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The farmer in the Dell: Hi-Ho, the Derry-O, the current status of worldwide science mapping on precision irrigation

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Abstract

Precision irrigation is essential to water-saving agricultural practices because agriculture and food are vital sectors for nations. This study evaluated how precision irrigation in agriculture is discussed in the current academic literature via science mapping of bibliometric data. A total of 967 documents spanning an 83-year publication timeline were accessed from the Scopus database using keywords related to precision irrigation. The extracted bibliographical information was analysed using Biblioshiny packages in R programming for trends, citation analysis, and intellectual structure. The findings show that precision irrigation research has grown over the past 20 years, with an average annual growth rate of 13.52% in publications. India is the most productive country in precision irrigation research, followed by China and the United States. Additionally, Hohai University has emerged as one of the top research institutions conducting precision irrigation research. In contrast, this study also shows that precision irrigation research has advanced from examining soil water and medium moisture content to creating an intelligent irrigation system to automate farmer decisions regarding crop water requirements and irrigation scheduling processes. These findings offer valuable insights for scholars seeking a deeper understanding of the global science mapping of precision irrigation for future research endeavours.

1. INTRODUCTION

Irrigation is practised worldwide to provide sufficient water for crop growth. It has become a critical element in water resource management, particularly during the off-planting season or when water resources are scarce in the cultivation area. Over 70% of all water extracted from surface and groundwater sources is used for agriculture (Wisser et al., 2008). India, the United States, and China had the most irrigated cropland area, with approximately 170 million hectares, 158 million hectares and 120 million hectares, respectively (FAO, 2020). According to Chaturvedi et al. (2015), countries such as China, India, and other South and East Asian countries will encounter the most significant increases in water demand. Ismail et al. (2020) projected future water demand in one of the granary areas in Malaysia from 2010 to 2099. They predicted that irrigation water demand would rise in the future, particularly during the dry season. The human population will also grow, necessitating the production of more food. Consequently, there is a need to plant more crops to meet human consumption needs as global water demand continues to rise (Wada et al., 2016).

Furthermore, unpredictable climate rapid change poses a challenge to farmers because it negatively impacts crop growth and indirectly reduces crop yield (Chaturvedi et al., 2015; Wisser et al., 2008). Abioye et al. (2020) classified irrigation methods into two categories: traditional techniques (flooding, furrow, and manual watering) and modern techniques (capillary, drip, and sprinkler). The suitability of the chosen irrigation method depends on factors such as crop type, environmental conditions, media characteristics, water quality, setup cost, and operating cost. As global water demand rises, each freshwater drop becomes more valuable, necessitating more efficient and intensive water management.

Precision irrigation is the long-term management of irrigation scheduling based on crop needs at the right place, right time, right amount, and correct method (Harun et al., 2015). Precision irrigation is a management irrigation practice that exploits sensors, computer software, and irrigation systems (Plaščak et al., 2021) in a management irrigation practice. Soil moisture sensors (Kumar et al., 2014; Liu et al., 2021; Mat et al., 2014; Jusoh et al., 2020), temperature and relative humidity sensors (Liu et al., 2021; Rafique et al., 2021), and plant water stress sensor (Stoochnoff et al., 2018; Venturin et al., 2020) are commonly used sensors in precision irrigation. However, Abidin et al. (2013) stated that using a plant water stress sensor is appropriate at the experimental level due to the system's limited information and time-

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consuming nature. The computer system and microcontroller used in precision irrigation vary in complexity depending on the system's scale. An advanced precision irrigation system with reliable data transmission is essential for open fields like paddy cultivation (Liu et al., 2021) due to its extensive coverage. Water distribution and nutrient supply can be monitored efficiently using precision irrigation techniques and higher crop yields can be produced (Mat et al., 2014; Plaščak et al., 2021). In addition, precision irrigation could increase economic efficiency since water can only be supplied to the field based on crop water requirement, resulting in optimal irrigation (Plaščak et al., 2021).

Bibliometric analysis is one of the rigorous science mappings (Donthu et al., 2021) and valuable tools (Xie et al., 2020) for analysing large volumes of scientific research. Bibliometric analysis studies aim to understand emerging issues and identify trends in any field for future research (Quevedo-Silva et al., 2016). Usually, the conduction of bibliometric analysis is assisted with the software tools such as Publish or Perish, Bibexcel, Biblioshiny, BiblioMaps, CiteSpace, SciMAT and VOSviewer (Moral-muñoz et al., 2020). The selection of suitable software tools depends on the study purpose, study objective, and database sources support. As analysed by Baas et al. (2020), Scopus has the most extensive worldwide coverage and serves as a high-quality bibliometric data source. Although Web of Science (WoS) provides excellent database sources, Scopus and WoS complement each other since no single database provider is perfect (Burnham, 2006).

The review on precision irrigation has been conducted by several scholars such as Abioye et al. (2020), Adeyemi et al. (2017), Wenting et al. (2020), Liang et al. (2020), Liang et al. (2021), Plaščak et al. (2021), and Zhang et al. (2021). However, the reviewing styles on precision irrigation were primarily focused on the narrative review, and there is limited coverage of bibliometric analysis. There was a chance that articles related to precision irrigation research would not be considered due to author accessibility or bias in article selection during the reviewing process. There is an urgent need to review broader articles on precision irrigation so that the direction of precision irrigation can be clearly understood.

