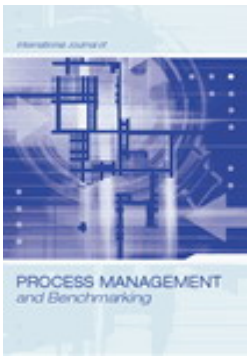

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Smart irrigation systems enabled with internet of things: a bibliometric review

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Smart irrigation systems enabled with internet of things: a bibliometric review

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Abstract: Precision agriculture, often known as smart farming, has emerged as a cutting-edge method for addressing current agricultural sustainability concerns. Agricultural equipment integrated with the internet of things (IoT) is a major element of the next agricultural revolution. The purpose of this paper is to study a bibliometric review of the IoT-enabled next-generation smart irrigation system. The study identifies major research streams and future research objectives in the literature on IoT-based soil health monitoring using bibliometric analysis. Methods like co-occurrence; bibliometric coupling, trend topic analysis were applied to identify potential research areas, recent technologies, and other important parameters that would help in future research streams.

Keywords: internet of things; IoT; bibliometric; co-occurrence; bibliometric coupling; smart technology; agriculture.

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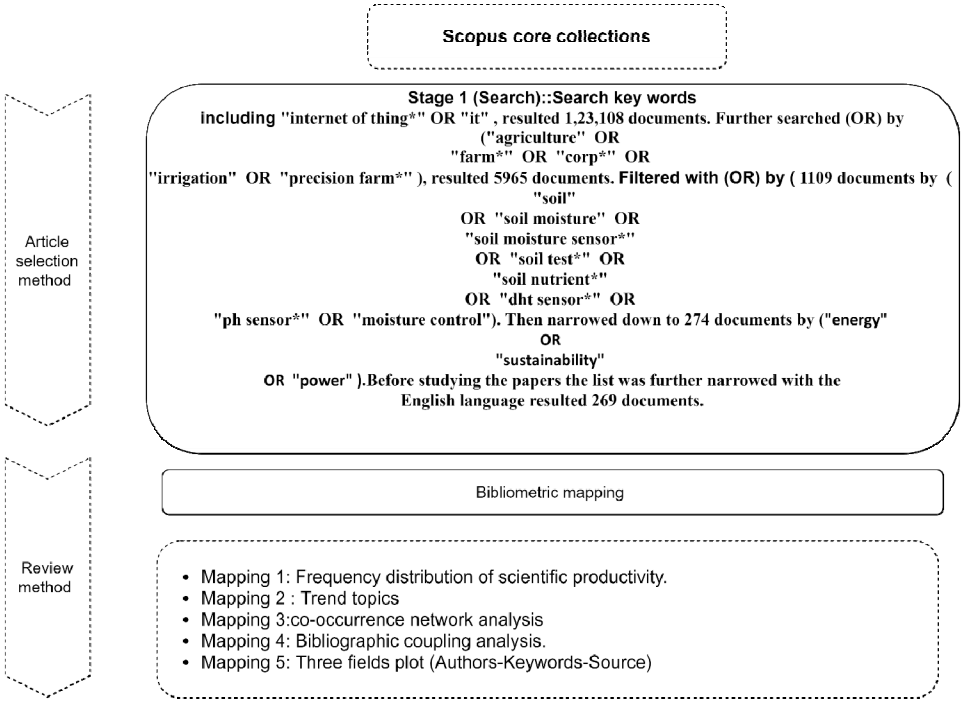
1 Introduction

The internet of things (IoT) is a cutting-edge technology in computing and communications that points to the future. Its development is dependent on constant advances in a variety of critical sectors. After the development of programmable logic controllers (PLCs) and robotics, the programming aspects became associated with the IoT. The IoT focuses on taking advantage of the internet's communication and computational capabilities, including cloud infrastructure. Apart from the advantages of IoT there is still a lack of understanding of the different parameters (Vikram, 2021). Different methods can be applied to study smart irrigation systems in agriculture, for example, systematic review, bibliometric analysis, comprehensive analysis (Rahul, 2012).

