid projects combining ICT with traditional extension services (Shantichandra et al., 2013). The utilization of social media in agricultural marketing is growing rapidly, with many service providers offering enhanced facilities to farmers, such as BSNL's Mahakrishi plan. These ICT tools are relatively user-friendly and are increasingly popular in the agricultural sector (Bhattacharjee and Raj, 2016). Thus, ICT is a powerful tool for overcoming information asymmetry among farmers, which is a significant obstacle to agricultural development (George et al., 2011). By effectively utilizing ICT, farmers can expand their business opportunities and improve their livelihoods.

Aker (2011) tops the list of globally cited authors with 405 total citations, emphasizing the transformative potential of ICT-based extension services in agriculture. Similar findings have been reported by Mansingh et al. (2020). ICT-based extension services play a crucial role in bridging the digital divide, enabling equitable access to information that enhances agricultural productivity and sustainability (World Bank Group, 2016). Studies by Mwalupaso et al. (2019) and Larochelle et al. (2019) highlight ICT's importance in improving farmers' efficiency by providing

TABLE 5 List of items under each thematic cluster.

Clusters	Items	Clusters	Items
Cluster 1	Android e-agriculture e-extension ICT in agriculture Machine learning Mobile application Ontology Semantic web Service-oriented architecture Technology acceptance model Web service	Cluster 2	Adoption Advisory Agricultural extension services Awareness Gender ICT tools ICT4d Information and communication technologies Mobile phone Utilization
Cluster 3	Agriculture Big data Crowdsourcing Decision support tool IoT Knowledge management Mobile Precision agriculture Smart farming Sustainability	Cluster 4	Access Climate change adaptation Communication Communication technologies Information Information technology Social media Technology
Cluster 5	Cloud computing Extension services Extension workers Innovation diffusion Internet of things Irrigation Knowledge Smart agriculture	Cluster 6	Climate change Climate-smart agriculture Cyber extension Digital technology Extension education Indian agriculture Livelihood
Cluster 7	Agricultural information Education Farmers Impact Innovation Kvk Sms	Cluster 8	Agricultural development Farmer learning videos ICT Information dissemination Internet Perceptions Videos
Cluster 9	Adaptation Decision-making Development Food security Information system Smallholder farmers	Cluster 10	Decision support system E-learning Expert system Farming Knowledge transfer Wireless sensor network
Cluster 11	Advisory services Data mining Developing countries Digital agriculture Smallholder agriculture Sustainable agriculture	Cluster 12	Agricultural productivity Digitalization Social capital Sustainable development
Cluster 13	Agricultural extension Extension methods Perception Technology adoption		

up-to-date agricultural knowledge, leading to increased crop productivity and rural economic development.

Among organizations, China Agricultural University leads with 21 articles, indicating its active engagement in this field. India's significant efforts are evident, with a total of 446 publications, making it the leader in this research domain. These findings are consistent with those of Mansingh et al. (2020). Prominent Indian organizations contributing to this field include Odisha University of Agriculture & Technology (Bhubaneshwar); Indian Institute of Technology (Bombay); Pusa (New Delhi) and ICAR-National Institute of Agricultural Economics and Policy Research (New Delhi). However, for Indian organizations to ascend the global productivity rankings, more targeted efforts and collaborations are essential. They must focus on enhancing research quantity and quality, fostering interdisciplinary collaborations, and leveraging emerging technologies to address agricultural challenges effectively. Such strategic initiatives can propel Indian organizations toward greater prominence in the global research landscape. The USA tops the list of most cited countries, with 1,101 total citations, showcasing the impact of its research output. The results are consistent with the findings of Mansingh et al. (2020).