In this study, we assessed the science mapping progress on precision irrigation worldwide. We attempt to answer the following specific research questions: a) What are the global research trends on precision irrigation application?, b) Who are the leading countries in precision irrigation research? and c) What is the knowledge growth in the past, current, and future perspectives of precision irrigation research?. Therefore, a bibliometric analysis approach was utilised to answer the highlighted research questions.

2. MATERIALS AND METHODS

The data were excessed and extracted from the Scopus database published by Elsevier (Netherlands) in January 2022. Scopus is the largest abstract and indexing database covering nearly 36,377 titles from approximately 11,678 publishers. Among these, 34,346 are categorized as peer-reviewed journals in various disciplines such as life sciences, social sciences, physical sciences, and health sciences (Burnham, 2006). According to Baas et al. (2020), Scopus is a curated and top-notch source of bibliometric data with good data quality for academic research in quantitative science subjects. The methodology of the current study was based on the workflow for science mapping as described in Aria and Cuccurullo (2017) and Donthu et al. (2021).

The search string used in this study was TITLE (“precis* irrigat*” OR “water saving irrigat*” OR “smart irrigat*” OR “digit* irrigat*” OR “site specific irrigat*” OR “automat* irrigat*”). The keyword search was conducted in the title field to ensure that only the most relevant articles were included in this study for future analysis. The selection of keywords was based on synonyms and suggested keywords from Scopus. Phrase searching, the Boolean operator of ‘OR’, and truncation were embedded into the search string for comprehensive and effective coverage of the literature (Prill et al., 2021). The records were excluded for non-English documents and papers published from 2022 onwards. Moral-muñoz et al. (2020) suggest that the extracted database records between 500 and 50,000 are sufficient depending on the field of study. The simplified methodology of the present study in the form of a flow diagram is shown in Figure 1.

The refined records were exported into comma-separated values (CSV) files as raw source data. The science mapping tools of Biblioshiny, a part of the R packages (Version 4.1.2 for Windows), were adopted for text mining and quantitative analysis of the findings. The graphical representations were created using Microsoft Office Professional Plus 2019 (Version 2111) and Biblioshiny. The analysis focused on the dataset's frequency, social structure, and conceptual framework related to precision irrigation.

The annual scientific production of the literature calculated in Biblioshiny is based on the Compound Annual Growth Rate (CAGR), commonly used in the business field over a specified time,as in Equation 1 (Ahmi, 2022) where V_{final} is end value, $V_{initial}$ is stat value, and t is time in years.

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$$CAGR = \left(\frac{V_{final}}{V_{initial}}\right)^{1/t} - 1 \qquad (1)$$

