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A Bibliometric Analysis of the Evolution of IoT Applications in Smart Agriculture

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ABSTRACT

This study presents a bibliometric analysis to map the evolving landscape of Internet of Things (IoT) applications in smart agriculture, identifying pivotal research, influential authors, and significant trends from 2016 to 2023. Utilizing the SCOPUS database, the research compiled a dataset of 1277 documents, from which the 100 most-cited articles were meticulously analyzed. Employing VOSviewer for bibliometric evaluations, this study explored keyword occurrences, co-authorship networks, and bibliometric coupling networks. The findings indicate a marked increase in research interest in IoT applications in smart agriculture during the studied period, with India, the United States, and China leading in contributions, supported by various global researchers. Key journals contributing to this field include "Sensors (Switzerland)" and "Computers and Electronics in Agriculture." This analysis illuminates the field's trajectory, spotlighting essential authors, prevalent keywords, and leading journals. Dominant keywords encompassed IoT, smart agriculture, smart farming, precision agriculture, crops, irrigation systems, and agricultural technology. The research underscores the significant potential of IoT in enhancing agricultural institutions, farmers, producers, and researchers globally, contributing to increased agricultural productivity, performance, and food security. However, the study's limitations include reliance on a single database, SCOPUS, and a focus on highly cited publications. Future research would benefit from incorporating multiple databases and considering a wider range of publications. Further investigation in smart agriculture should prioritize how digital technology can optimize decision-making and bolster the sustainability of agricultural practices.

1. INTRODUCTION

The IoT, encompassing networks of vehicles, home appliances, physical devices, and other items embedded with electronics, sensors, and connectivity, has emerged as a transformative force across various domains [1]. In recent years, its applications have extended to diverse fields, including smart cities, healthcare, smart homes, and notably, agriculture. The integration of IoT in smart agriculture bridges the physical and virtual worlds, facilitating data exchange via the Internet. This technology has gained prominence in the agricultural sector, addressing the critical challenge of food security in the face of a growing global population and diminishing resources [2].

Wireless Sensor Networks (WSNs) have seen widespread adoption in agriculture to enhance farming efficiency by monitoring field parameters such as humidity, temperature, and transportation of agricultural goods [3, 4]. These networks play a pivotal role in managing factors impacting crop growth and yield. The application of WSNs in agriculture extends to environmental monitoring, precision farming, livestock management, greenhouse control, and food traceability [5, 6]. The utilization of WSNs has demonstrated efficacy in optimizing irrigation systems, conserving water resources, and augmenting crop production [7].

The advent of the "smart agriculture revolution," underscored by the implementation of Artificial Intelligence (AI) and IoT, aims to elevate the quality and quantity of agricultural products [8]. Smart farming, powered by IoT technology, enables real-time monitoring of critical parameters like soil moisture, weather conditions, and crop health through sensor networks [9]. This data, accessible via mobile applications or web interfaces, empowers farmers to make informed decisions remotely. IoT sensors used in smart farming include water volume, humidity, soil moisture, and air temperature sensors [3, 10, 11].

Precision agriculture, leveraging IoT technology, optimizes resource allocation to enhance crop yields while reducing operational costs. The market for smart agriculture is projected to experience substantial growth, with estimates suggesting it will triple by 2025 to $15.3 billion. Moreover, the deployment of IoT devices in the agriculture sector is expected to reach 75 million by 2020, exhibiting a 20% annual growth rate [12]. IoT technologies in agriculture enable farmers to access decision-making tools and automated technologies that integrate products, information, and services, thereby augmenting productivity, quality, and profitability [9, 12]. Recent investigations into IoT have concentrated on the challenges and limitations encountered in pilot projects within the agri-food supply chain, with a particular emphasis on resolving security and privacy issues, especially in sensitive domains such as the agri-food supply chain [13-15].

Table 1. Research questions and their significance

Research Questions	Significance
RQ1: What are the overall publication trends regarding publication output?	It would assist researchers in examining the state and development patterns of IoT technology in a study on smart agriculture.
RQ2: Which countries have actively participated in IOT technology in smart agriculture research?	It would make it possible for researchers to locate global and potential IoT technology collaborators for research on smart agriculture. This would make it easier to examine how articles are distributed spatially.
RQ3: Who are the authors that have been actively engaged in research on IoT technology in the field of smart agriculture?	It would help researchers recognize productive authors and potential collaborators on IOT technology in smart agriculture research.
RQ4: What are the most important cited journals that constitute the knowledge field of IOT technology in smart agriculture research?	It would be anticipated for researchers to locate appropriate journals for publishing IOT technology in smart agriculture-related papers quickly.
RQ5: What are the most commonly used keywords among the 100 most-cited publications on IOT in smart agriculture?	It would help researchers in selecting IOT technology for agricultural research problems.
RQ6: What are Future research direction in IOT in smart agriculture domains	In this way, researchers can gain a deeper understanding of research domains and directions in the future.

This study endeavors to bridge a gap in existing literature, contributing to the burgeoning research on IoT in smart agriculture. IoT's transformative potential in enhancing agricultural efficiency, sustainability, and decision-making processes is acknowledged, signaling a significant shift towards modern agriculture. The research aims to analyze trends, identify key contributors, map knowledge networks, explore keyword evolution, and assess the regional impacts of IoT in smart agriculture. Collaboration between researchers and institutions is expected to yield insights critical for decision-makers in agricultural technology.