The IoT-based smart agricultural techniques are progressing enormously with a dynamic shift from manual to automation (Jarin et al., 2021). With the improvement of tracking system the IoT also improves the production (Alavi et al., 2022; Pereira et al., 2022). It is fundamental for smart farming to integrate IoT-based UAV prospects that are used to update the database with observed data (Kuruvilla et al., 2022). But the improvements of IoT-based agriculture require an in-depth understanding of market demands as well as untapped areas of exploration. Extensive literature, so far, on IoT base agriculture requires to be summarised and systematically synthesised. Because of the large data size, a citation-based bibliometric review is the best approach exploring the top contributing authors, journal sources, and institutions (Al Mamun et al., 2021). In addition, the scientific citation mapping in bibliometric analysis revisits the trending topic words and keywords for exploring key research streams and future research directions. The trending topics also indicate recent technologies that can be implemented in smart irrigation systems (Harun, 2021).

To obtain more unbiased information, bibliometric analysis is highly effective. The purpose of this paper is to review IoT-based smart agricultural techniques using bibliometric analysis (Yuir, 2021). Sensors, image processing algorithms, smart irrigation techniques are the major sectors that need bibliometric analysis (Yin, 2021; Tin, 2022).

Figure 1 Article selection process



2 Methodology

Structured review, review for model/framework building, review based on theory, hybrid-future research, bibliometric review, and content analysis are some of the review methodologies that have been used over the years (Kousis and Tjortjis, (2021). This study uses bibliometric analysis to identify significant research streams and future research agendas in the literature on IoT-based soil health monitoring. The following sub-sections discuss different aspects of methodology and helps to understand the significance of adapting smart agricultural systems.

2.1 Research methods

The bibliometric method provides researchers a tool to comprehend the connections and trends in the literature. Bibliometric techniques look for undiscovered connections in the literature's bibliographic information. For example, co-citation network analysis can be used to group scientific documents based on their citation links and semantic similarities and co-occurrence keyword analysis can be used to identify the main research areas and methods and techniques in a given area of research (Chen et al., 2010). Various software are used for the above analysis – R, VOSviewer, Bibexcel, Histcite and others – that help to visualise publication, citations, author's data and interconnections between them. These show a literature's knowledge-map as well as provide comprehensive bibliometric analysis in statistical findings. These visualisations provide an understanding of existing

knowledge and potential research areas. Thus, a comprehensive investigation in the field of soil health monitoring and smart farming is possible using bibliometric analysis.

2.2 Data collection

2.2.1 Database

Scopes databases were used to find relevant documents. Scopus is an abstract and citation database created by Elsevier in 2004. Scopus has over 36,377 titles (22,794 active titles and 13,583 inactive titles) from 11,678 publishers, with 34,346 peer-reviewed journals in top-level topic disciplines such as biological sciences, social sciences, physical sciences, and health sciences. It is divided into three categories: book series, journals, and trade journals. Every year, all journals in the Scopus database are evaluated for adequate high quality using four different numerical quality measures for every title.

2.2.2 The searching steps

The searching terms are formed in four steps. The first step is using 'internet of thing*' OR 'iot' and the database showed 123,108 documents. This is the most relevant keyword with the topic. These documents were filtered using keywords – 'agriculture' OR 'farm*' OR 'corp*' OR 'irrigation' OR 'precision farm*'. These terms find the specific related documents in the database and showed 5,965 results. Having these results the list was narrowed by searching different keywords: 'soil' OR 'soil moisture' OR 'soil moisture sensor*' OR 'soil test*' OR 'soil nutrient*' OR 'dht sensor*' OR 'ph sensor*' OR 'moisture control', resulting 1,109 documents. AS energy, power consumption and sustainability are important areas to study, the documents were filtered using keywords: 'energy' OR 'sustainability' OR 'power' resulting 274 documents. Before studying the papers, the list was further narrowed with the English language resulted 269 documents.

2.3 Data analysis

2.3.1 Co-occurrence analysis

Co-occurrence analysis is a method that detects matched data that appears in different articles and datasets. Co-occurrence networks are commonly used to visualise potential relationships between researchers, organisations, sources, methods, and concepts visually. Co-occurrence networks are displayed graphically, and conclusions can be derived about relationships between things in the domain. As a result, these co-occurrence keywords may be regarded as the knowledge base research issue of the study (Buzydlowski, 2015).

2.3.2 Bibliographic coupling analysis

If two documents refer one or more documents in common, they are bibliographically connected. The 'coupling strength' of two specified papers increases as the number of citations to other papers they share increases. The diagram to the right depicts the concept of bibliographic coupling (Rabbi, 2011). Two writers are said to be bibliographically coupled if the cumulative reference lists of their respective oeuvres both contain a reference to a shared document, and the degree of their coupling increases as the number

of citations to other texts that they both share increases as well (Boyack and Klavans, 2010).