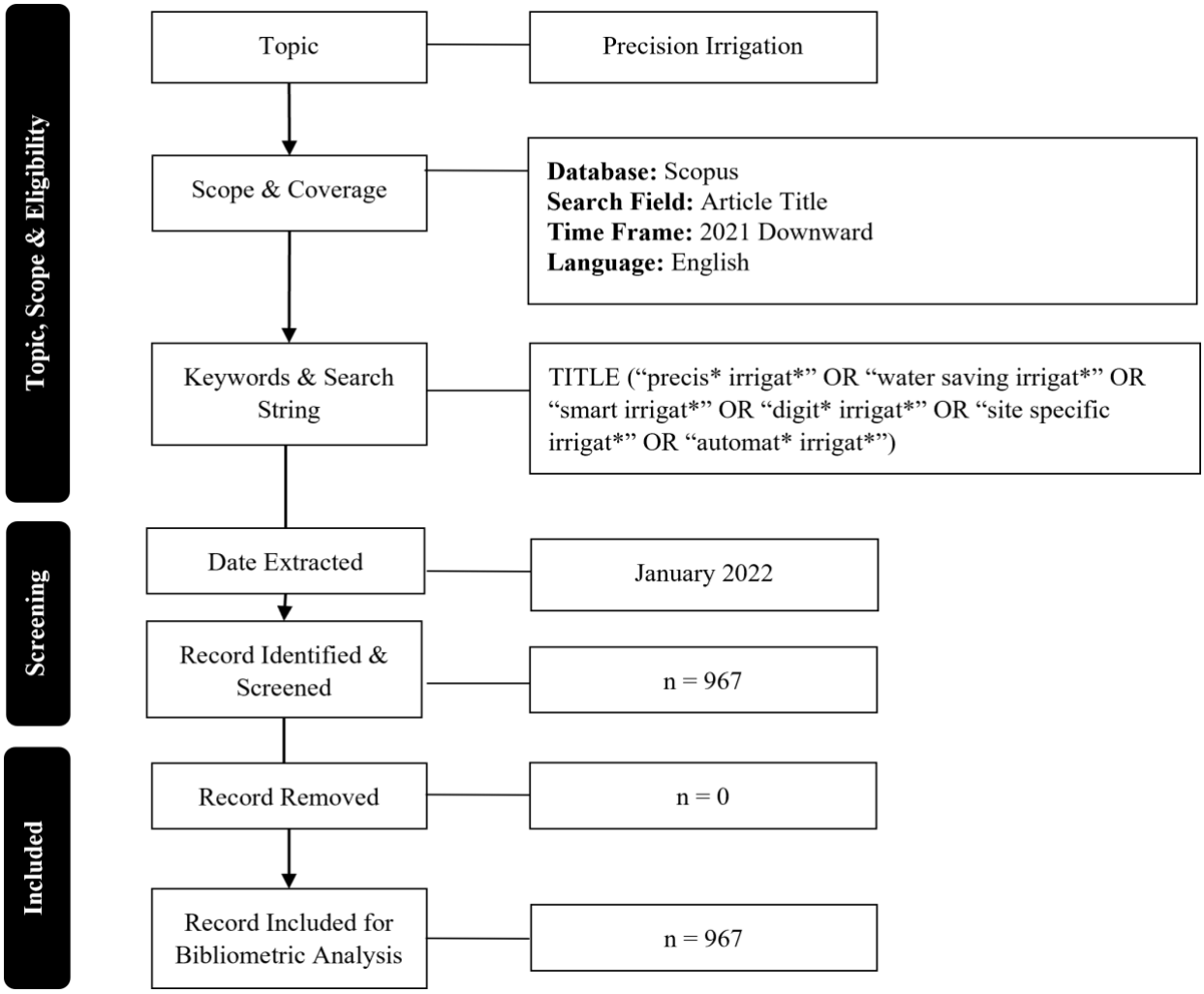

Figure 1: Flow diagram of the search strategy (Adopted from Zakaria et al., 2021)

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3. RESULT AND DISCUSSION

3.1 Global Research Trends

A total of 967 documents on precision irrigation were retrieved from the Scopus databases from 1938 until 2021. Most of the published literature comprises conference proceedings (n=441) and complete research articles (n=480). Some of the records are published in the form of book chapters (n=21), review articles (n=12) and the rest (n=13) were published in other forms (editorial, erratum, note and short survey). Based on the searching strategy, the first paper that appeared in the database was the article of Lott (1938), where the author discussed the fundamentals of automatic irrigation mechanisms for sandy soil. The analysis revealed that 2991 scholars wrote papers on precision irrigation research across 8 different document types. Most published articles involved multiple co-authors (2949 authors) with various institutions. The overall collaboration index of the authors on the precision irrigation study was 3.2. Only 2% or 42 authors published the papers with a single author. Collaboration among researchers is vital since it increases the quality and complexity of interdisciplinary research publications (Stallings et al., 2013). Although the collaboration index indicates cooperation between authors, it is not an absolute collaboration among researchers since not all cooperation ended with publication (Cabrera et al., 2018). Detailed information on precision irrigation research from the Scopus database is provided in Table 1.

General Information	Results
Time span	1938 - 2021
No of documents	967
Average citations per document	9.511
No of references	23178
Document Types	
Article	480
Book chapter	21
Conference paper	441
Editorial	3
Erratum	3
Note	5
Review	12
Short survey	2
Authorship and Authors Collaboration	
No of authors	2991
Authors of single-authored documents	42
Authors of multi-authored documents	2949
Documents per Author	0.323
Authors per document	3.09
Collaboration index	3.2

Table 1: Main information on precision irrigation research extracted from Scopus database (1938-2021).

Figure 2 illustrates the annual trends in precision irrigation research growth over the course of 83 years, from 1938 to 2021. The annual growth rate of precision irrigation research is 13.52 %, as analysed by Biblioshiny. The articles published follow the second-order polynomial equation ($y = 0.5813x^2 + 6.6723x + 24.671$) with an R squared value of 0.8844. In the early research exploration, only a few articles on precision irrigation caught scholars' attention (1938 to 1999). For 61 years (1938 to 1999), most of the years did not record any publications, which is not depicted in this result. However, starting in the new millennium, precision irrigation research has quickly attracted scholars.

