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Bibliometric Analysis of Digital Agricultural Research Knowledge Maps in the Global Agricultural Sector

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ABSTRACT

Digital agriculture has emerged as a transformative approach for improving agricultural productivity, resource efficiency, and sustainability through the integration of advanced digital technologies. The rapid growth of research in this field has generated a diverse and multidisciplinary body of knowledge, making it increasingly important to understand its intellectual structure and developmental trends. This study aims to analyze the global landscape of digital agriculture research using a bibliometric approach. Data were collected from the Scopus database and analyzed using VOSviewer to identify publication trends, influential publications, collaboration networks, and thematic developments within the field. The results indicate a significant increase in scholarly interest in digital agriculture, particularly in topics related to artificial intelligence, precision agriculture, smart farming, the Internet of Things (IoT), digital transformation, and sustainable development. Country collaboration analysis reveals that China, India, the Russian Federation, the United States, Germany, Italy, and the United Kingdom are among the leading contributors to knowledge production and international research cooperation. Citation analysis highlights the foundational role of studies on big data, Agriculture 4.0, and smart farming in shaping the field's intellectual development. Furthermore, keyword co-occurrence, overlay, and density visualizations demonstrate that research has evolved from digital infrastructure and data management toward advanced technologies such as machine learning, deep learning, blockchain, and intelligent decision-support systems. The findings suggest that digital agriculture has become a dynamic and interdisciplinary research domain that integrates technological innovation with agricultural sustainability and food security objectives. This study contributes to the understanding of global research trends and provides valuable insights for researchers, policymakers, and practitioners seeking to advance the digital transformation of agriculture.

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1. INTRODUCTION

The agricultural sector is undergoing a profound transformation driven by rapid advancements in digital technologies. As the global population continues to increase and the demand for food security becomes more urgent, traditional agricultural practices are increasingly being supplemented by innovative digital solutions that enhance productivity, efficiency, and sustainability [1]. Digital agriculture refers to the integration of information and communication technologies, artificial intelligence, big data analytics, the Internet of Things (IoT), remote sensing, drones, robotics, cloud computing, and other digital innovations into agricultural systems [2]. These technologies enable farmers, researchers, and policymakers to make data-driven decisions that improve crop yields, optimize resource utilization, reduce environmental impacts, and strengthen agricultural resilience. The emergence of digital agriculture has become particularly significant in addressing contemporary challenges such as climate change, resource scarcity, labor shortages, and the need for sustainable food production systems. Consequently, digital agriculture has evolved from a niche technological concept into a multidisciplinary research domain that attracts scholars from agriculture, computer science, engineering, environmental science, economics, and policy studies. As the field continues to expand, understanding its intellectual structure, research dynamics, and emerging themes becomes increasingly important for guiding future scientific development and practical implementation [3], [4].

The growing importance of digital agriculture has been accompanied by a substantial increase in scientific publications worldwide. Researchers have explored diverse applications of digital technologies in agriculture, including precision farming, smart irrigation systems, crop monitoring, disease detection, livestock management, supply chain optimization, and agricultural decision-support systems [5]–[7]. The convergence of technological innovation and agricultural development has generated a complex and rapidly evolving body of literature that reflects both theoretical advancements and practical applications. Moreover, governments, international organizations, and private sector stakeholders have invested heavily in agricultural digitalization initiatives to improve food security and support sustainable development goals. These investments have further stimulated academic research and interdisciplinary collaboration, resulting in a diverse knowledge base that spans multiple disciplines and geographic regions. However, the rapid growth of publications has also created challenges for researchers attempting to identify influential studies, emerging research fronts, collaborative networks, and thematic trends within the field. Without a systematic understanding of the existing literature, scholars may encounter difficulties in recognizing knowledge gaps, avoiding duplication of research efforts, and identifying opportunities for future investigations [8].