Co-occurrence analysis of keywords reveals key thematic areas, covering a wide range of topics including sustainable agricultural practices, innovation diffusion, knowledge management, technology adoption, etc., highlighting the multidimensional nature of ICT-based EAS in agriculture. A perusal of the list of items under each thematic cluster (Table 5) indicates that Cluster 1 focuses on integrating technology for enhanced e-extension services, emphasizing the importance of ICT in modernizing agricultural extension. Recognizing the significance of ICTs in driving socio-economic growth in rural areas, the World Bank emphasizes the need for supportive policies and infrastructure to leverage this potential fully (George et al., 2011). Furthermore, several extension interventions integrate ICT channels, such as mobile phone services, with traditional communication channels, like radio (USAID, 2010). Combining traditional media with new ICTs can broaden the outreach of extension services, but achieving a high adoption rate necessitates farmer engagement in determining relevance, creating content, and having the opportunity to interact with information/service providers (Francis and Addom, 2014). Cluster 2 highlights the significance of gender-aware ICT utilization in enhancing agricultural advisory services, emphasizing inclusivity. ICT-based solutions are particularly beneficial for delivering extension services to economically disadvantaged rural farmers, especially women (Manfre and Nordehn, 2013). Cluster 3 underscores the use of big data and IoT for sustainable smart farming, showcasing the role of technology in precision agriculture. Cluster 4 places a strong emphasis on accessing ICTs, like social media, for climate change adaptation, highlighting ICT's role in resilience-building. Social media, originally used for entertainment, now holds significant potential for knowledge sharing and collaboration in agriculture (Goyal, 2012). Cluster 5 emphasizes the use of cloud computing and IoT in smart agriculture, illustrating the potential of these technologies in improving agricultural practices. Cluster 6 draws attention to the convergence of digital technology, climate-smart

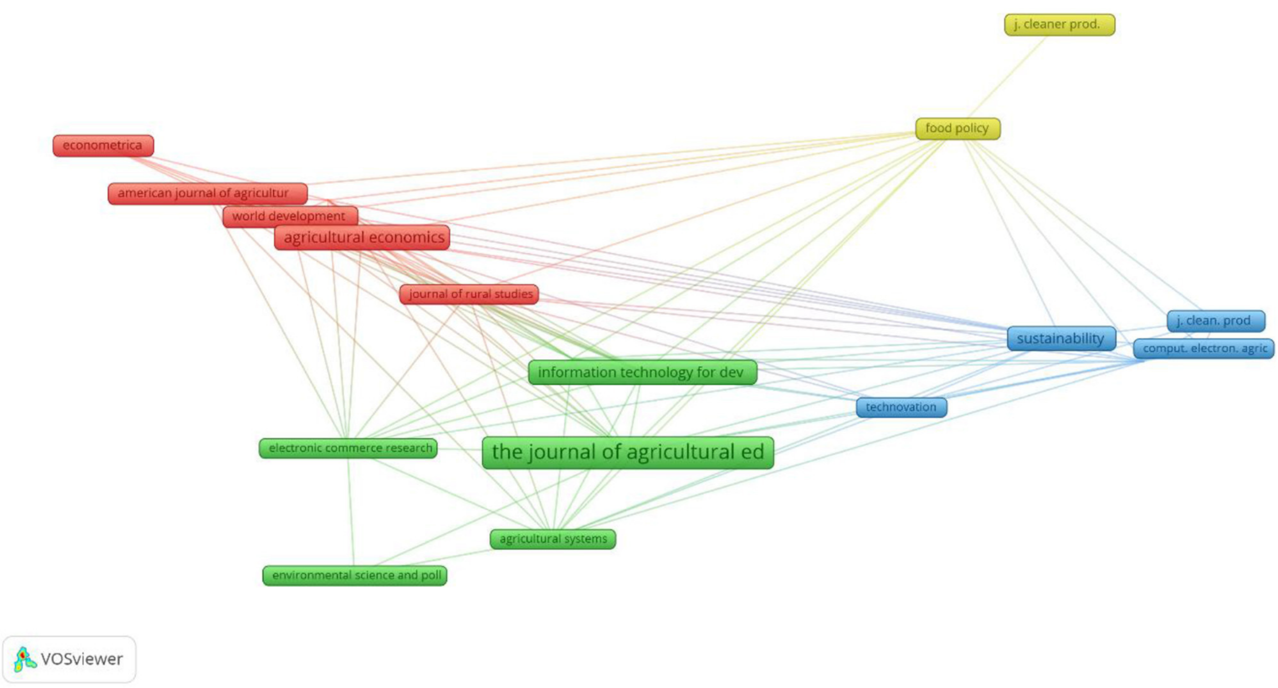

FIGURE 6
Co-citation analysis of journals showing the interconnections and influence of academic publications within the field (Each node represents a journal; each line indicates the link between the journals co-cited; thickness of the line indicates the strength of co-occurrence of journals in research publications; while the color reflects the thematic clusters of co-occurrences).