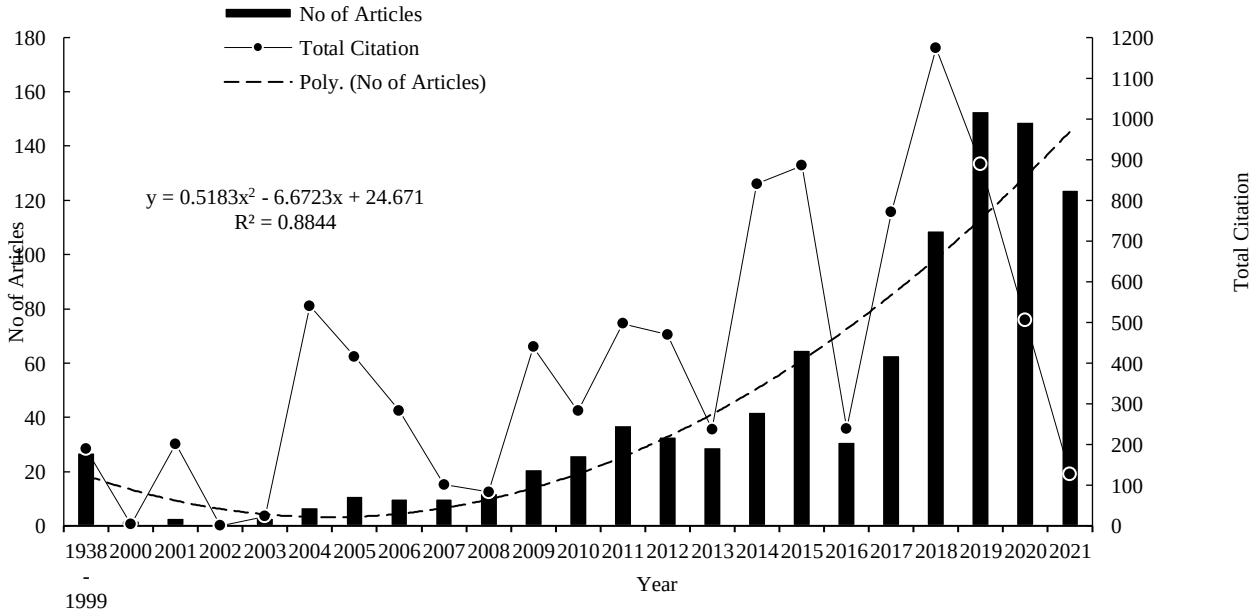

Figure 2: Yearly growth trends of precision irrigation research over 83 years.

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From the data extraction, the scholars rarely used the precision irrigation term in their article title (Pierce, 2010; Plaščak et al., 2021). It has been reported that precision irrigation research emerged in the early 1990s in the United States and other countries where most of the development was based on a refinement of the mobile irrigation system, which, due to its current degree of automation, covers large areas and applies varying amounts of water. In addition, the recent development of modern irrigation mostly involves the use of various sensors to detect media conditions and environmental changes, which has become quite popular in the new millennium era (Li et al., 2020; Munoth et al., 2016). The number of published articles increased steadily, starting from 2004 until 2011. However, it started to fluctuate in increasing trends from 2012 until 2017. The total publication peaked in 2019 (n=153), while total citations recorded the highest in 2018 (n=1174). This pattern demonstrates that over the past five years, more scholars have focused on research on precision irrigation. Although the present citation displays low numbers, it is anticipated that the overall number of citations for the most recent year of publication will rise in the future.

3.2 Leading Country in Precision Irrigation Research

Table 2 lists the top 10 productive countries in precision irrigation research from eighty-five countries in the dataset. The finding revealed that India published the most (n=242), followed by China (n=227) and the United States (n=155). Surprisingly, if total citations were considered, they were ranked inversely with the country's number of publications.

Despite the United States producing fewer articles than the top two countries, their research impacted the academic society, where more researchers cited their work. Spain, Australia, Japan and Iran produced less than 50 documents on precision irrigation. However, their scholars received a considerable number of total citations more than 100 times. Brazil, Italy, and Malaysia shared the lowest rank, with a total publication of 21 articles. Among the paper published are related to Internet of Things (IoT) and smartphone-based irrigation (Ismail et al., 2019; Leh et al., 2019; Lie et al., 2021; Munusamy et al., 2021; Yusof et al., 2019), machine learning-based irrigation (Abioye et al., 2021; Rahim et al., 2020), and wireless network-based irrigation (Harun et al., 2015; Mat et al., 2014). The published articles discussed various strategies to irrigate the crop efficiently and promote water saving in irrigation practices.

Table 2: Top 10 most productive countries in precision irrigation research.

Rank	Country	No of Publications	Total Citations
1	India	242	403
2	China	227	1118
3	United States	155	1351
4	Spain	38	678
5	Australia	27	229
6	Japan	23	194
7	Iran	22	246
8	Brazil	21	234
9	Italy	21	101
10	Malaysia	21	49

In addition, Figure 3 describes a three fields plot based on a Sankey diagram that illustrates the connections between nations, author affiliation, and keywords. Keyword plus is the indexed keywords provided and chosen by the content suppliers of the database. It can also be clearly seen that Hohai University, Huazhong Agricultural University, China Agricultural University, the University of Georgia, and the University of Florida are among the top research institutions that conducted precision irrigation research. The keywords such as "water-saving irrigation", "water conservation", "moisture control", "water management", and "precision irrigation" represent the strategies by farmers to minimise the use of water for irrigation. Meanwhile, terms such as 'internet of things", "agricultural robots", and "automation" represent the current method in the implementation of precision irrigation practices. A collaboration map was developed to further investigate the collaboration between the countries. Figure 4(a) illustrates the collaboration network among authors in precision irrigation research. The grey colour represents no contribution from the country. The number of publications is increasing from light blue to darker blue. The individual country collaboration can be seen in Figure 4(b). The lines connecting the nodes indicate the relationship between the most active countries publishing articles on precision irrigation. The researchers from the United States strongly collaborate with China and several European countries. Generally, the number of published papers, the total number of citations, and the H-Index are good indicators for measuring scholarly work (Vavryčuk, 2018).