Bibliometric analysis has emerged as a valuable methodological approach for examining the development of scientific fields and mapping knowledge structures. Unlike traditional literature reviews, bibliometric techniques utilize quantitative methods to analyze large volumes of scholarly publications and reveal patterns related to publication productivity, citation impact, collaboration networks, and thematic evolution. Through visualization tools and network analyses, bibliometric studies can provide comprehensive insights into how research domains evolve over time and how knowledge is generated and disseminated among scholars and institutions. In recent years, bibliometric methods have been widely applied across various scientific disciplines to explore emerging technologies, sustainability issues, healthcare innovations, and digital transformation phenomena. Nevertheless, despite the growing significance of digital agriculture, comprehensive bibliometric investigations focusing on the global development of this research area remain relatively limited. Existing studies often concentrate on specific technologies, such as

precision agriculture or artificial intelligence, rather than examining the broader landscape of digital agriculture research. Furthermore, many previous reviews rely primarily on qualitative synthesis approaches, which may not fully capture the structural relationships and intellectual connections within the literature. Therefore, a comprehensive bibliometric assessment is necessary to provide a more systematic and data-driven understanding of the field.

The increasing complexity of digital agriculture research highlights the need for knowledge mapping techniques that can identify major research clusters, influential contributors, and emerging thematic directions. Knowledge mapping enables researchers to visualize relationships among keywords, authors, institutions, countries, and publications, thereby revealing the intellectual foundations and developmental trajectories of a scientific domain. Such analyses are particularly valuable in interdisciplinary fields like digital agriculture, where knowledge production involves interactions among multiple disciplines and stakeholders. By examining co-authorship networks, citation structures, and keyword co-occurrence patterns, researchers can gain insights into collaborative dynamics and thematic concentrations that shape the evolution of the field. Furthermore, knowledge mapping can support strategic decision-making by helping policymakers, funding agencies, and academic institutions identify priority research areas and opportunities for international collaboration. Given the accelerating pace of technological innovation in agriculture and the growing global emphasis on sustainable food systems, a comprehensive understanding of research trends and knowledge structures is essential for fostering future scientific advancement and practical implementation. This need is further reinforced by the emergence of new technologies such as machine learning, digital twins, blockchain, autonomous farming systems, and advanced sensor networks, which continue to redefine the scope and direction of digital agriculture research.

Based on these considerations, this study aims to conduct a comprehensive bibliometric analysis of global digital agriculture research to map its intellectual structure, identify influential contributors, examine collaboration patterns, and explore emerging research trends. Specifically, the study seeks to answer several key questions: How has digital agriculture research evolved over time? Which authors, institutions, countries, and journals have contributed most significantly to the field? What are the dominant thematic clusters and emerging topics that characterize current research developments? How are international collaborations shaping the production and dissemination of knowledge in digital agriculture? To address these questions, bibliometric techniques and knowledge mapping tools are employed to analyze scholarly publications indexed in a major scientific database. The findings are expected to provide a comprehensive overview of the research landscape, contribute to the understanding of knowledge development in digital agriculture, and offer valuable insights for researchers, practitioners, policymakers, and other stakeholders interested in advancing agricultural digitalization. Ultimately, this study contributes to the growing body of literature on digital transformation in agriculture by presenting a systematic evaluation of global research trends and identifying future directions that may support the development of more sustainable, efficient, and resilient agricultural systems.

2. METHODS

This study employed a bibliometric analysis approach to systematically examine the development of digital agriculture research at the global level. Bibliometric analysis was selected because it enables the quantitative evaluation of scientific publications and provides insights into the intellectual structure, research trends, and collaborative patterns within a specific field of study. The data used in this research were obtained from the Scopus database, which is recognized as one of the largest and most

comprehensive multidisciplinary citation databases. Scopus was chosen due to its extensive coverage of high-quality peer-reviewed journals, conference proceedings, books, and review articles across various scientific disciplines. Data retrieval was conducted using relevant keywords associated with digital agriculture, including terms such as "digital agriculture," "smart farming," "precision agriculture," "agriculture 4.0," and related concepts. The search was performed on publication titles, abstracts, and keywords to ensure broad coverage of relevant literature. After applying inclusion criteria and removing duplicate or irrelevant records, the final dataset was exported in CSV format for further bibliometric analysis.

The collected bibliographic data were analyzed using VOSviewer software, a widely adopted tool for constructing and visualizing bibliometric networks. VOSviewer was selected because of its capability to generate graphical representations of relationships among authors, institutions, countries, references, and keywords. Several bibliometric indicators were examined in this study, including annual publication trends, citation performance, leading authors, productive institutions, influential journals, and country contributions. In addition, co-authorship analysis was conducted to identify collaboration patterns among researchers and countries, while citation and co-citation analyses were used to reveal influential publications and intellectual foundations within the field. These analyses provided a comprehensive overview of the knowledge production and dissemination processes that characterize digital agriculture research worldwide.