The primary objective of this study is to perform a bibliometric analysis of IoT technology within the context of smart agriculture. In pursuit of this goal, specific research questions have been formulated, with Table 1 detailing these questions and elucidating their significance.

The structure of the article is methodically organized: Section II provides an in-depth overview of IoT technology and its relevance to current research. Section III describes the research methodology. Section IV delineates the study's findings, while Section V synthesizes these findings into a comprehensive discussion. Finally, Section VI presents the conclusions drawn from the research. This systematic approach ensures a thorough and coherent exploration of IoT applications in smart agriculture.

2. LITERATURE REVIEW

2.1 Applications and advantages of IoT

In the realm of smart agriculture, the integration of IoT technology, encompassing an array of sensors, devices, and data analytics tools, has been instrumental in enhancing efficiency, productivity, and sustainability [16-18]. IoT systems, through the collection of real-time field data, enable farmers to base decisions on precise information, thus optimizing resource allocation. The broad spectrum of benefits provided by IoT is transforming traditional farming practices. The implementation of sensors for monitoring soil conditions, weather patterns, and crop health facilitates precision farming. This approach aids farmers in maximizing irrigation, fertilization, and pest management, thereby increasing agricultural yields and resource efficiency [17].

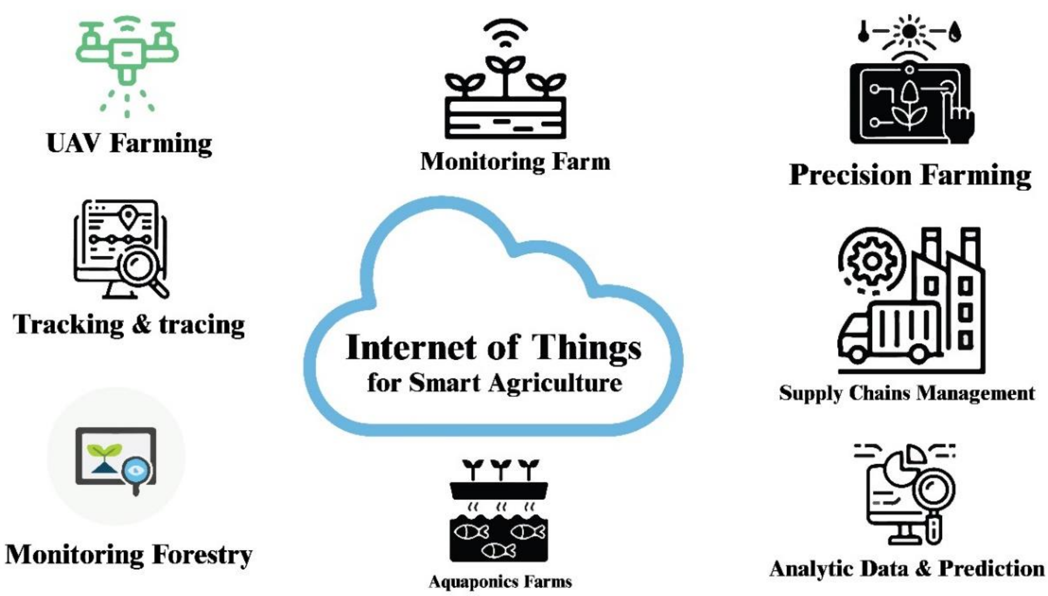

Figure 1. A depiction of IoT applications about smart agriculture

Furthermore, IoT's role in crop health monitoring is significant, allowing for early detection of issues, thereby minimizing yield losses [19]. The technology's ability to automate and optimize resource usage reduces environmental impacts and operational costs. It also bolsters crop monitoring by identifying early signs of disease or nutrient deficiencies and streamlines livestock management through health and behavior tracking. The vast data generated by IoT systems supports data-driven decision-making, enhancing the optimization of planting schedules, yield prediction, and supply chain management [18]. IoT's integration of connected weather stations further provides localized weather data, mitigating weather-related risks. As indicated by Farooq [16], IoT enhances traceability and ensures food safety throughout the supply chain, empowering farmers to make informed decisions regarding market access and product sales [17]. In essence, IoT technologies facilitate more efficient farming operations, elevate productivity, and strengthen the resilience of food supply chains, all while promoting environmental sustainability. An illustration of IoT applications for smart agriculture is shown in Figure 1.

In recent years, advancements in IoT technologies, particularly in communication infrastructure, have significantly impacted the agriculture sector. This evolution encompasses the interfacing of smart objects, cloud-based intelligent analysis, remote data collection, the use of mobile devices and the Internet for sensor and vehicle connectivity, and the automation of agricultural operations [17]. These advancements have led to notable improvements in resource management, climate change mitigation, and crop productivity in the agricultural industry [20].

2.2 Challenges

Despite the numerous advantages IoT brings to agriculture, several challenges impede its widespread adoption. One of the primary hurdles is the high initial cost associated with deploying IoT infrastructure, posing a significant barrier, particularly for smaller farms [21]. Additionally, the management and integration of the vast volume of data generated by IoT systems are complex, presenting significant challenges in data handling. Data security and privacy emerge as critical concerns, considering the sensitivity of agricultural data [22]. Furthermore, interoperability issues, compounded by limited connectivity in rural areas, can impede seamless data sharing, crucial for the effective use of IoT in agriculture. Supply reliability, technical skill gaps, and environmental implications also demand attention [23]. Addressing these challenges requires collaborative efforts among stakeholders to ensure IoT's application in agriculture is accessible, secure, and sustainable [22, 24]. Recent studies have shed light on various agricultural IoT applications, including evaluating IoT applications in farming activities, exploring IoT architectures in food control, and assessing the integration of IoT with agricultural UAVs in the context of smart farming [23, 25, 26]. Furthermore, the literature highlights IoT's role in diverse agricultural domains such as soil management, irrigation management, precision agriculture, and smart farming [17, 25].