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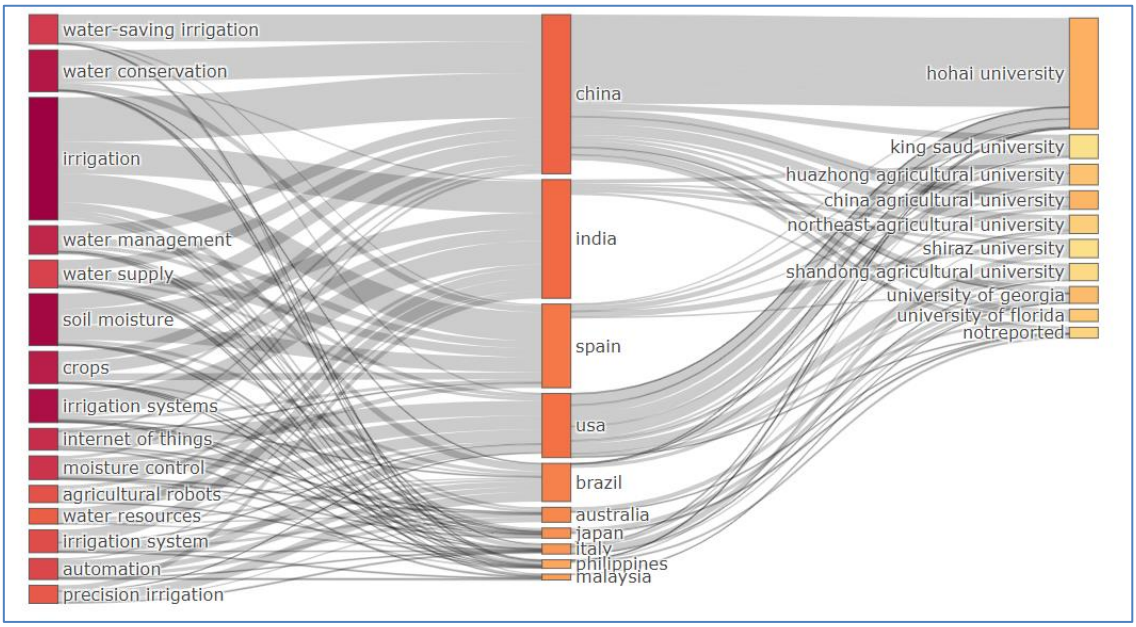

Figure 3: Three field plots as the country in the middle, keyword at the left and author affiliation at the right

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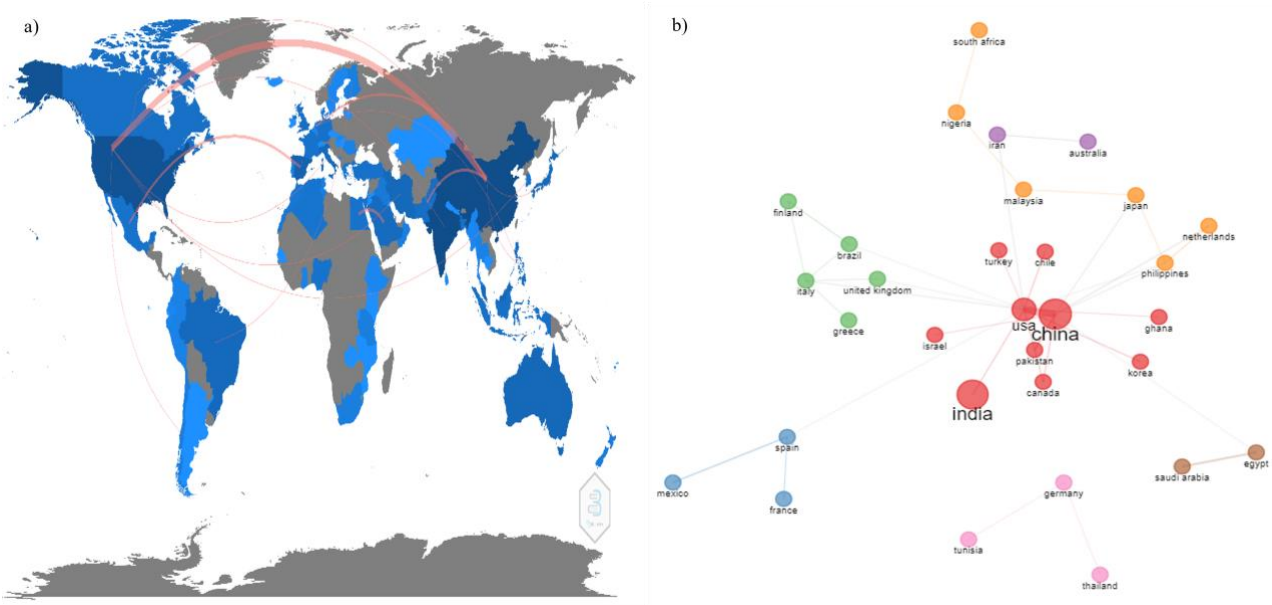

Figure 4: Collaboration network (a) and country collaboration (b) among authors in precision irrigation research.