Furthermore, keyword co-occurrence analysis was performed using VOSviewer to identify major research themes, thematic clusters, and emerging topics within the literature. Network visualization was utilized to illustrate relationships among frequently occurring keywords, while overlay visualization was employed to examine the temporal evolution of research topics and identify recent trends. Density visualization was also generated to highlight areas of high research concentration and thematic prominence. Through the integration of these bibliometric techniques, the study provides a comprehensive knowledge map of digital agriculture research, enabling the identification of research hotspots, collaborative structures, and future research opportunities. The methodological framework adopted in this study ensures a systematic and objective assessment of the global scientific landscape of digital agriculture.

3. RESULT AND DISCUSSION

3.1 Co-Author Analysis

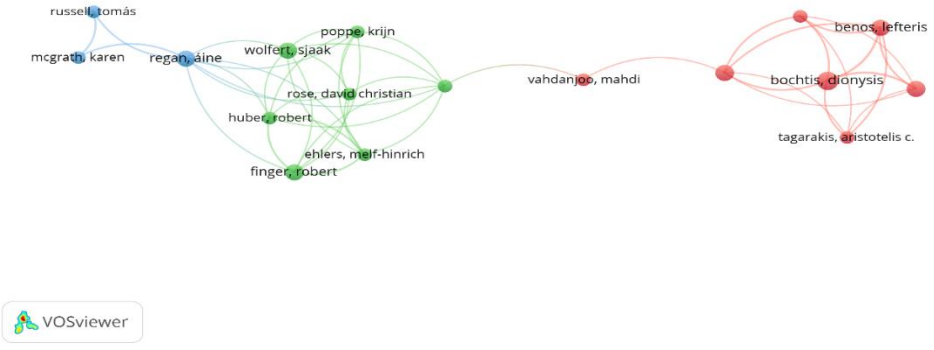

Figure 1. Author Visualization
Source: Data Analysis

The visualization graph for author co-citation analysis demonstrates the presence of three main author clusters in the field of digital agriculture research. It can be assumed that these authors form interconnected yet separate research communities in the area under discussion. First, the green cluster includes Rose, David Christian, Wolfert, Sjaak, Ehlers, Melf-Hinrich, Huber, Robert, Finger, Robert, and Poppe, Krijn. These authors display great collaboration potential and form the key nodes of the network. This fact indicates their high level of influence on the scientific development in the discussed sphere. Next, the red cluster features authors like Bochtis, Dionysis, Benos, Lefteris, and Tagarakis, Aristotelis C. They form the cluster of closely interacting authors working in the field of technology and engineering. Finally, the blue cluster contains authors such as Regan, Áine, Russell, Tomás, and McGrath, Karen. This cluster has fewer members than any other and forms a bridge between itself and the green cluster via Regan, Áine. Thus, collaboration in digital agriculture research occurs mainly between two research communities represented by authors from the green and blue clusters.

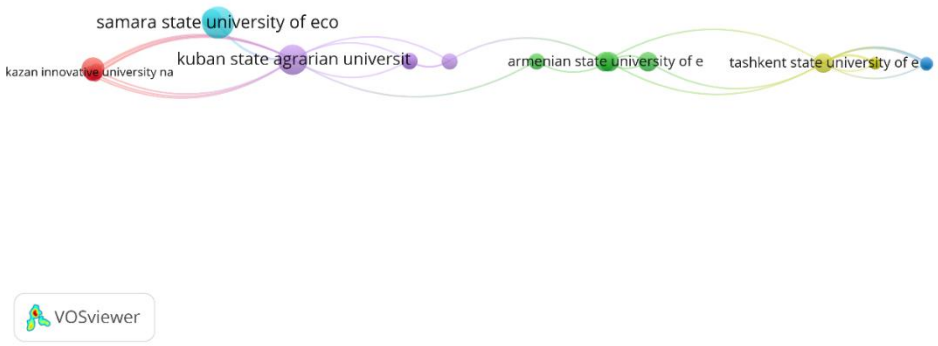

Figure 2. Institution Visualization
Source: Data Analysis

Institutional Collaboration Network indicates that studies of digital agriculture involve a range of connected universities represented in the form of collaboration clusters. The most central actor in the institutional collaboration network turns out to be Kuban State Agrarian University since it acts as a collaboration node that links multiple universities through other clusters. At the same time, this university holds strong connections with Samara State University of Economics and Kazan Innovative University and represents one of the collaborative research networks. An additional collaboration cluster involves Armenian State University of Economics. This institution works as a link between the cluster formed around Kuban State Agrarian University and others located on the right-hand side of the map. One more relevant actor in the network is Tashkent State University of Economics that collaborates with its neighbors to facilitate knowledge exchange among research networks. As seen from the analysis of the network, the collaboration of universities working on the topic of digital agriculture continues to remain linear and limited to only a few universities with the presence of intermediaries. The varying node sizes indicate differences in publication output or collaborative influence, with Kuban State Agrarian University and Samara State