3. RESEARCH METHODOLOGY

Researchers have employed diverse quantitative and qualitative methodologies to examine and assess prior research findings and insights [16]. The range of techniques used in earlier studies includes systematic literature reviews based on frameworks: Meta-analysis and bibliometric analysis [19, 20, 27]. The present research uses science mapping to summarize the body of knowledge that is currently available concerning IoT in smart agriculture. Science mapping is used to analyze literature and scholarly papers based on their bibliometric data [28].

The Bibliometric method, a commonly used review approach, allows researchers to analyze a collection of publications quantitatively as well as objectively identify relevant similarities, relationships, and trends [29]. This approach helps mitigate potential idiosyncratic biases often associated with more qualitative reviews. Bibliometric methods have been used by researchers across various fields, including IoT in smart agriculture, to examine the impact of specific journals, authors, and articles [18]. Additionally, bibliometric analysis combined with text mining and content analysis can facilitate science mapping by revealing key themes established in the literature [28]. These approaches have been employed to analyze the integration of IoT as well as agriculture UAVs with regard to smart farming, investigate IoT architectures for food control, and assess the current state of IoT uses in farming activities. The potential benefits of IoT in several facets of agriculture, including precision agriculture, soil management, irrigation management, and smart farming, have been emphasized by this research. These techniques have offered insightful information on the prospective uses of IoT technology in smart agriculture and the issues that must be resolved to ensure its general acceptance and success.

This research aims to measure the impact of contributions and chart essential themes. To achieve this, we utilize a combination of bibliometric and thematic analysis methods sequentially, following the selection of the literature sample.

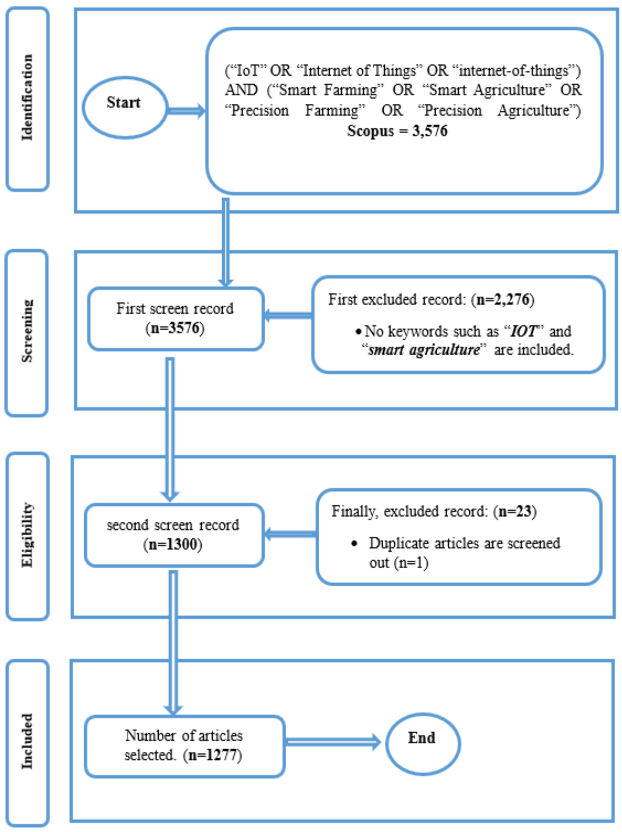

Figure 2. Literature search and screening strategy

Additional information regarding the review procedures can be found in Figure 2.

3.1 Data extraction

To comprehensively cover international research on IoT in smart agriculture, we accessed a substantial body of professional and scientific literature from the Scopus database [18]. Our study specifically utilized electronic data from published articles related to IoT technology in smart agriculture, sourced exclusively from the Scopus database, spanning from 2016 to mid-2023. Data retrieval occurred on September 6, 2023, and we conducted independent assessments of the retrieved articles, applying inclusion and exclusion criteria in order to ensure their suitability for analysis and to facilitate well-informed conclusions. The exported Scopus records contained extensive and in-depth information, comprising complete records and cited references that were exported as text files. These records included data on publication year, authorship, affiliations, and source journals [30]. The search was primarily based on titles, keywords, and abstracts in order to explore theories and explore content relationships in this IoT for smart agriculture field. Furthermore, the search technique utilized for this database's work research sought terms that were used to describe IoT technologies in smart agriculture, which include "Precision Farming," "Precision Agriculture," "Smart Farming" as well as "Smart Agriculture" in connection with "IoT" or its synonyms. The research was limited to English-language articles published in journals and conferences. Accordingly, the database search instructions were as follows:

("IoT" OR "Internet of Things" OR "internet-of-things") AND ("Smart Farming" OR "Smart Agriculture" OR "Precision Farming" OR "Precision Agriculture")

3.2 The exclusion and inclusion of criteria

Table 2. Inclusion and exclusion criteria

Inclusion	Exclusion
Publications that focus on IoT technology in smart agriculture	Publications unrelated to IoT technology in smart agriculture
Publication peoriod: 2016 to 2023	Publications outside the specified timeframe (pre-2016 or post-2023
English-language journal articles	Non-English language publications
Papers offering noteworthy contributions to IoT in agriculture	Articles not aligned with the study's objectives