agriculture, and extension education, with a focus on Indian agriculture and livelihoods. Cluster 7 highlights the value of educating and informing farmers about agriculture, as well as the impacts of technologies like SMS and farmer education initiatives. Despite the potential benefits offered by ICT-based EAS, challenges such as low farmer awareness and the lack of timely advisories hinder effective utilization as reported in the case of m-Kisan (Saikanth et al., 2022). To address these challenges, Saikanth et al. (2022) suggested integrating more services within the SMS Portal, tailoring advisories to farmers' specific needs, and implementing voice recognition-based messaging to enhance user engagement. Therefore, leveraging mobile telephony and digital platforms like m-Kisan and Kisan Sarathi can optimize agricultural extension services, closing information gaps and empowering farmers with personalized advice to enhance agricultural practices and productivity in India. Cluster 8 emphasizes the use of ICTs for agricultural development and learning, highlighting their role in capacity building. Empowering smallholder farmers with information for adaptive decision-making, and showcasing the transformative power of information access are the main focus of cluster 9. Cluster 10 highlights enhancing farming decisions through expert systems and e-learning, illustrating the potential of ICT in improving agricultural productivity. Saikanth et al. (2022) research on the m-Kisan portal's usage in Nagarkurnool district underscores the crucial role of ICTs in providing farmers with essential agricultural information for informed decision-making. Cluster 11 focuses on digital advisory services, highlighting ICT's role in promoting sustainable practices in developing nations. Cluster 12 focuses on the significance of social capital and digitalization in agricultural productivity and sustainable development. In 2011, Aleke et al. conducted a study on the uptake of ICT innovations, such as internet access, computers, and online portals, by small agribusinesses in indigenous communities in Nigeria (Aleke et al., 2011). They found that social considerations play a significant role in adoption within these communities. Therefore, it is crucial to strike a balance between designing effective ICT solutions and addressing social factors such as language and traditional lifestyles to encourage greater acceptance of ICT innovations. Finally, Cluster 13 emphasizes improving technology adoption through innovative agricultural extension methods, showcasing the role of ICT in facilitating technology uptake in agriculture. Gandhi et al. (2009) highlighted that the Digital Green project demonstrated a seven-fold increase in the adoption of specific agricultural practices compared to classical extension methods. The project was also found to be ten times more cost-effective, with an 85 per cent adoption rate of improved technologies, in contrast to the 11 per cent adoption rate associated with traditional extension approaches.

The result of co-citation analysis offers valuable insights into the network of journals within the realm of ICT-based EAS in agriculture. Identifying the most influential journals allows researchers to gain a better understanding of the scholarly landscape and make informed decisions regarding where to publish their work and which journals to refer to for the latest research in this field.

5 Conclusion

This bibliometric analysis offers critical insights into the research landscape of ICT-based agricultural EAS, shedding light on both theoretical and practical implications. The study reveals key trends, influential authors, top journals, and leading countries in this domain, emphasizing the transformative role of emerging technologies such as big data, IoT, and cloud computing in enhancing agricultural productivity and sustainability. Additionally, it underscores the importance of gender-sensitive ICT-based extension services and the role of social media in resilience-building for rural communities. The findings suggest that policymakers should prioritize building robust ICT infrastructure, designing user-centric solutions tailored to farmers' needs, and investing in capacity-building initiatives to improve ICT literacy among rural communities. Given the dominance of Indian research output, policymakers should consider fostering greater international collaborations to enhance the global impact of Indian ICT-based agricultural research. Such collaborations could lead to the exchange of innovative ideas, access to advanced technologies, and wider dissemination of research findings on a global scale. Furthermore, targeted initiatives to promote interdisciplinary research and public-private partnerships could play a significant role in addressing challenges faced by the agricultural sector. The practical contribution of this study lies in its potential to inform evidence-based policies that can enhance ICT integration and agricultural development. Such policies would facilitate the widespread adoption of ICT in agricultural extension services, improving the livelihoods of farmers and rural communities.