Figure 5 compares Lotka's Law and the scientific publication on precision irrigation. Lotka's Law determines authors' productivity patterns (Patra et al., 2006). Based on Lotka's Law, the number of authors making n contributions is about $\frac{1}{n^2}$ of those making one (Lotka, 1926). Regarding proportion for a given discipline, 60% of authors have one publication each, 15% have two publications, and so on. Most authors (83.5%) have just one publication, although Lotka's Law predicts 60%. Similarly, when Lotka's Law predicted 15% of authors had two publications, precision irrigation articles had only 10%. The same goes for three and four publications where the observed percentage is lower than the value predicted by Lotka's Law. Based on this finding, the dataset publications on precision irrigation do not currently follow and comply with Lotka's Law. It is unsurprised and acceptable since precision irrigation is one of the emerging topics.

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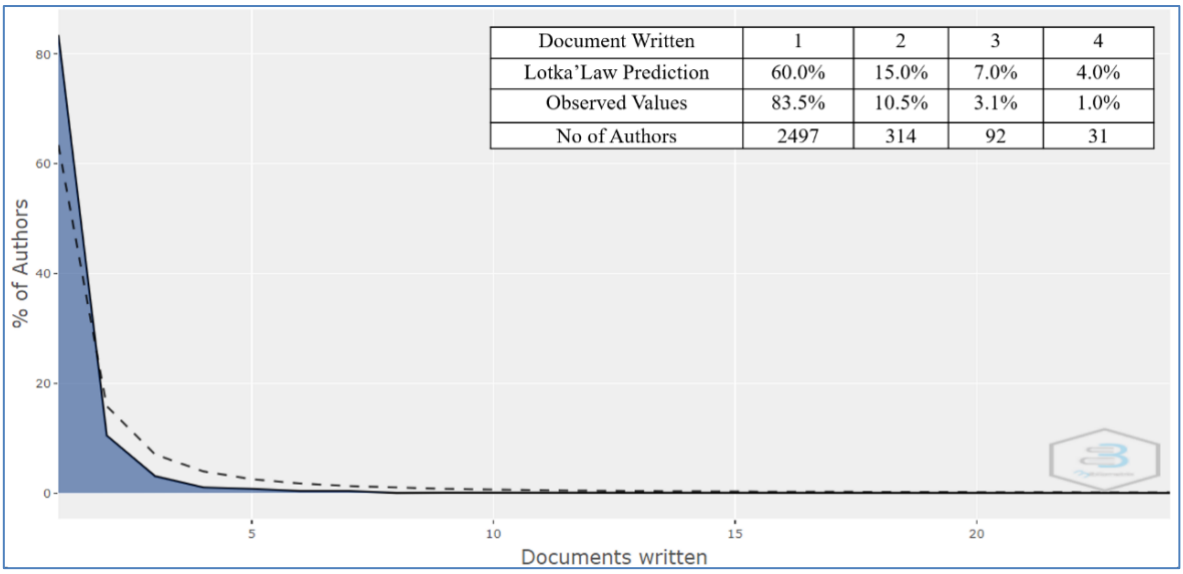

Document Written	1	2	3	4
Lotka'Law Prediction	60.0%	15.0%	7.0%	4.0%
Observed Values	83.5%	10.5%	3.1%	1.0%
No of Authors	2497	314	92	31

Figure 5: The frequency distribution of scientific productivity on precision irrigation with Lotka's Low. The dashed line indicates the publication according to Lotka's Law

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3.3 Knowledge Growth of Precision Irrigation Research

Figure 6 illustrates the trending topic in precision irrigation research based on the article title. The precision irrigation system has become the most popular article title between 2011 and 2013. Later, the water-saving irrigation technique with the wireless sensor network application became one of the popular article titles in 2015. Between 2014 and 2019, most of the article's topics focused on irrigation or control systems. Afterwards, more scholars published articles related to the automatic irrigation system. The transformation implied that the knowledge growth on manual irrigation practice had been mechanised to the semi-automatic or fully automated irrigation system. From 2018 onwards, scholars have further developed the topics by several methods, such as smart-based irrigation systems, IoT-based irrigation and automatic irrigation by embedding decision support systems into irrigation practices. The researchers tend to develop a smart irrigation system to ease farmers' activities in monitoring their crops, including crop health and checking for nutrient deficiencies. The development of autonomous irrigation practices can significantly improve yield, crop management and field productivity (Talaviya et al., 2020). The studied topic has been sliced into five periods to further investigate the knowledge growth on precision irrigation, as shown in Figure 7. The period slice 1 (1938-1999) was the longest time (61 years), showing the beginning of the research development. Slice 2 (2000-2005), slice 3(2006-2010), slice 4 (2011-2015) and slice 5 (2016-2021) consist of a duration of around five or six years which showed the development of precision irrigation research for the last 21 years. Thematic evolution visualises the knowledge discipline's research hotspot, frontier, and trends (Xie et al., 2020). In this analysis, the information in the abstract has been chosen since the abstract includes the most important information and gives an overview of an article. Thematic evolution analysis in precision irrigation based on the abstract reveals that the study of the irrigation system is the most relevant and essential topic since the term appeared in every slice of thematic evolution. Based on the thematic analysis, "soil moisture", "water content", and "water saving" themes are vital concepts in precision irrigation where these terms appear and are relevant all over the research timeline. Technology application themes such as "remote sensing", "sensor networks", "genetic algorithms", and "radio communication" have become the most popular terms used in precision irrigation documents for the last ten years. The basic concept of irrigation was later integrated with the current technology practices to develop better irrigation systems and management. From 2006 to 2010, the theme "irrigation regime" and "irrigation strategies" evolved to "water-saving irrigation" and "irrigation control", respectively, in the subsequent period. Researchers continuously innovate to improve the developed irrigation system for efficient water use.