In our study, we meticulously executed a research plan structured into four distinct phases. Phase I entailed a systematic exploration of the literature, targeting articles focused on IoT technology in smart agriculture from 2016 to 2023. This period was chosen strategically due to the significant surge in publications, largely attributable to the evolution of e-journals. In Phase II, we conducted a comprehensive full-text screening process. During this phase, we rigorously applied specific inclusion criteria, excluding 3576 articles that did not align with our research parameters. Phase III was dedicated to the meticulous removal of all duplicate articles. This step ensured the dataset's integrity and eliminated redundancy. Finally, Phase IV involved a detailed manual assessment of the remaining 1277 articles. Our objective was to identify and select articles that made noteworthy contributions to IoT in smart agriculture. The inclusion criteria for this phase encompassed papers specifically connected to IoT in smart agriculture, English-language journal articles, and publications falling within the 2016 to 2023 timeframe as indicated Table 2. This systematic approach effectively sifted through the literature, ensuring selected articles aligned with our research goals.

3.3 Bibliometric analysis

We examined a wide range of crucial factors in our thorough bibliometric analysis of the 100 papers chosen for this research: i) the number of citations, ii) authors, iii) journals, iv) nations, v) institutions, vi) year of publication, as well as vii) author keywords, as per the guidance of van Eck (2010). To ensure a robust examination, we adopted a multifaceted approach that utilized keyword maps, co-author networks spanning multiple countries, and a bibliographic link network. Our analysis extended to exploring publications, citations and identifying noteworthy journals associated with the 100 most cited papers about IoT in smart agriculture. To enhance the clarity and brevity of our presentation, we segmented the analysis of citation distributions into equal segments spanning the last seven years. This strategic division allowed for a more focused assessment of citation trends and patterns, contributing to a comprehensive understanding of the bibliometric landscape within this domain.

In the study, bibliometric maps and networks were visualized with VOSviewer (available at www.vosviewer.com), and graphs were created in Microsoft Excel using the data generated by VOSviewer. There are various ways to visualize science maps, including graphical, temporal, and distance-based models. Each approach's nodes (circles) and edges (connecting lines) contribute to a unique interpretation. With the distance-based method, nodes with closer connections indicate stronger connections, while with the graph-based approach, edges indicate connections. Nodes are organized by time in a temporal analysis.

4. RESULTS AND DISCUSSION

In our analysis using VOSviewer, we applied various bibliometric techniques, including assessing the relationships between authors, articles, and journal publications and investigating keyword co-occurrences, conceptual structure analysis, network mapping, bibliographic coupling, and thematic evolutions. In alignment with our objectives, our examination of IoT technology in smart agriculture led us to conclude that recent studies have made significant advancements in this field.

4.1 RQ1: What are the overall publication trends and citations?

A chart illustrating the annual production of scientific articles on the IoT employed in smart agriculture is presented in Figure 3. The graph provides an overview of yearly publication figures from 2016 to 2023, revealing a consistent upward trajectory marked by intermittent fluctuations. By commencing at 20 publications in 2016, this number nearly doubled the following year, reaching 36 publications. There was substantial year-on-year growth in subsequent years, peaking at 338 publications in 2022, the zenith of this dataset.

However, in 2023, there was a significant decline to 191 publications, indicating a potential alteration in research output trends. This dataset underscores the dynamic nature of research productivity, which is susceptible to various influencing factors over time.

As illustrated in Figure 4, total citations gradually increased from 2016 through 2019, peaking at 5102 citations in 2019. As a result, citation counts significantly declined in 2020, 2021, and 2023. The pattern suggests that the research focus has shifted or that recent publications have yet to have the same impact.