In terms of limitations, this study is restricted by its reliance solely on Scopus as the data source. Expanding the scope to include other platforms such as Web of Science or Google Scholar would have allowed for a more comprehensive generalization of the results. Additionally, certain emerging research areas may have been underrepresented due to this limitation. Another significant limitation pertains to the inherent biases in bibliometric analysis. Citation patterns can often reflect factors unrelated to research quality, such as language biases, regional preferences, or self-citation practices, which may have influenced the results. Future research should focus on further exploring the integration of ICT in various agricultural systems, especially in diverse geographical contexts. Themes such as the impact of ICT on smallholder farmers, ICT's role in climate resilience, and the development of more inclusive, gender-sensitive technologies should be prioritized. Exploring these areas will help guide the creation of robust ICT-based extension frameworks that meet the evolving needs of agriculture in the digital age. Overall, this research serves as a valuable resource for advancing ICT-based agricultural EAS by identifying trends, gaps, and future research directions, aiding researchers, policymakers, and practitioners in fostering innovation and policy development in the sector.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

SM: Conceptualization, Data curation, Methodology, Software, Writing – original draft, Writing – review & editing, Formal analysis. RP: Conceptualization, Supervision, Writing – review & editing. RB: Conceptualization, Supervision, Writing – review & editing. PV: Conceptualization, Data curation, Formal analysis, Methodology, Software, Writing – review & editing. GM: Formal analysis, Software, Writing – review & editing. KA: Formal analysis, Software, Writing – review & editing. SSah: Formal analysis, Software, Writing – review & editing. SSai: Formal analysis, Software, Writing – original draft, Writing – review & editing. SM: Formal analysis, Software, Writing – review & editing. SQ: Writing – original draft, Writing – review & editing. KS: Data curation, Writing – original draft, Writing – review & editing. BG: Writing – original draft, Writing – review & editing. AB: Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Aker, J. C. (2008). "Does digital divide or provide? The impact of cell phones on grain markets in Niger," in *Center for Global Development working paper* (Washington, DC), 154.

Aker, J. C. (2011). Dial "A" for agriculture: a review of information and communication technologies for agricultural extension in developing countries. *Agric. Econ.* 42, 631–647. doi: 10.1111/j.1574-0862.2011.00545.x

Aldosari, F., Al Shunaifi, M. S., Ullah, M. A., Muddassir, M., and Noor, M. A. (2019). Farmers' perceptions regarding the use of information and communication technology (ICT) in Khyber Pakhtunkhwa, Northern Pakistan. *J. Saudi Soc. Agric. Sci.* 18, 211–217. doi: 10.1016/j.jssas.2017.05.004

Aleke, B., Ojiako, U., and Wainwright, D. W. (2011). ICT adoption in developing countries: perspectives from small-scale agribusinesses. *J. Enterp. Inf. Manag.* 24, 68–84. doi: 10.1108/17410391111097438

Ali, J., and Kumar, S. (2011). Information and communication technologies (ICTs) and farmers' decision-making across the agricultural supply chain. *Int. J. Inf. Manag.* 31, 149–159. doi: 10.1016/j.ijinfomgt.2010.07.008

Aregu, R., Bagaya, P., and Nerbonne, J. (2008). "An ICT-based digital content information access framework in developing countries: the case of agricultural informatics access and management in Uganda," in *Proceedings of IST-Africa Conference and Exhibition* (Windhoek), 07–09.

Ayre, M., Mc Collum, V., Waters, W., Samson, P., Curro, A., Nettle, R., et al. (2019). Supporting and practising digital innovation with advisers in smart farming. *NJAS - Wagening. J. Life Sci.* 90:100302. doi: 10.1016/j.njas.2019.05.001

Baker, H. K., Kumar, S., and Pandey, N. (2021). Forty years of the Journal of Futures Markets: a bibliometric overview. *J. Futures Mark.* 41, 1027–1054. doi: 10.1002/fut.22211

Baker, H. K., Pandey, N., Kumar, S., and Haldar, A. (2020). A bibliometric analysis of board diversity: current status, development, and future research directions. *J. Bus. Res.* 108, 232–246. doi: 10.1016/j.jbusres.2019.11.025

Balaji, V., Meera, N., and Dixit, S. (2007). ICT-enabled knowledge sharing in support of extension: addressing the agrarian challenges of the developing world threatened by climate change, with a case study from India. *J. SAT Agric. Res.* 4, 1–18. Available at: http://oar.icrisat.org/id/eprint/2604

Barber, J., Mangnus, E., and Bitzer, V. (2016). "Harnessing ICT for agricultural extension," in *KIT Working Paper 2016* (Amsterdam), 4.

Bell, M. (2015). *ICT- Powering Behaviour Change for a Brighter Agricultural Future*. MEAS Discussion Paper. Davis, CA: University of California, Davis.