2.3.3 Frequency distribution of scientific productivity

In a specific field, it describes the frequency with which authors publish their work. 1/x is a fraction of the number of authors who make a single contribution in a given period, according to the formula d1/Xa, where Xa nearly always equals two, i.e., an approximately inverse-square law, where the number of authors publishing a certain number of articles is a fixed ratio to that of authors publishing a single article. As the number of papers published rises, the frequency with which authors publish decreases.

2.3.4 Three fields plot analysis

Three-field to represent the proportion of study topics for each nation and the recency of the papers that they mentioned, a plot (Sankey diagram) of country, keyword, and year of publication of the cited references was generated.

2.4 Framework of research methods

Having bibliometric methods discussed above, a framework is designed, showed in Figure 1. The steps are:

Step 1 Searching related keywords in the Scopus database a number of documents (269 out of 5,965) were selected for analysing.

Step 2 The less relevant literature was eliminated in the second step by examining the content of the title and abstract in each record quickly. The remaining records were then saved for further bibliometric analysis. The knowledge evaluation was tracked down by time-span co-citation analysis. Then, the knowledge domain was identified analysing documents co-citation analysis. Lastly, co-occurrence analysis was done to identify the knowledge frontier. To represent the existing achievements, the entire dataset was used in the first and second methods. The final analysis used a dataset that included recently published articles to demonstrate the most recent research trends.

Step 3 Having the desired data, the co-citation analysis, co-occurrence, and time-span analysis was done with the help of bibliometric visualisations.

Step 4 Using further analysis methods.

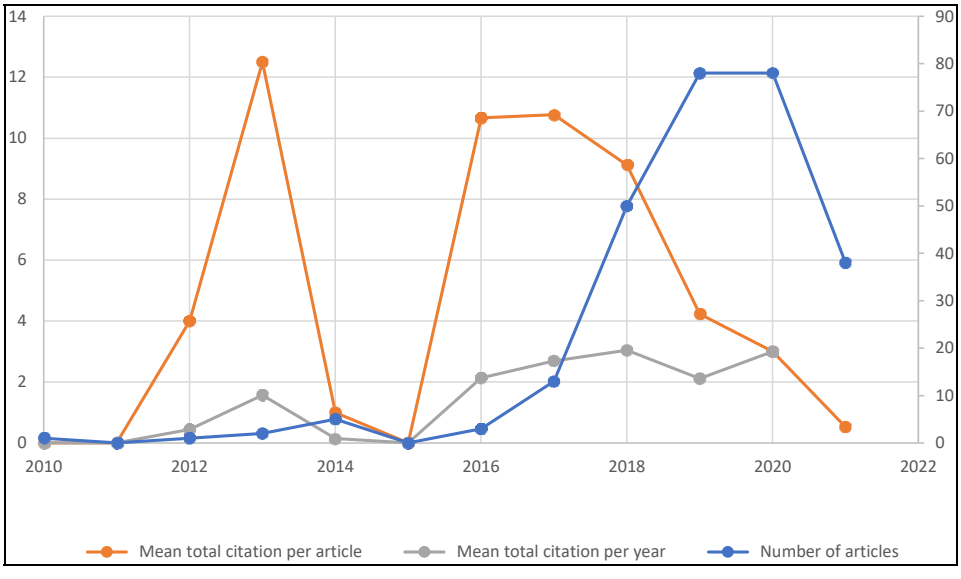
3 Results from bibliometric analysis

3.1 Journal citation and publication in recent times

According to the Scopus database, the first article on soil health monitoring was done in 2010. However, an IoT-based monitoring system was first introduced in 2012 (L. Li, M. Zhang et al.). Science then, the growth of publications on IoT-based monitoring system and citation per article has been increasing. Figure 2 presents publication and

citation records on application of IoT in soil health monitoring. In 2013, citation per article reached the highest as there were only a few articles available. Besides having the lowest number of average total citations per year and publication in 2015, the citation and publication growth began to rise a year after. In the time span of 11 years (2010–2021), there are 269 publications that took place having average years from publications about 1.94. Average citation per year remained somewhat steady throughout the years 2016 to 2020. However, in 2016, the number of publications has increased significantly causing a lower number of citations per article. The similarities between the documents are analysed by co-citation network analysis.