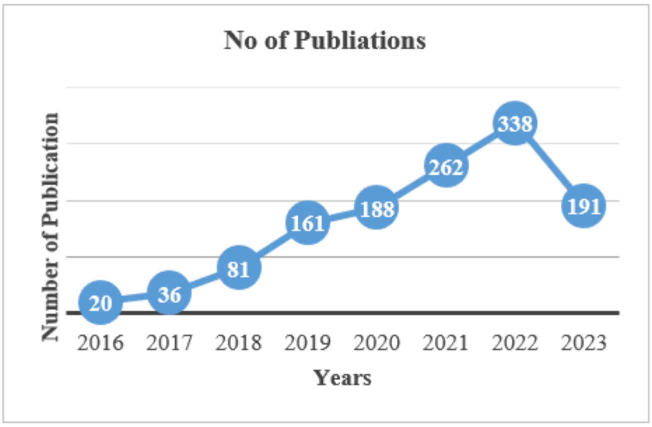

Figure 3. Annual scientific production

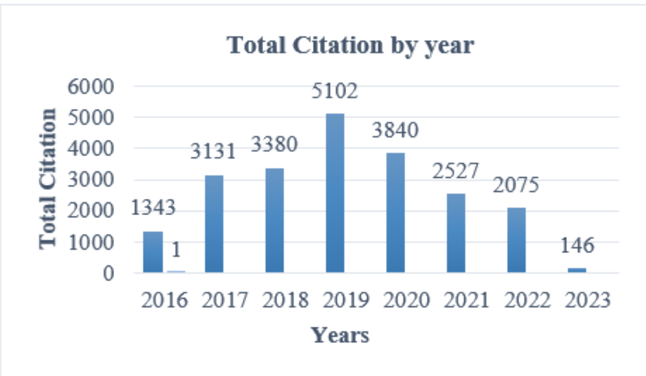

Figure 4. Yearly Citations

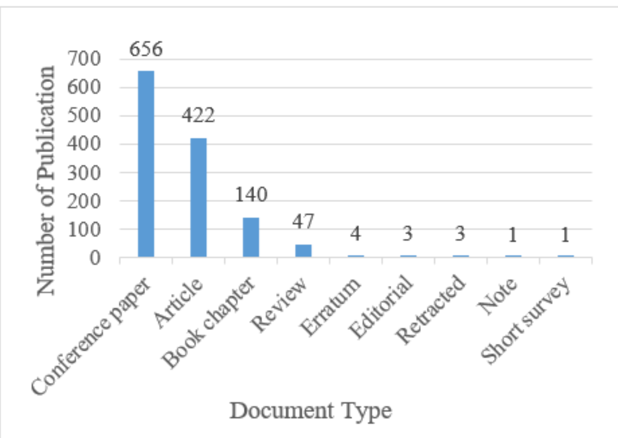

Figure 5. Type of Document

The chart in Figure 5 categorizes 1,277 publications related to IoT technology in smart agriculture. Conference Papers (656) are the most prevalent, signifying active knowledge sharing at conferences. Articles (422) represent scholarly work in journals, showcasing in-depth research. Book Chapters (140) denote contributions to broader literature. Reviews (47) provide summarized insights from existing research. Categories like Erratum (4) underscore a commitment to accuracy, while Retracted (3) emphasizes transparency. Editorials (3) provide expert commentary and Note (1) and Short Survey (1) indicate occasional brief communications.

As illustrated in Figure 5, these publications show the dynamic and multifaceted nature of IoT research within smart agriculture.

4.2 RQ2: Which countries have actively participated in IOT technology in smart agriculture research?

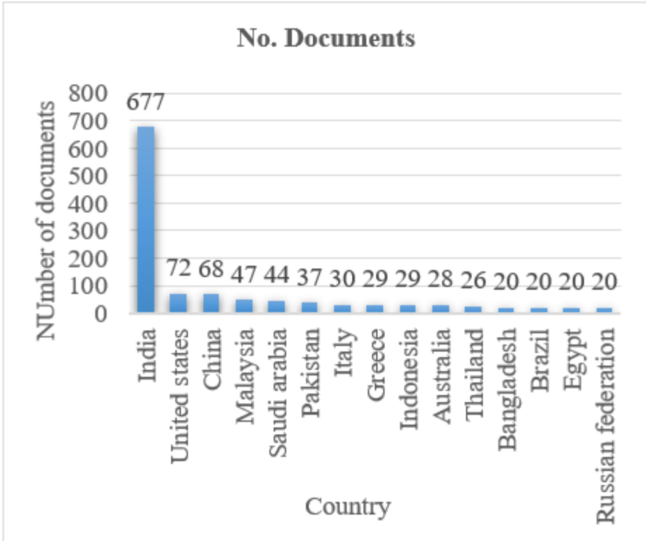

Figure 6. The distribution of the number of publications by country

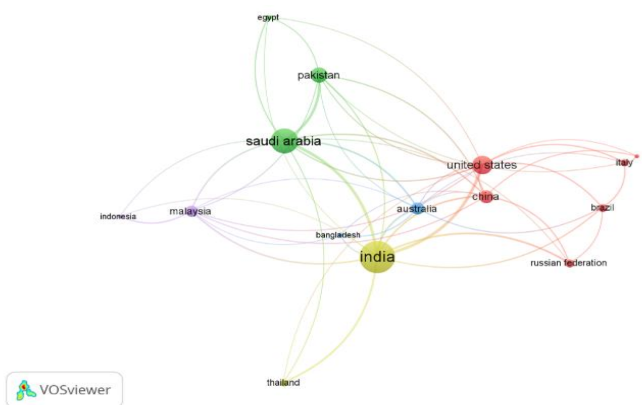

Figure 7. A network of cooperation among the countries

The chart in Figure 6 presents a breakdown of research documents by country, revealing their respective publication counts. India leads with 677 papers, signifying a significant research presence. The United States follows with 72 publications, while China closely follows with 68, both contributing prominently to the field. Other countries such as Malaysia (47), Saudi Arabia (44), and Pakistan (37) also exhibit substantial research activity. Additionally, Italy (30), Greece (29), Indonesia (29), Australia (28), Thailand (26), Bangladesh (20), Brazil (20), Egypt (20), and the Russian

Federation (20) play notable roles in the research landscape. This chart emphasizes the diverse global participation in research on the IOT in smart agriculture, illustrating varying degrees of research engagement and contributions from different countries.

The study examined over 100 publications, indicating a level of collaboration among the countries involved. Consequently, the results of using VOSviewer to create a collaborative network between these nations are shown in Figure 7. The findings reveal a network of research cooperation among countries, with "Links" indicating connections and "Total Link Strength" quantifying collaboration intensity. India leads with 12 links and a total link strength of 76, highlighting its key role and extensive, significant collaborations. Saudi Arabia, having 10 links and a total link strength of 54, signifies substantial international research engagement. The United States demonstrates 11 links and a total link strength of 38, reflecting active global research participation. With 8 links and a total link strength of 29, Pakistan is actively involved in research partnerships. Having 9 links and a total link strength of 24 indicates China's international research involvement. Australia and Malaysia, with 9 links and 8 links, respectively, engage in research cooperation, although with varying link strengths. As a result of these findings, international collaboration has become increasingly significant for producing highly influential publications.