Bhattacharjee, S., and Raj, S. (2016). "Social media: Shaping the future of agricultural extension and advisory services," in *GFRAS interest group on ICT4RAS discussion paper* (Lindau: GFRAS), 9.

Casaburi, L., Kremer, M., Mullainathan, S., and Ramrattan, R. (2014). *Harnessing ICT to* increase agricultural production: Evidence from *Kenya*.

Cecchini, S., and Raina, M. (2002). *Warana: The Case of an Indian Rural Community Adopting ICT*.

Chahal, S. S., Sidhu, M. S., and Kaur, P. (2012). Impact assessment of reuters market light (RML) in agricultural information dissemination in Punjab. *Agric. Econ. Res. Rev.* 25, 373–378. doi: 10.22004/ag.econ.136756

Chemeltorit, P., Saavedra, Y., and Gema, J. (2018). *Food Traceability in the Domestic Horticulture Sector in Kenya: An overview. 3R Research Report 003.* 3R Kenya Project. Centre for Development Innovation, Wageningen UR.

Cobo, M. J. L'opez-Herrera, A. G., Herrera-Viedma, E., Herrera, F. (2011). An approach for detecting, quantifying, and visualizing the evolution of a research field: a practical application to the Fuzzy Sets Theory field. *J. Informetr.* 5, 146–166. doi: 10.1016/j.joi.2010.10.002

Das, S. (2016). *Enhancing the Role of ICT in Disseminating Agricultural Information to Farmers in Bangladesh* (Ph.D. thesis). Bangladesh: University of Dhaka.

De Looze, M. A., and Lemarié, J. (1997). Corpus relevance through co-word analysis: an application to plant proteints. *Scientometrics* 39, 267–280. doi: 10.1007/BF02458530

De Silva, H., and Ratnadiwakara, D. (2010). Using ICT to *Reduce Transaction Costs* in *Agriculture* through *Better Communication*: A *Case Study* from Sri Lanka. Colombo: LIRNEasia .

Deichmann, U., Goyal, A., and Mishra, D. (2016). Will digital technologies transform agriculture in developing countries? *Agric. Econ.* 47, 21–33. doi: 10.1111/agec.12300

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., and Lim, W. M. (2021a). How to conduct a bibliometric analysis: an overview and guidelines. *J. Bus. Res.* 133, 285–296. doi: 10.1016/j.jbusres.2021.04.070

Donthu, N., Kumar, S., and Pandey, N. (2020). A retrospective evaluation of Marketing Intelligence and Planning: 1983–2019. *Mark. Intell. Plan.* 39, 48–73. doi: 10.1108/MIP-02-2020-0066

Donthu, N., Kumar, S., Pandey, N., and Lim, W. M. (2021b). Research constituents, intellectual structure, and collaboration patterns in Journal of International Marketing: an analytical retrospective. *J. Int. Mark.* 29, 1–25. doi: 10.1177/1069031X211004234

Donthu, N., Reinartz, W., Kumar, S., and Pattnaik, D. (2021c). A retrospective review of the first 35 years of the International Journal of Research in Marketing. *Int. J. Res. Mark.* 38, 232–269. doi: 10.1016/j.ijresmar.2020.10.006

Emeana, E. M., Trenchard, L., and Dehnen-Schmutz, K. (2020). The revolution of mobile phone-enabled services for agricultural development (m-Agri services) in Africa: the challenges for sustainability. *Sustainability* 12:485. doi: 10.3390/su12020485

Fabregas, R., Kremer, M., and Schilbach, F. (2019). Realizing the potential of digital development: the case of agricultural advice. *Science* 366:eaay3038. doi: 10.1126/science.aay3038

FAO (2015). *Success stories on information and communication technologies for rural development. RAP Publication 2015/02.* Bangkok: FAO Regional Office for Asia and the Pacific.

FAO/WB (2000). *Agricultural Knowledge and Information System for Rural Development (AKIS/ RD): Strategic Vision and Guiding Principles*. Rome: Food and Agriculture Organization of the United Nations and the AKIS Thematic Group of the World Bank.

Feder, G., Willett, A., and Zijp, W. (2013). Agricultural Extension: Generic Challenges and Some Ingredients for Solutions. *Policy Research Working Papers*. Washington, DC: World Bank Group.