Figure 2 Journal citation and publication bygone times (see online version for colours)

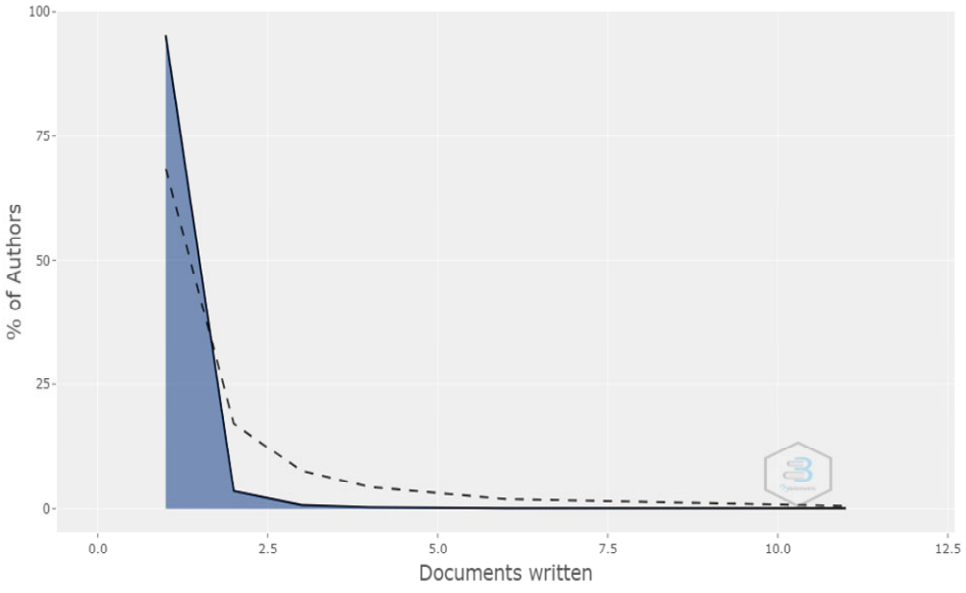


3.2 Lotka's law

Lotka's law describes the frequency of publications in a particular dataset in a given time frame. It has been used to determine the productivity of publication in a particular field. Here % of authors vs. documents written graph was established using a dataset collected from the Scopus database. This graph indicates with the increase of the percentage of authors the number of written documents decreases (Boilo, 1965).

The figure shows that most of the authors have written less than two documents. By comparing the ideal pattern and existing pattern of document writing it was found that 95.3% of authors have written only one document, which is higher than the ideal patterns of article writing. On the other hand, only 3.5% of authors have written two documents. Only 0.7% of authors managed to write documents on IoT-based agricultural monitoring system, which is much less than the expected pattern. This visualisation indicates two things, first, there is a research gap in this particular field, which is essential for the development of agricultural production. Lastly, in the future, this research area would be a great sector for researchers as agricultural innovation continues to move forward.

Figure 3 Frequency distribution of scientific productivity (see online version for colours)