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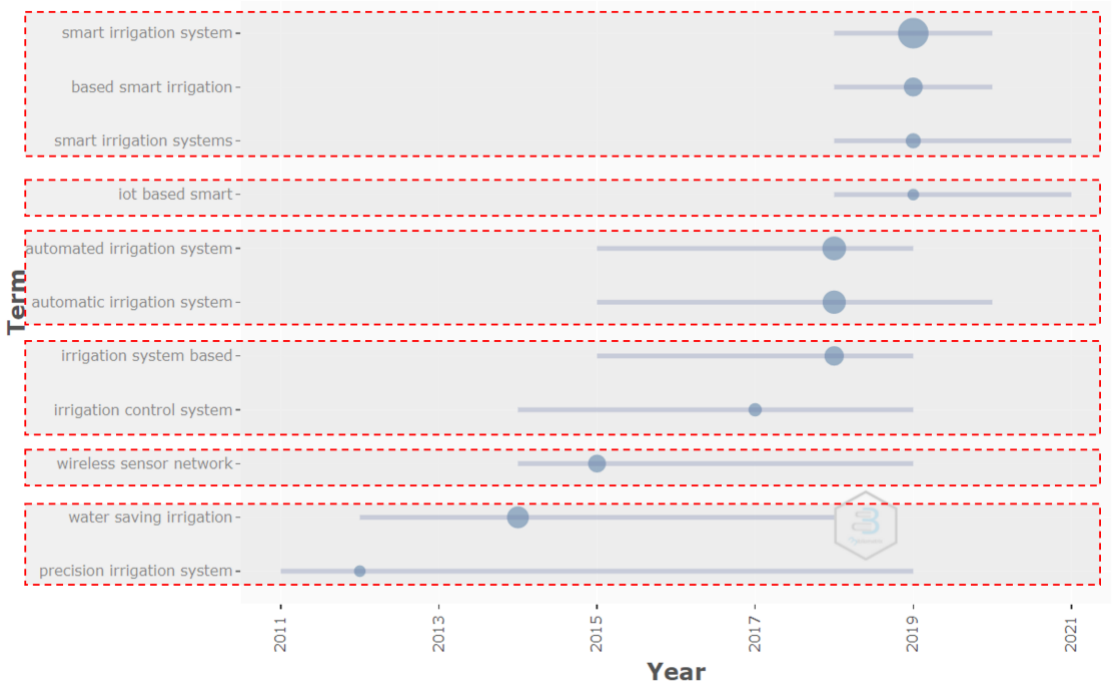

Figure 6: Trends topic on precision irrigation based on article title over time.

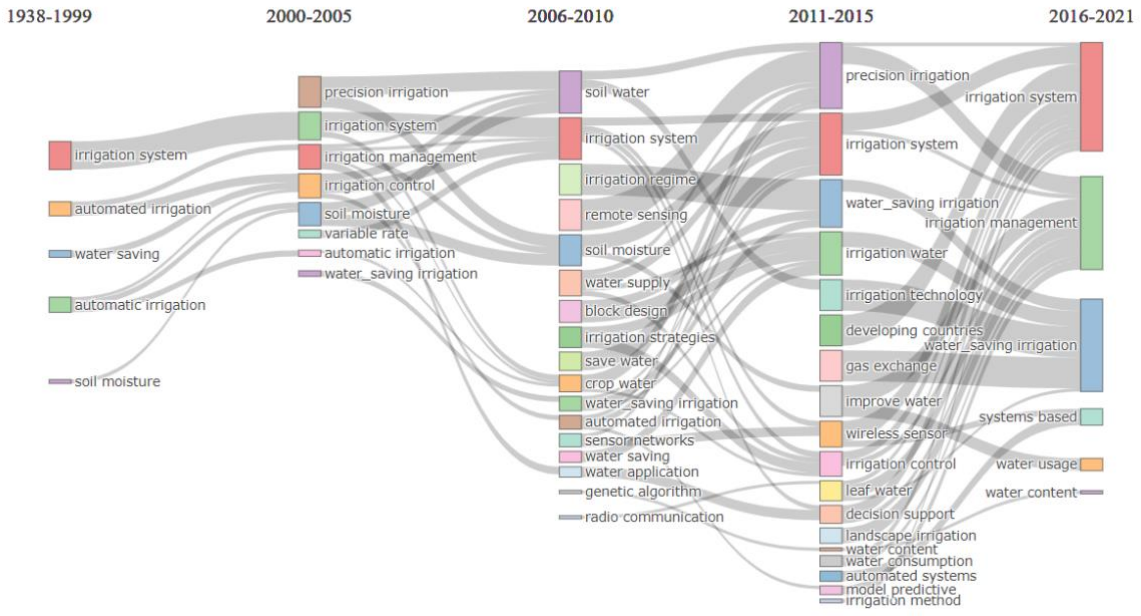

Figure 7: Thematic evolution for 83 years of research on precision irrigation based on abstract content.