Fraisse, C. W., Breuer, N. E., Zierden, D., Bellow, J. G., Paz, J., Cabrera, V. E., et al. (2006). AgClimate: a climate forecast information system for agricultural risk management in the southeastern USA. *Comput. Electron. Agric.* 53, 13–27. doi: 10.1016/j.compag.2006.03.002

Francis, J., and Addom, B. J. (2014). Modern ICTs and rural extension: have we reached the tipping point? *Rural* 21, 22—24.

Gandhi, R., Veeraraghavan, R., Toyama, K., and Ramprasad, V. (2007). "Digital green: participatory video for agricultural extension," in *2007 International conference on information and communication technologies and development* (Bangalore: IEEE), 1–10. doi: 10.1109/ICTD.2007.4937388

Gandhi, R., Veeraraghavan, R., Toyama, K., and Ramprasad, V. (2009). Digital green: participatory video and mediated instruction for agricultural extension. *Inf. Technol. Int. Dev.* 5, 1—15.

George, T., Bagazonzya, H., Ballantyne, P., Belden, C., Birner, R., Del Castello, R., et al. (2011). *ICT in Agriculture: Connecting Smallholders to Knowledge, Networks, and Institutions*. (No. 64605). Washington, DC: World Bank, 1–428.

Glendenning, C. J., and Ficarelli, P. P. (2012). *The Relevance of Content in ICT Initiatives in Indian Agriculture*. Washington, DC: International Food Policy Research Institute, 1–40.

Goyal, S. (2012). "Social networks on the Web," in *The Oxford Handbook of the Digital Economy*, eds. M. Peitz, and J. Waldfogel (Oxford: Oxford University Press), 434–459. doi: 10.1093/oxfordhb/9780195397840.013.0016

Hall, A., Clark, N., Sulaiman, V. R., Sivamohan, M. V. S., and Yoganand, B. (2000). "Coping with new policy agendas for agricultural research: The role of institutional innovations," in *National Centre for Agricultural Economics and Policy Research (NCAP) Policy Brief No. 13.* (New Delhi: Indian Council of Agricultural Research).

Khan, N. A., Qijie, G., Ali, S., Shahbaz, B., and Shah, A. A. (2019). Farmers' use of mobile phone for accessing agricultural information in Pakistan: a case of Punjab province. *Cienc. Rural* 49. doi: 10.1590/0103-8478cr20181016

Kumawat, S. R., Nagal, G., Puniya, M. M., and Ola, B. C. (2020). Impact of mobile phone based extension services in crop management by farmers of jodhpur district of Rajasthan. *J. Progress. Agric.* 11, 24–30.

Larochelle, C., Alwang, J., Travis, E., Barrera, V. H., and Dominguez Andrade, J. M. (2019). Did you really get the message? Using text reminders to stimulate adoption of agricultural technologies. *J. Dev. Stud.* 55, 548–564. doi: 10.1080/00220388.2017.1393522

Maja, M. M., and Ayano, S. F. (2021). The impact of population growth on natural resources and farmers' capacity to adapt to climate change in low-income countries. *Earth Syst. Environ.* 5, 271–283. doi: 10.1007/s41748-021-00209-6

Manfre, C., and Nordehn, C. (2013). Exploring the promise of information and communication technologies for women farmers in Kenya. *MEAS Case Study* 4:c2013.

Mansingh, J. P., Makarla, R., Nisha, A., Anbarasan, P., and Endris, E. A. (2020). Bibliometric analysis of information communication technology research in agricultural extension. *PalArch's J. Archaeol. Egypt/Egyptol.* 17, 4070–4085.

Masiero, S. (2012). Reframing empowerment: a new paradigm for ICT4D. *iSCHANNEL* 6, 6–13.

Mathur, D., Gupta, P., and Sridevi, A. (2009). "e-Governance approach in India- The National e-Governance Plan (NeGP)," in *Transforming Government: e-Government Initiatives in India*, eds. R. K. Bagga, and P. Gupta (Hyderabad: The ICFAI University Press), 3–50.

McNamara, K., Belden, C., Kelly, T., Pehu, E., and Donavan, K. (2011). "Introduction: ICT in agricultural development," in *ICT in Agriculture Connecting Smallholders to Knowledge, Networks, and Institutions (e-book)*, eds. The World Bank (Washington, DC: World Bank), 3–14.