4.3 RQ3: Who are the authors that have been actively engaged in research on IoT technology in the field of smart agriculture?

In this section, we analyzed the references cited in the most widely referenced publications concerning IoT technology in smart agriculture. It was done to uncover shared themes among those referenced by authors in these works. We conducted a bibliometric analysis employing VOSviewer. The software's outcomes for this topic are visually presented in Figure 8. According to our discoveries, using the sources that the most-cited papers cite, four separate groups can be identified. For instance, the red cluster represents publications that delve into the application of IoT in agricultural technology. Similarly, the green cluster signifies those publications that have explored IoT's role in agriculture. Furthermore, the blue cluster encompasses publications primarily centered on the exploration of smart farming, while the yellow cluster is associated with publications related to smart agriculture.

Despite the noticeable distance between the green and yellow clusters and their close relationships, there is no significant similarity between the cited works within these groups. In contrast, the other clusters, such as the blue and red ones, are closely positioned relative to each other and exhibit numerous interconnections, indicating higher similarity among the referenced works in these publication groups.

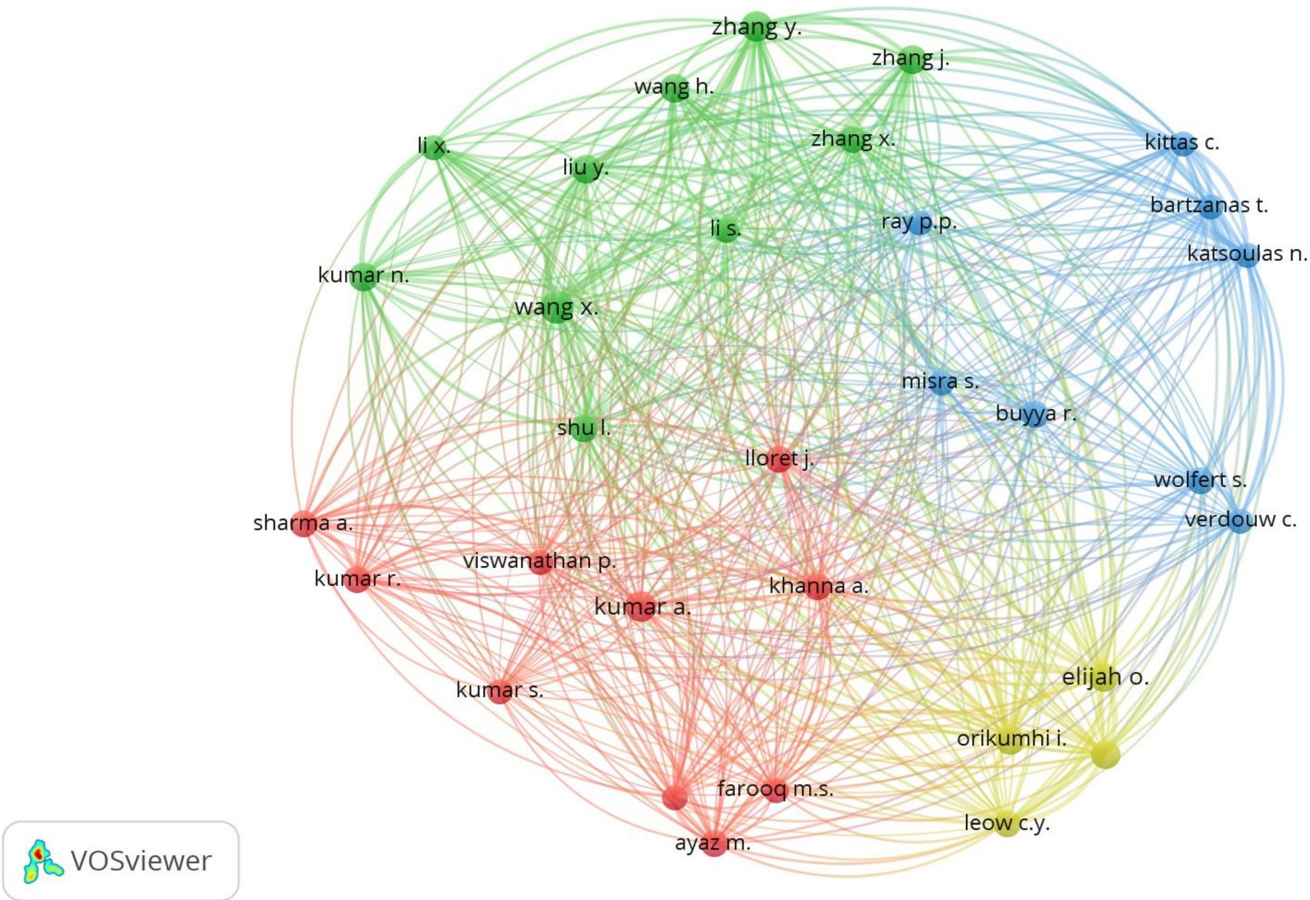

Figure 8. Author collaboration network

4.4 RQ4: What are the most important cited journals that constitute the knowledge field of IOT technology in smart agriculture research?