3.3 Trend topics

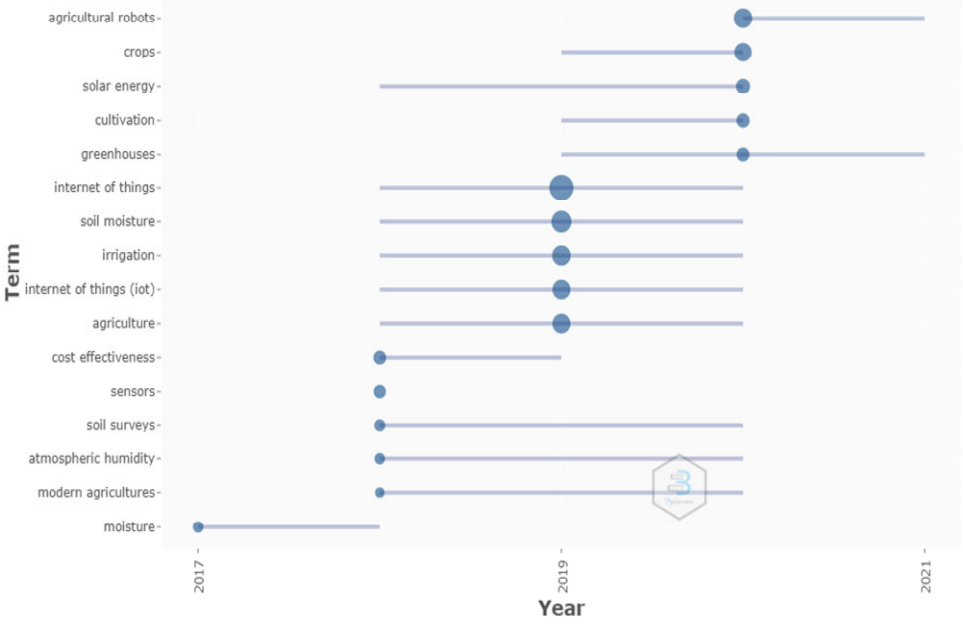
To identify the trend topics, word growth was analysed using a Scopus index dataset. The time span is from 2010 to 2021 soil moisture was a trending topic in 2017 which has a term frequency of 7. That indicates it was a trending research area which continued up to 2018. Modern agriculture, atmospheric humidity, sensors, cost effectiveness, IoT, agriculture, irrigation, soil moisture were the trending topic from 2018 to 2020. Within this trending topics IoT has the highest term frequency (154). Cost effectiveness (2018–2019), cultivation (2019–2020) and crops (2019–2020) hast the term frequency of 14, 16 and 49 respectively. Solar energy was the trending topic from 2017 to 2020 having the term frequency of 21. Greenhouse and agricultural robots were also the trending topics in 2020 having the term frequency of 14 and 62 respectively.

3.4 Co-occurrence network

A keyword co-occurrence network analyses information components and knowledge structure based on their frequent occurrence in literatures. In our calculation, the minimum number of occurrences of a keyword was set to 5 which resulted 119 author keywords grouped in five clusters with 3,066 links and with a total link strength of 7,934. The possible areas of research were identified by the keyword clusters in Figure 5. Among the five identified clusters, cluster 1 (red) contains 34 keywords. The main keywords occurrence in cluster 1 are: IoT – 173 times, agricultural robots – 63 times, wireless sensor network – 41 times, precision agriculture – 41 times, smart agriculture – 18 times. In cluster 2 (green) some of the major occurrence among the 24 keywords are: humidity control – 6 times, image processing – 5 times, intelligent systems – 6 times, smart irrigation system – 5 times, microcontrollers – 6 times. In the third cluster (blue),

artificial intelligence – 12 times, data handling – 7 times, decision making – 13 times, cloud computing – 7 times, decision support system – 6 times, water management – 13 times occurred in the dataset. Similarly in cluster 4 (yellow), moisture control – 39 times, automatic irrigation system – 5 times, machine learning – 9 times, pH sensors – 5 times and in cluster 5 (purple), data mining – 5 times, greenhouse – 14 times, remote sensing – 5 times, sustainable development – 15 occurred among the most occurred keywords in the clusters.

Figure 4 Trend topics visualisation (see online version for colours)



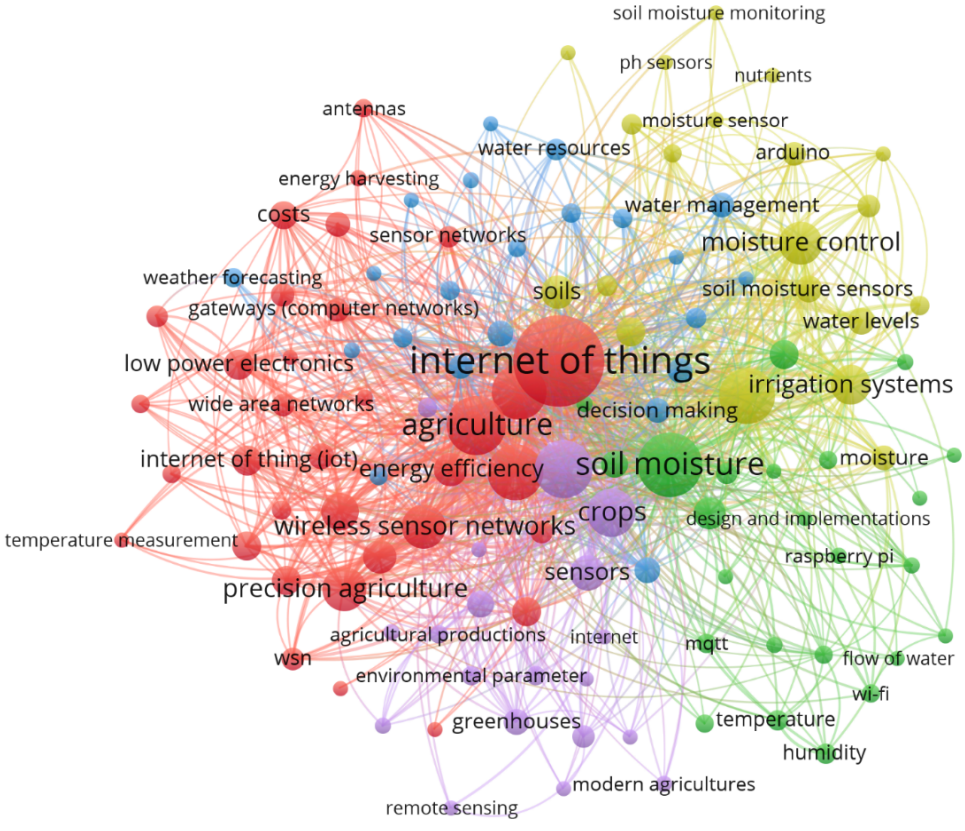
3.5 Bibliographic coupling of the documents