University of Economics exhibiting greater prominence than other institutions.,

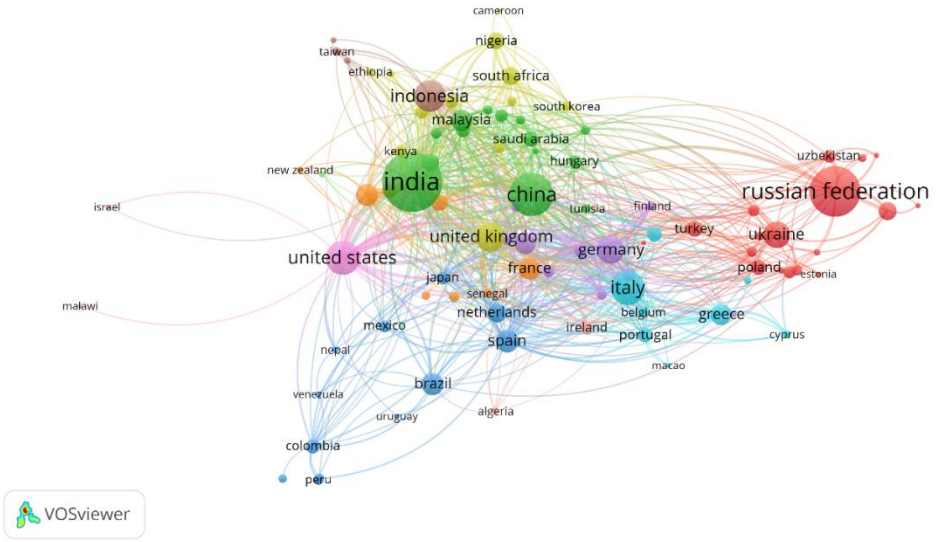

Figure 3. Country Visualization
Source: Data Analysis

The country collaboration network illustrates a highly interconnected and globally distributed research landscape in digital agriculture. Several countries emerge as major hubs of international collaboration, particularly China, India, the Russian Federation, the United States, Germany, Italy, and the United Kingdom, as indicated by their large node sizes and extensive linkages with other countries. Among these, China and India occupy central positions within the network, reflecting their substantial research output and active engagement in international scientific cooperation. The Russian Federation forms a prominent cluster connected closely with countries such as Ukraine, Poland, Uzbekistan, and Estonia, suggesting strong regional collaboration patterns. Meanwhile, European countries including Germany, Italy, France, Spain, the Netherlands, and Greece constitute another densely connected group, demonstrating the importance of cross-border research partnerships within Europe. The United States also plays a significant bridging role by connecting with countries across multiple regions, including Latin America, Asia, and Europe. Notably, emerging economies such as Indonesia, Malaysia, Nigeria, South Africa, Saudi Arabia, and Ethiopia are well integrated into the network, indicating the growing global interest in digital agriculture beyond traditionally dominant research nations. The dense web of connections throughout the visualization suggests that digital agriculture is inherently multidisciplinary and international, requiring collaboration among countries with diverse agricultural systems, technological capabilities, and policy environments

3.2 Citation Analysis

Table 1. Top Cited Literature

Citations	Authors and Year	Title
946	[9]	A review on the practice of big data analysis in agriculture
562	[10]	Enhancing smart farming through the applications of Agriculture 4.0 technologies
536	[11]	Industry 4.0: Opportunities and challenges for operations management

466	[12]	Smart farming for improving agricultural management
434	[13]	Will digital technologies transform agriculture in developing countries?
433	[14]	The digitization of agricultural industry – a systematic literature review on agriculture 4.0
414	[15]	Automation and digitization of agriculture using artificial intelligence and internet of things
359	[16]	Big Data in food and agriculture
356	[17]	Cyber-Physical Power System (CPPS): A Review on Modeling, Simulation, and Analysis with Cyber Security Applications
333	[18]	Beyond agricultural innovation systems? Exploring an agricultural innovation ecosystems approach for niche design and development in sustainability transitions