Table 3 outlines the top 10 journals having the most-cited publications, featuring details such as the journal's name, average Citations per Publication (CPP), Total number of Publications (TP), Total number of Citations (TC), Citescore, Source Normalized Impact per Publication (SNIP), Scimago Journal & Country Rank (SJR), ranking, and publisher. In Table 2, SNIP serves as a metric for evaluating the average CPP in a particular journal relative to its citation potential within its subject field [31]. When a journal's average CPP exceeds one, it is said to have exceeded its field's potential for citations (SNIP score greater than 1). The table below shows that, with 1881 citations, the journal "Sensors (Switzerland)" is the most cited. It is followed by "IEEE Access" (1511 citations) and "Computers and Electronics in Agriculture" (1445 citations). Additionally, "Computers and Electronics in Agriculture" also has the greatest SNIP of 2.473 and a Citescore of 13.6. Notably, it also holds the highest SJR of 1.92 in this list and is ranked as a Q1 journal. Table 2 reveals that most of the journals are ranked in Q1, Q2, and Q4 by ScimagoJR. Additionally, the table shows that Springer Nature is the leading publisher, with the highest representation in the top 10, featuring 5 journals, whereas other publishers have only 1 journal each. This table provides valuable insights into influential journals in terms of citations, offering valuable guidance for researchers seeking to submit their work for publication in reputable academic publications.

Table 3. Top 10 journals with most-cited publications

No	Journal Name	TP	TC	CPP	Citescore	SNIP	SJR	Ranking	Publisher
1	Lecture notes in networks and systems	34	61	2	0.7	0.19	0.151	Q4	Springer Nature
2	Lecture notes in electrical engineering	23	99	4	0.6	0.158	0.147	Q4	Springer Nature
3	IEEE Access	19	1511	80	9	1.422	0.926	Q1	IEEE
4	Journal of Physics: conference series	17	85	5	1	0.26	0.183	Q4	IOP
5	Computers and electronics in agriculture	16	1445	90	13.6	2.473	1.587	Q1	Elsevier
6	Sensors (Switzerland)	16	1881	118	6.8	1.317	0.764	Q1	MDPI
7	Communications in computer and information science	14	82	6	1	0.241	0.194	Q4	Springer Nature
8	EAI/springer innovations in communication and computing	13	43	3	1.7	0.141	0.149	Q4	Springer Nature
9	ACM International Conference proceeding series	11	101	9	1.1	0.229	0.209	Q4	ACM
10	wireless personal communications	11	264	24	4.5	0.908	0.545	Q2	Springer Nature

4.5 RQ5: What are the most commonly used keywords among the 100 most-cited publications on IOT in smart agriculture?

Our analysis covered the top 100 articles that received the most citations. The co-occurrence of keywords, including author, journal, as well as journal-assigned keywords, as determined by VOSviewer, is depicted in Figure 9. Our findings have identified four major clusters that encapsulate the knowledge presented in these publications. Notably, these clusters are denoted by the most substantial keywords: "Internet of things," "Smart agriculture," "smart farming," and "crops." Figure 8 visually represents these clusters, which emerged from a dataset of 70 items with a minimum of 4 co-occurring keywords. Cluster 1 (Red, 17 items): This cluster encompasses keywords such as crops, agriculture monitoring, automation, cost-effectiveness, cultivation, data acquisition, digital storage, information management, irrigation, irrigation systems, moisture control, monitoring systems, productivity, sensors, soil moisture, soils, water levels, and water management. Cluster 2 (Green, 16 items): The second cluster includes keywords such as IoTs, agricultural robots, agriculture, agriculture applications, antennas, cloud computing, costs, data handling, energy efficiency, energy utilization, IoTs, low-power electronics, network architecture, precision agriculture, sensor nodes, and wireless sensor networks. Cluster 3 (Blue, 17 items): In the third cluster, you'll find keywords like smart farming, agricultural technology, AI, big data, climate change, DA, decision making, decision support systems, deep learning, farms, greenhouses, IoT, learning algorithms, learning systems, machine learning, smart development, and sustainable agriculture. Cluster 4 (Yellow, 10 items): The final cluster covers keywords such as Smart agriculture, smart agriculture, agricultural fields, agriculture sectors, agriculture systems, blockchain, food supply, IoT technology, IOT, and network security. These clusters visually represent the key themes and concepts prevalent in the highly cited articles, providing valuable insights into the primary areas of research and knowledge in the field.

4.6 RQ6: What are future research directions in IOT in smart agriculture domains?

The study's results point to significant future research paths in IoT applications within the context of smart agriculture. A proposed framework categorizes these avenues into four main dimensions: Precision Agriculture, IoT in Agriculture, Smart Agriculture, and Digital Agriculture, as illustrated in Figure 10. Within each dimension, specific sub-areas are identified for further exploration. The Precision Agriculture dimension highlights topics such as crop management, automation, irrigation systems, data acquisition, and digital storage. This area holds great potential for researchers interested in implementing precision agriculture techniques. The IoT in Agriculture dimension encompasses concerns related to agriculture robots, wireless devices, cloud computing, and energy-efficient technologies. Researchers focusing on IoT applications in agriculture would find this dimension particularly promising. The Smart Agriculture dimension delves into subjects like artificial intelligence, smart farming, Big Data, and agricultural technology. Researchers interested in smart agriculture would find abundant opportunities for exploration within this domain. Lastly, the Digital Agriculture dimension encompasses themes related to blockchain, agriculture systems, and food supply chain technologies. Researchers keen on digital agriculture would find this dimension to be a fertile ground for their interests.