Bibliographic coupling refers to the common research areas between the documents. The coupling strength depends on the number of citations are shared among the documents. As the minimum number of citations were set to 3, out of 272 documents, only 32 documents meet the threshold. The 32 items were grouped into total 7 clusters and total link strength was 164.

In cluster 1 (red), Agrawal et al. (2020) consists of the highest citations among the 9 other documents. It proposes an energy effective IoT enabled precision agricultural system (Agrawal et al., 2020). It uses advanced duty cycle algorithm to estimate energy requirements for IoT enabled agricultural system. Cluster 2 (green) consists of 4 documents. Vij et al. (2020) scored the highest citation (14) that proposed an IoT-based machine learning approaches for farm irrigation system (Vij et al., 2020; Krishnan et al., 2020). The system also consists of wireless sensor network for automation where sensor modules will store data on a common server and further analysis will be done using machine learning. Krishnan et al. (2020) consists the highest number of citation (29) in the third cluster (blue) where a smart irrigation system was proposed that uses GSM

technology and gives messages on current status of temperature, humidity with the help of fuzzy logic controller. The proposed system will also control the power supply to the motor according to the environmental behaviour for irrigation. A low-cost node of small dimensions that was easy to install and consumed less energy was developed Valente et al. (2015) which was cited most, seven times in the cluster 4 among four other documents. For the advancement of a cluster-based library, the node can be used immediately. For smart agriculture in Douro vineyards, the established nodes will represent a huge step forward (Valente et al., 2015).

Figure 5 A co-occurrence network analysis of author keyword (see online version for colours)



In cluster 5 Castellanos et al. (2020), a narrow band IoT system using UAV aided network was proposed using low power IoT technology which is cited most, ten times among four other documents. The system will also help to collect soil parameters from underground especially in potato cultivations. An NB-IoT-based access network and an LTE-based backhaul network with a UAV-mounted gateway are being built as a simulation tool (Castellanos et al., 2020). In cluster 6 Shafi et al. (2019), a review of agricultural sensor networks, including both near- and far-field networks, is provided, along with many issues and considerations were introduced in this document. WSN in agriculture contains sensors and wireless nodes for measuring environmental behaviour, platforms for obtaining crop spectral images, and common vegetation indexes that are

utilised in the analysis of those images are also discussed in the review paper. This document is cited 54 times, which is the highest among four other documents in this cluster. Feng et al. (2019) analysed agricultural application scenarios and experiments in order to uncover acceptable and practical wireless communication technologies for precision agriculture. Comprehensive analysis was done among WSN, ZigBee, NB-IoT, LoRa to determine better motoring facility in agricultural sector (Feng et al., 2019). This is the highest cited document among three other documents in this cluster. But other documents are also highly cited in this cluster. For example Pereira et al. (2020) The FAO56 method is used to analyse soil water balance (SWB) model approaches for determining crop irrigation requirements and scheduling irrigation. The Kc-ETo method is analysed in terms of foundation notions, such as standard vs. actual Kc concepts, as well as single and dual Kc methods. This paper is cited 15 times, which is the second highlight in this cluster.