Source: Scopus 2026

According to the top-cited literature, digital agriculture knowledge production is heavily based on three major knowledge streams that have been identified. Namely, these are big data analytics, Agriculture 4.0 technologies, and smart farms. In this context, the article by [9], which has received 946 citations, proves that big data analysis has already become an indispensable basis for comprehending digital technologies' impact on agricultural decisions. Also, highly cited articles by [10], [14], and [15] provide evidence for the increasing significance of Agriculture 4.0, AI, IoT, automation, and digitization of modern agriculture. Finally, the articles by [13] and [16] reveal some socioeconomic and regulatory issues, including the issue of digital transformation in developing countries and big data in the context of the global food system. At the same time, the presence of such articles as [11] and [17] indicates that digital agriculture has something in common with Industry 4.0 and cyber-physical systems.

3.3 Keyword Co-Occurrence

The keyword co-occurrence network reveals the intellectual structure of digital agriculture research and highlights the major themes that have shaped the field. The visualization is organized into three dominant clusters, represented by red, green, and blue colors, each reflecting a distinct research focus. The central position of keywords such as agriculture, artificial intelligence, precision agriculture, and agricultural sector indicates that these concepts serve as the primary foundations of the research domain. The dense interconnections among keywords suggest that digital agriculture is a highly interdisciplinary field that integrates agricultural science, information technology, sustainability studies, and economic development. The prominence of these central keywords further demonstrates that technological innovation is increasingly being viewed as a critical solution for addressing agricultural productivity, efficiency, and sustainability challenges.

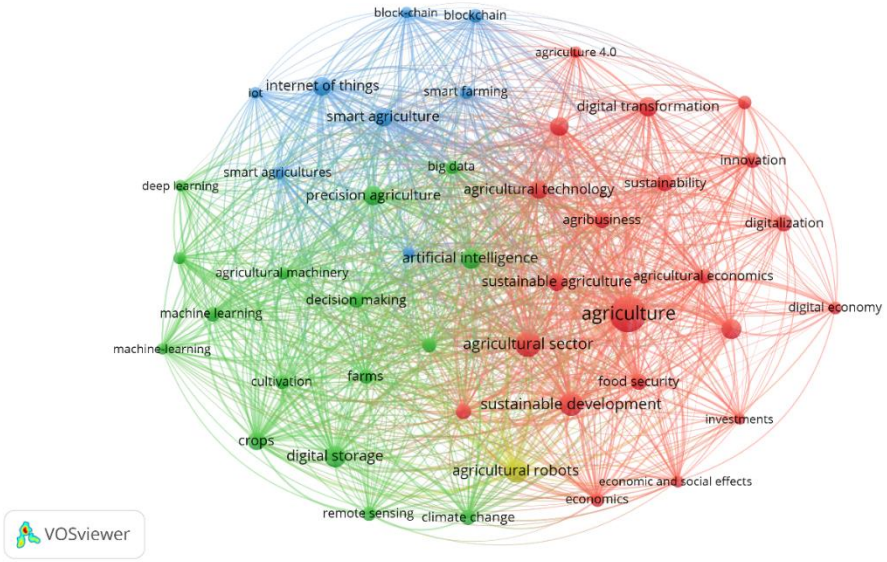

Figure 4. Network Visualization
Source: Data Analysis

The red group is largely centered on aspects of digital transformation, innovation, and socio-economic development in the field of agriculture. Some of the keywords contained in this group include digital transformation, digitalization, innovation, sustainability, agribusiness, agricultural economics, food security, digital economy, and sustainable development. The presence of such keywords in this cluster implies that a significant number of studies in the literature address digital technology in relation to their contribution towards the achievement of broader economic and social objectives in agriculture. Scholars in this cluster are concerned with the strategic significance of technology usage, innovations in modern agriculture, and the role of technology in ensuring sustainable development.