The fast growth of internet service industry coverage and better access to internet coverage have led to increasing connections between devices (Beenish & Fahad, 2019). The fifth generation of wireless technology (5G) has been launched and deployed worldwide to users. It is projected that 5G connections will reach 1 billion users in 2022 after just 3.5 years of use (Buchholz, 2022). Although the 6G wireless technology technically does not exist, an effort has been made to provide better internet services in the future. The 6G internet coverage is expected to be available around 2030 (Ye et al., 2022). Borrero and Zabalo (2020) comprehensively discussed wireless

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technology for real-time water monitoring in agricultural practices. Nowadays, open-source programming languages such as Python and R programming are preferred and favoured by developers for data analytics, data science, and artificial intelligence. Due to the accessibility and availability of agricultural data, machine learning and data-driven innovation are predicted to be the future of precision irrigation decision-making. Large communities promote open-source programming languages, making it simple for new or novice users to use since they receive quicker community support. Additionally, they can learn from the numerous free project examples available online. IoT and machine learning have gained popularity as study areas with the advent of the Fourth Industrial Revolution, particularly in irrigation-related studies (Hamid et al., 2022). IoT deployment in agriculture improves water use efficiency (Jiménez et al., 2022) and eases irrigation management (Mujoo et al., 2021). This factor has become the accelerator engine driving precision irrigation research worldwide (Jusoh et al., 2021).

To our knowledge, the current research is a novel study published on bibliometric analysis using R programming on precision irrigation. The application of bibliometric analysis in the agricultural field is relatively new. This review provides a valuable source of information for scholars to understand the study trends in worldwide precision irrigation research. Understanding the topic under study can add to the corpus of knowledge on irrigation water management techniques. The study does have limitations that become barriers to generalizing the results. Using only one database source from Scopus could give different findings and interpretations. In ideal conditions, the precision irrigation dataset should be explored by various database providers to produce a more comprehensive interpretation. However, combining many database types into a single, unified dataset appears difficult. The data integration between several databases may provide better result interpretation on this topic. Additionally, this analysis is only able to use published resources as of 2021. The addition of the latest and current publications solidifies the findings of the recent research paper. To ensure fixed data analysis, the publication time frame was set early to prevent changes in results and data interpretation, considering that the Scopus database is updated daily.

4. CONCLUSION

The current study used the R bibliometric tool to understand the science mapping of precision irrigation from the Scopus database. We extracted the relevant information from the respective database, such as number of publications, year of publications, total citation, author productivity, keyword and abstract for trend analysis, productive country and knowledge growth structure. All documents processed are written in English to avoid the language barrier in data extraction. A total of 967 publications from 83 years were accessed to understand the status of science mapping on precision irrigation. In addition, the documents extracted primarily come from agricultural and biological sciences, computer science, engineering, and environmental science fields.

We analysed the global precision irrigation research trend and found that precision irrigation is an emerging research topic based on the published annual growth rate and Lotka Law. Precision irrigation research has become the highest publication title for the past five years between 2017 and 2021. The citation for precision irrigation research in the rising trend indicates worldwide scholars' attention to seriously exploring the precision irrigation research practices in agricultural water management. This paper also examined the most productive and active country in precision irrigation research. We ranked the top 10 countries with the highest publication on worldwide precision irrigation research. India is the most productive country in precision irrigation research, followed by China and the United States. India and China are developing countries with the highest populations in the world. Hence, India and China are developing countries with the highest populations in the world with a vast area for higher agricultural activity. This could be the reason why they led precision irrigation research at the moment. Malaysia is the sole representative from the Southeast Asian region, with the highest publication on precision irrigation research. Among the active research institutions worldwide that conducted precision irrigation research are Hohai University, Huazhong Agricultural University, China Agricultural University, the University of Georgia, and the University of Florida.

Finally, this paper has discussed the knowledge growth of precision irrigation research. The focus of the research has shifted from exploring the fundamentals of soil water and its characteristics to creating an organized system for managing water use in agriculture. However, the researcher used a different method in controlling or automating the irrigation system suitable to the advancement and technological development of the current time. For example, the implementation of IoT in the new millennium has triggered researchers to attach and embed sensors and IoT-based irrigation in their proposed irrigation systems. However, the knowledge maturity of the precision irrigation field is still in progress. The scope of artificial intelligence, including machine learning and deep learning with accessible open-source tools, has become popular in precision irrigation research. The application of free resources, software and tools in the future could reduce farmers' ownership of this precision irrigation technology. The results offer a fundamental understanding of worldwide precision irrigation research

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and provide relevant information on the direction of precision research in the future.

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