Table 1 Comparison of previous literature review papers

References	*Methods*	*Findings*	*Future works*
Issad et al. (2019)	Comprehensive literature review	• In the data mining process for smart agriculture, image analysis must be combined with other sensed real-time data. • The development of models that consume less time, space, and give adequate accuracy for integration into mobile devices is essential.	• More accurate techniques for data mining is needed. • Data quality, spatial and semantic data integration can be improved.
De and Singh (2021)	Systematic literature review	• Real-time applications such as GIS and big should be used widely. • Fuzzy-based capacitated cold storage location models should be used more. • Real-time models should be used in environmental and sustainability issues.	• Non-fuzzy-based applications can also be analysed for deep learning. • Using dataset of other index will provide better learning.
Halgamuge et al. (2021)		• Use of recycled water and hydroponic systems were most prevalent for implementing VGs. • Comparison of the power usages in VGs. • Solar power energy needs more implementation in VGs.	• New security implementation is required. • For smart farming IoT-based research should be done. • Hydroponic, aeroponics, aquaponics technologies implementation is needed for greenhouse system advancement.

Table 1 Comparison of previous literature review papers (continued)

References	*Methods*	*Findings*	*Future works*
Sharma et al. (2020)	Comprehensive literature review	• Low literacy rate creates gap between technology and farmers. • Farmers are less motivated to use smart farming tools. • Smart sensors require heavy energy consumptions. • Harvesting using machine learning technology provides higher accuracy in firming. • Development in image processing algorithms will provide higher accuracy of detecting crop disease. • Swarm intelligence, adaptive machine learning algorithms can be used for more precision agriculture.	• Different types of algorithms like hybrid algorithms can be analysed for further sustainable use of resources.
Bersani et al. (2020)		• Technological development in greenhouse farming is necessary. • Solar greenhouses system has the best technological strategy. • The ICT control system has a great potential for greenhouse farming.	• More advanced power management system can be analysed.
Shaf et al. (2019)		• Limited use of drone technology among the farmers. • Environmental variation affects the accuracy of collected data.	• Analysing other soil parameters will help in decision-making in smart agriculture.
Li et al. (2020)		• Automated sprinkler irrigation reduces cost and ensures minimum watering in the fields.	

3.6 Three fields plot

Considering 15 items, the three fields plot authors-keywords-source based on the Sankey diagram was established. According to the graph, four (R.K. Kodali, A. Kumar, H.B. Mahajan and A. Badarla) authors have more than three documents on smart farming. The major keywords IoT, smart farming, precision agriculture are used in the documents. Advanced intelligent systems and computing, sensors (Switzerland),

international journal of advanced science and technology are some top sources considering incoming flow count.

Figure 6 Bibliographic coupling analysis (see online version for colours)