The green cluster focuses more on practical application in the field of agriculture. Key terms from this cluster include artificial intelligence, machine learning, deep learning, precision agriculture, agricultural machinery, crops, remote sensing, decision making, digital storage, and climate change. In this cluster, the emergence of computational techniques and technologies to support the improvement of agricultural practices is evident. Notably, there is much focus on artificial intelligence and machine learning, which shows the significance of using such technologies to support predictive analytics and other tasks associated with agriculture. The connection between this cluster and remote sensing and climate change shows the increased focus on solving environmental issues through the use of new data-based technologies.

The blue cluster deals with technologies for smart agriculture and infrastructure, which form the basis of modern agrarian systems. The key phrases used in this cluster include Internet of Things (IoT), smart agriculture, smart farming, blockchain, big data, and agriculture 4.0. It is evident that these keywords denote the basic features of digital technologies that characterize digital agriculture. The tight relationship of IoT, big data, and smart farming confirms the increased significance of digital environments, which ensure the uninterrupted control and optimization of farming processes. In addition to this, the emergence of blockchain technology indicates the increased attention paid to the traceability and transparency of agricultural supply chains.

The diagram proves that research related to digital agriculture has taken a multidisciplinary shape with a combination of cutting-edge technologies, sustainable

development goals, and agricultural development techniques. The association between the three groups clearly shows that technologies like artificial intelligence, Internet of Things (IoT), big data analytics, and blockchain are not being invented separately from each other but are becoming an inseparable part of economic, ecological, and social considerations. Sustainability, food security, climate change, and digital transformation as the prevailing topics in the field may imply that further research will be dedicated to the creation of intelligent agricultural systems.

Temporal evolution in the overlay visualization is presented by the keyword trends for digital agriculture in the period of 2022 to 2024. The earlier topics in darker blue and purple include digital storage, remote sensing, climate change, economics, and robots in agriculture. These keywords suggest that the basis of research started off with strong connections to data management and economic issues.

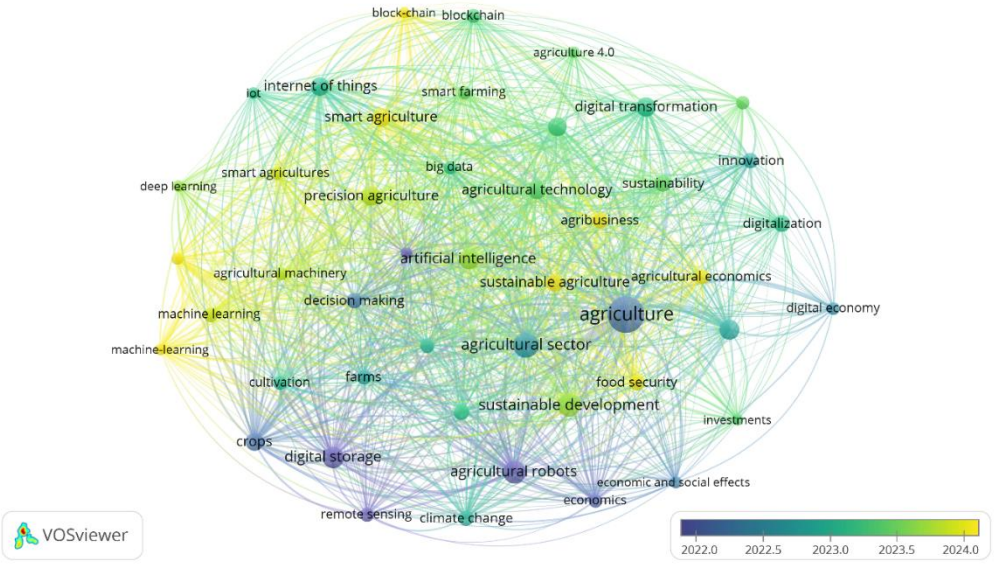

Figure 5. Overlay Visualization

Source: Data Analysis

The middle period, represented by green tones, is dominated by broader and more established themes such as agriculture, agricultural sector, artificial intelligence, precision agriculture, Internet of Things, smart agriculture, digital transformation, sustainability, and agricultural technology. This suggests that digital agriculture research began to consolidate around integrated technological systems, where AI, IoT, smart farming, and digital transformation became central concepts in improving agricultural productivity and sustainability.

The most recent topics, shown in yellow, include machine learning, deep learning, blockchain, agricultural machinery, decision making, agribusiness, and food security. These emerging themes indicate that current research is moving toward more advanced analytical models, transparent supply chains, intelligent decision-support systems, and practical applications for strengthening food security.