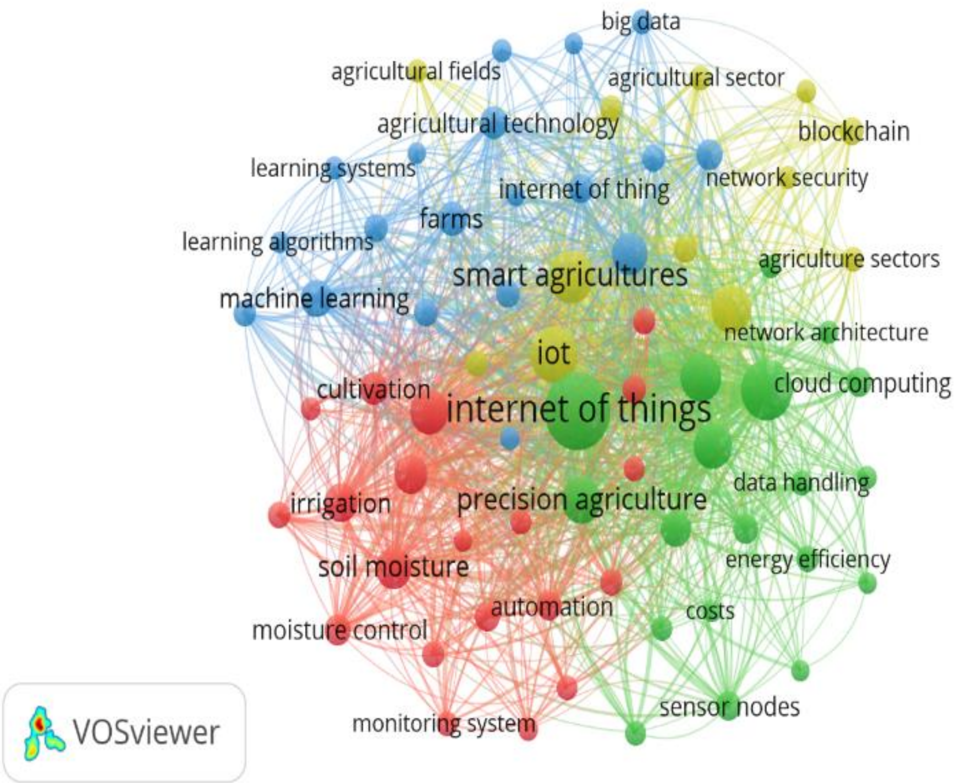

Figure 9. Keyword co-occurrence

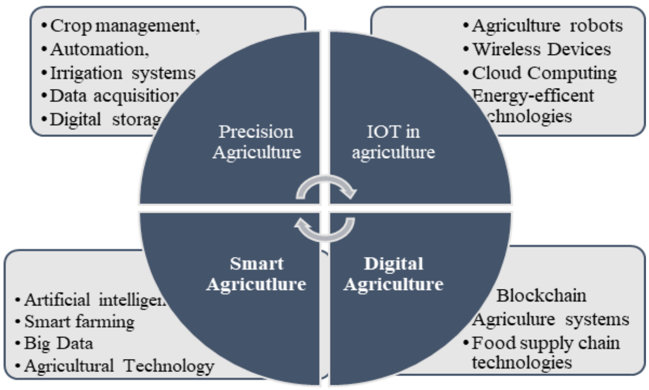

Figure 10. Future research directions in IOT in smart agriculture

5. LIMITATIONS

This bibliometric investigation comes with certain limitations that merit acknowledgement. Firstly, our literature search was confined to a single database, with the SCOPUS database chosen for its comprehensive coverage of IoT in smart agriculture. Nevertheless, employing alternative databases or a combination thereof may yield slightly different findings. The study primarily focuses on the IoT applications in smart agriculture within a bibliometric context, and it may not encompass broader interdisciplinary perspectives. In this analysis, only publications between 2016 and 2023 have been considered, and it primarily reflects research trends during those years.

Moreover, the analysis was limited to the topmost cited publications, which might have resulted in different conclusions if we had considered a broader range of publications. The study's findings are sensitive to the inclusion criteria for selecting articles, and variations in these criteria could yield different outcomes. Despite our efforts to maintain objectivity, it is essential to note that certain aspects of subjectivity were challenging to mitigate entirely, particularly in generating and interpreting results. The limitations of this study suggest that future studies should adopt a more comprehensive approach to incorporating datasets from diverse databases or sources.

6. CONCLUSION

This bibliometric study focusing on the most-cited IoT publications pertaining to smart agriculture has unveiled intriguing insights. It indicates that the topic has garnered significant attention from scholars, with a notable surge in publications and citations, particularly between 2016 and 2023. Additionally, India leads in IoT research for smart agriculture, followed by the United States and China, with substantial contributions from countries like Malaysia, Saudi Arabia, and Italy, underlining the global relevance of this research field. Furthermore, the study identifies top-cited journals, notably "Sensors (Switzerland)" and "Computers and Electronics in Agriculture," with "Computers and Electronics in Agriculture" being particularly prominent. These findings offer valuable guidance for researchers, indicating key authors, essential keywords, and suitable publication avenues within the IoT domain for smart agriculture. Moreover, this comprehensive mapping of IoT literature has provided significant insights into influential authors, journals, as well as countries. Therefore, these results provide a helpful tool for future researchers who are fascinated by the topic of IoT in smart agriculture. It can aid them in navigating the research landscape and enriching the collective knowledge base in this field. In light of these finds, the future research of IoT in smart agriculture should be studied in four areas: Precision Agriculture (crop management, automation), IoT in Agriculture (robots, wireless devices, cloud computing), Smart Agriculture (AI, smart farming, big data), and Digital Agriculture (blockchain, agriculture systems). Each of these dimensions provides varied opportunities for further exploration.

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