Minet, J., Curnel, Y., Gobin, A., Goffart, J. P., Mélard, F., Tychon, B., et al. (2017). Crowdsourcing for agricultural applications: a review of uses and opportunities for a farmsourcing approach. *Comput. Electron. Agric.* 142, 126–138. doi: 10.1016/j.compag.2017.08.026

Mittal, S., and Mehar, M. (2012). How mobile phones contribute to growth of small farmers? Evidence from India. *Q. J. Int. Agric.* 51, 227–244. doi: 10.22004/ag.econ.155478

Munyua, H. (2007). ICTs and small-scale agriculture in Africa: a scoping study. Final Report to *International Development Research Centre (IDRC)* (Ottawa).

Mwalupaso, G. E., Tian, X., Matafwali, E., Mwamba, M. C., Alavo, J.-P. E, Mamo, A., et al. (2019). Understanding the purpose and potential popularity of mobile phone use in Zambia's Maize production. *J. Agric. Sci.* 11:32. doi: 10.5539/jas.v11n6p32

Norton, G. W., and Alwang, J. (2020). Changes in agricultural extension and implications for farmer adoption of new practices. *Appl. Econ. Perspect. Policy* 42, 8–20. doi: 10.1002/aepp.13008

NSSO (National Sample Survey Organisation) (2005). *Situation assessment survey of farmers: Access to modern technology for farming, 59th round (January–December 2003).* Report No. 499(59/33/2). New Delhi: Ministry of Statistics and Programme Implementation.

Ogutu, S. O., Okello, J. J., and Otieno, D. J. (2014). Impact of information and communication technology-based market information services on smallholder farm input use and productivity: the case of Kenya. *World Dev.* 64, 311–321. doi: 10.1016/j.worlddev.2014.06.011

Oladele, O. I. (2015). Effect of information communication technology (ICT) on agricultural information access among extension officers in North West Province South Africa. *S. Afr. J. Agric. Ext.* 43, 30–41. doi: 10.17159/2413-3221/2015/v43n2a344

Parmar, R. S., Kathiriya, D. R., and Kamani, G. J. (2015). New ICT in agriculture: Opportunities and challenges. *Guj. J. Ext. Edu.* 26, 14–17.

Paudel, R., Baral, P., Lamichhane, S., and Marahatta, B. P. (2018). ICT based agro-advisory services in Nepal. *J. Inst. Agric. Anim. Sci.* 35, 21–28. doi: 10.3126/jiaas.v35i1.22510

Planning Commission (2001). *Approach Paper to the Tenth Five Year Plan (2002–2007).* New Delhi: Yojana Bhavan.

Planning Commission (2005). *Midterm appraisal of the 10th five year plan (2002–2007).* New Delhi: Yojana Bhavan.

Planning Commission (2006). *Towards faster and more inclusive growth: An approach to the 11th five year plan (2007–2012).* New Delhi: Yojana Bhavan.

Raabe, K. (2008). *Reforming the agricultural extension system in India: What do we know about what works where and why? IFPRI Discussion Paper 00775.* Washington, DC: International Food Policy Research Institute.

Ramos-Rodrígue, A. R., and Ruíz-Navarro, J. (2004). Changes in the intellectual structure of strategic management research: a bibliometric study of the Strategic Management Journal, 1980–2000. *Strateg. Manag. J.* 25, 981–1004. doi: 10.1002/smj.397

Reddy, G. P., Sontakki, B. S., Rao, V. K. J., and Shenoy, S. (2006). "Assessment Strategic Research Extension Plan (SREP) methodology for upscaling and institutionalisation of R-E-F linkages," in *Paper Presented at the Agricultural Economists Conference* (Gold Coast, QLD).

Reddy, P. K., and Ankaiah, R. (2005). A framework of information technology-based agriculture information dissemination system to improve crop productivity. *Curr. Sci.* 88, 1905–1913. Available at: http://www.jstor.org/stable/24110616

Riaman, S., Supian, S., and Ismail, N. (2022). Mapping in the topic of mathematical model in Paddy agricultural insurance based on bibliometric analysis: a systematic review approach. *Computation* 10:50. doi: 10.3390/computation10040050

Rohila, A. K., Yadav, K., and Ghanghas, B. S. (2017). Role of Information and communication technology (ICT) in agriculture and extension. *J. Appl. and Nat. Sci.* 9, 1097–1100. doi: 10.31018/jans.v9i2.1328