From the density map, one can determine the major topics or themes that are mostly discussed by researchers when doing research in digital agriculture. The areas colored bright yellow are those keywords that have the highest occurrence rates and connections to other keywords or topics. The keyword 'agriculture' is shown as the dominant hotspot in this analysis, and this means that the term forms the core theme around which digital agriculture research revolves. Some of the high-density topics in the area are 'agricultural sector', 'sustainable

development', 'agricultural economics', 'precision agriculture', 'artificial intelligence', and 'agricultural technology'. From this, it is evident that the present scholarship focuses more on the integration of digital technology in the agricultural sector with an aim to achieve sustainable development and improve economic performances.

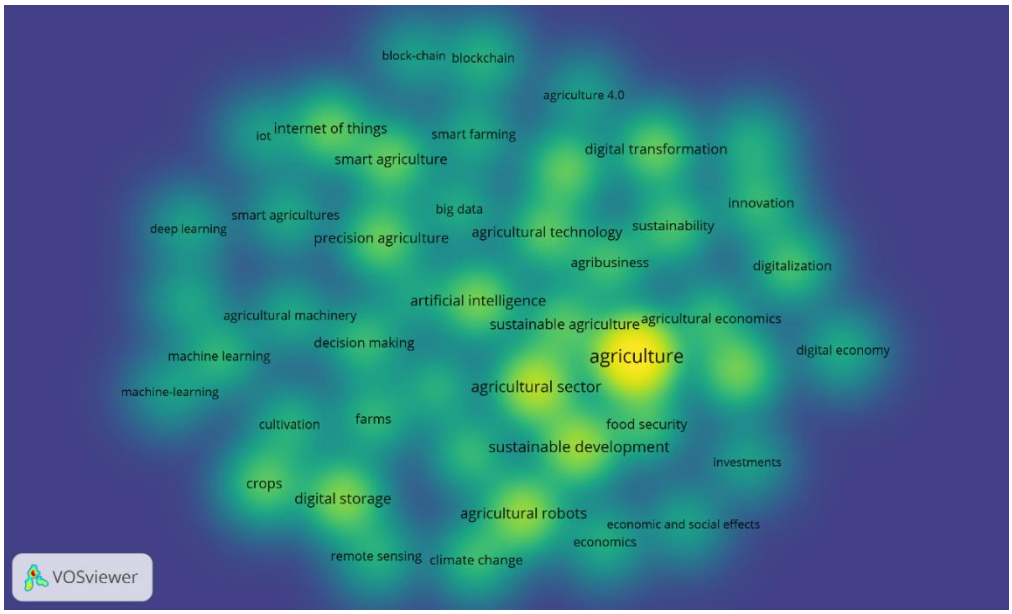

Figure 6. Density Visualization

Source: Data Analysis

In contrast, topics such as blockchain, deep learning, machine learning, digital economy, investments, remote sensing, agricultural robots, and climate change appear in lower-density areas, represented by green and blue shades. Although these themes are less prominent in terms of publication volume, they represent important specialized and emerging research directions within the field. Their presence indicates growing scholarly interest in advanced automation, intelligent analytics, traceability systems, and climate-resilient agricultural practices.

4. CONCLUSION

This bibliometric study provides a comprehensive overview of the global development of digital agriculture research and reveals a rapidly expanding and increasingly interdisciplinary field. The findings indicate that digital agriculture research is primarily driven by themes related to artificial intelligence, precision agriculture, smart farming, Internet of Things (IoT), digital transformation, and sustainable development. The co-authorship, institutional, and country collaboration analyses demonstrate the existence of active international research networks, with countries such as China, India, the Russian Federation, the United States, Germany, Italy, and the United Kingdom playing significant roles in knowledge production and dissemination. Citation analysis further reveals that foundational studies on big data, Agriculture 4.0, smart farming, and agricultural digitalization have strongly influenced the evolution of the field. Keyword mapping, overlay visualization, and density analysis show that research has evolved from early concerns related to data management and digital infrastructure toward more advanced topics such as machine learning, deep learning, blockchain, intelligent decision-making, food security, and sustainability-oriented agricultural innovation. Overall, the results suggest that digital agriculture has become a strategic research domain that integrates technological advancement with agricultural productivity, economic development, and environmental sustainability. Future research should

continue exploring emerging technologies and strengthen interdisciplinary and international collaborations to support the development of resilient, efficient, and sustainable agricultural systems worldwide.

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