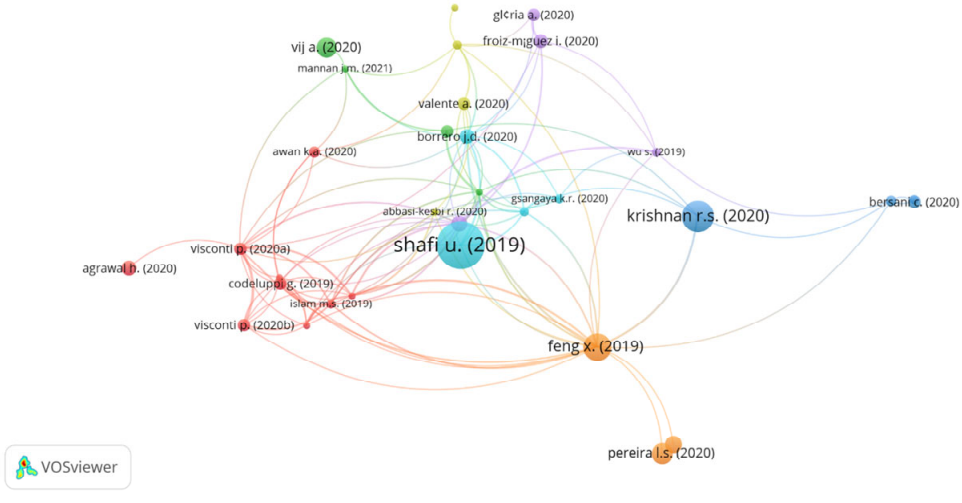
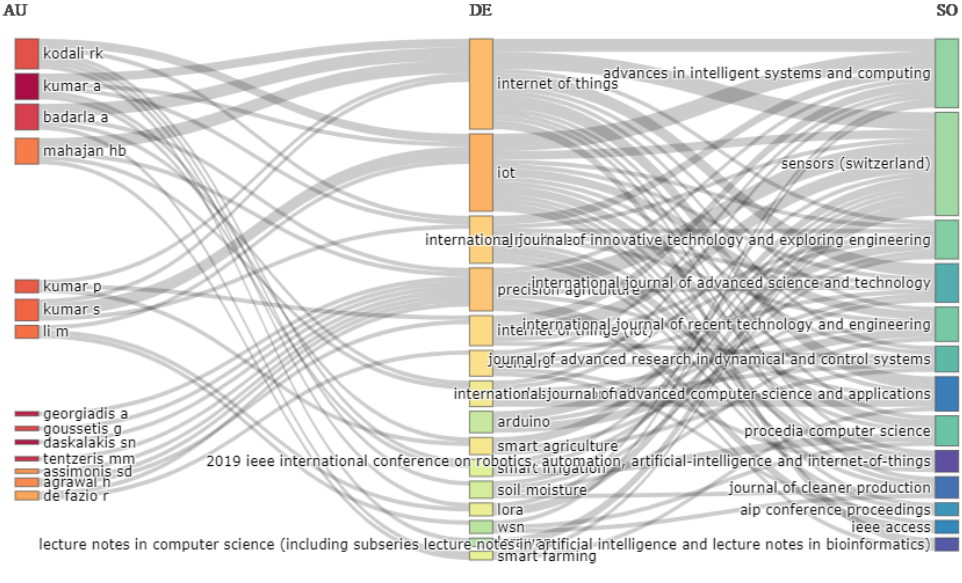


Figure 7 Three fields plot authors-keywords-source based on the Sankey diagram (see online version for colours)



4 Conclusions

Technologies like the IoT, image processing, soil nutrient sensing were reviewed using bibliometric analysis. Publication and citation records on the application of IoT in

agriculture reveal that in recent times there are fewer publications, creating a gap in the research areas. As the amount of agricultural data expands, powerful analytical tools capable of processing and evaluating enormous volumes of data are becoming highly significant (Harun, 2021; Lost, 2020). Trend topics, bibliographic couplings, co-occurrences network analysis brings the information to understand the recent topics as well as the authors working with updated methods. Modern technologies require deep analysis, such as analysis of the sensors, data processing and machine learning that can be studied using bibliometric analysis (Emira et al., 2019; Syafrudin et al., 2019).

With the help of the bibliometric method, an idea was generated about the authors and publishing sources (Farooq et al., 2019). The most vital finding is a smaller number of publications were found during the previous years which are alarming as most of the authors have written only one paper about this topic according to our dataset. Lotka's law also indicates that more effective research is needed in this smart farming sector. This review will lead towards necessary improvement areas of IoT-based smart farming techniques. The majority of the authors have only written one or two papers. The graph also reveals that 95.3% of authors have authored just one paper that is why more authors should contribute to this field to reveal different potential sectors.

Trend topic analysis revealed the recent situation and technologies applying to this sector (Farooq et al., 2019). The analysis also revealed the future topics for the smart irrigation sector. Bibliographic coupling analysis helps to identify the most cited papers that need to be reviewed to have a clear picture of this continuously improving sector (Haque et al., 2016; Kour and Arora, 2020; Odoi-Lartey and Ansong, 2018). Relations between topics, scientific indexing, advanced information technology are visualised through the co-occurrence network which reveals that the IoT – 173 times, agricultural robots – 63 times, wireless sensor network – 41 times are referred in papers. The findings emphasise that IoT-based smart agriculture has the most recent research interest among the authors in this field. Among the papers, 32 papers have the most common research interest, which was analysed by bibliographic coupling (Thiam et al., 2021).

More researchers should be done on how to minimise the gap between farmers and smart irrigation technologies (Kousis and Tjortjis, 2021; Loganathan, 2022). More accurate algorithms can be used in technologies to ensure precision farming. The adaptation process of these new methods and electronic devices must be another major aspect to study. To achieve this goal review on this topic is necessary (Kour and Arora, 2020; Odoi-Lartey and Ansong, 2018).

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