Rwamigisa, P. B., Birner, R., Mangheni, M. N., and Semana, A. (2018). How to promote institutional reforms in the agricultural sector: a case study of Uganda's National Agricultural Advisory Services (NAADS). *Dev. Polic. Rev.* 36, 607–627. doi: 10.1111/dpr.12318

Saikanth, D. R. K., Murugan, P. P., Prasanth, A., Mahandrakumar, K., and Prabakaran, K. (2022). utilisation pattern of m-Kisan portal by farmers of Nagarkurnool district of Telangana. *Pharm. Innov. J.* 11, 337–339. doi: 10.22271/tpi.2022.v11.i2Se.10616

Saini, S., Burman, R. R., Padaria, R. N., Mahra, G. S., Bishnoi, S., Aditya, K., et al. (2023). Mapping the research trends of migration behavior in agricultural households: a bibliometric analysis. *Front. Sustain. Food Syst.* 7:1241716. doi: 10.3389/fsufs.2023.1241716

Saravanan, R. (2008). "e-Arik," in *Transforming Government: eGovernment Initiatives in India*, eds. R. K. Bagga, and P. Gupta (Hyderabad: The ICFAI University Press), 260–269.

Saravanan, R. (2012). "ICTs for agricultural extension in India: policy implications for developing countries," in *Proc. of 8th Asian Conference for Information Technology in Agriculture, AFITA* (Taipei), 1–11.

Shantichandra, E. T., Freeler, R. E., and Dickson, I. O. (2013). *Impact of social media in enhancing Agriculture extension.* Balurghat: Agriculture & Food e-Newsletter.

Singh, R., Syiem, W., Feroze, S. M., Devarani, L., Ray, L. I., Singh, A. K., et al. (2015). Impact assessment of mobile based agro-advisory: a Case study of tribal farmers of Ri-Bhoi district of Meghalaya. *Agric. Econ. Res. Rev.* 28, 183–187. doi: 10.5958/0974-0279.2015.00033.6

Singh, S. (2004). Leveraging ICTs for agricultural development: a case study of E-choupals of ITC. *Paradigm* 8, 1–6. doi: 10.1177/0971890720040101

Sulaiman, R., Hall, A., and Suresh, N. (2005). *Effectiveness of private sector extension in India and lessons for the new extension policy agenda.* Network Paper 141. London: Agricultural Research and Extension Network.

Sulaiman, R., and van den Ban, A. W. (2003). Funding and delivering agricultural extension in India. *J. Int. Agric. Ext. Educ.* 10, 21–30. doi: 10.5191/jiaee.2003.10103

Suvedi, M., and Kaplowitz, M. (2016). *What every extension worker should know – Core Competency Handbook.* East Lansing, MI: Department of Community Sustainability, Michigan State University East Lansing, Michigan. U.S. Agency for International Development (USAID) Project Modernizing Extension and Advisory Services (MEAS).

Swanson, B. E. (2009). "Changing extension paradigms within a rapidly changing global economy," in *Proceedings of the 19th European Seminar on Extension Education: Theory and Practice of Advisory Work in a Time of Turbulences* (Assisi), 113–117.

Tadesse, G., and Bahiigwa, G. (2015). Mobile phones and farmers' marketing decisions in Ethiopia. *World Dev.* 68, 296–307. doi: 10.1016/j.worlddev.2014.12.010

Tunger, D., and Eulerich, M. (2018). Bibliometric analysis of corporate governance research in German-speaking countries: applying bibliometrics to business research using a custom-made database. *Scientometrics* 117, 2041–2059. doi: 10.1007/s11192-018-2919-z

USAID (2010). *ICT to Enhance Farm Extension Services in Africa.* Briefing Paper. Available at http://pdf.usaid.gov/pdf_docs/PA00J7P8.pdf (accessed January 8, 2024).

Verma, S., and Gustafsson, A. (2020). Investigating the emerging COVID-19 research trends in the field of business and management: a bibliometric analysis approach. *J. Bus. Res.* 118, 253–261. doi: 10.1016/j.jbusres.2020.06.057

Working Group on Agricultural Extension (2007). *Recommendations of working group on agricultural extension for formulation of eleventh five-year plan (2007–12).* New Delhi: Planning Commission. Available at: http://www.fao.org/sd/2003/KN0603a_en.htm (accessed January 14, 2024).

World Bank Group (2016). *World development report 2016: Digital dividends.* Washington, DC: World Bank Publications. doi: 10.1596/978-1-4648-0671-1