2024 International Conference on Intelligent and Innovative Computing Applications (ICONIC)
7th-9th November 2024, Pearle Beach Resort & Spa, Flic en Flac, Mauritius
https://doi.org/10.59200/ICONIC.2024.013

The Developments and Challenges in Agriculture Towards the Adoption of Smart Irrigation Technologies: A Review of the Most Cited Literature

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Abstract
This study critically reviews the top 10 most widely cited publications on farmers' use of smart irrigation systems. The systematic literature review was conducted through extracting data using a python code. The python algorithm was intended to use the CrossRef API to retrieve 50 academic publications on a related subject of "adoption of smart irrigation technologies by farmers". After the 50 journals were extracted, we manually selected the top 10 papers based on highest citation counts, recent publications, and talks about the related topic. The aim was to learn about the latest trends and technological advancements and in identify key themes that encourages the adoption of smart irrigation technologies. It was found that smart irrigation solutions such as IoT and AI, incorporate sensors, controls, and algorithms, to improve water management and crop yields by delivering accurate water volumes at the right moment. It was also highlighted that in the face of global agricultural concerns such as water shortages and climatic variability, these technologies are critical to sustainable farming practices. This review's findings will inform future research initiatives and policy decisions aimed at improving agricultural water efficiency, food security and sustainability.

Keywords: Smart irrigation technology, Smart farming, Python data extraction, Agriculture

1. Introduction

The potential of smart irrigation systems to help reduce water scarcity and optimize agricultural practices has garnered considerable attention on a global scale (Karunathilake et al. (2023). Due to its water shortage, South Africa has witnessed an increase in interest in both the development and implementation of smart irrigation technologies (Mango et al., 2018). With a focus on the use of smart irrigation technologies, existing literature is thoroughly analyzed in this journal review. The idea of smart irrigation technology was first introduced some decades ago, with the primary focus of early developments being on mechanical controllers and simple timers (Evans et al. 2013). More advanced methods were made possible, meanwhile, by the development of digital technology and the internet revolution in the late 20th and early 21st centuries (Sahu and Behera, 2015). The advancement of smart irrigation technology has been greatly accelerated by the growth of IoT and AI.

This paper reviews the top 10 highly cited journals on the adoption of smart irrigation technologies by farmers, examining the various factors influencing adoption, the benefits realized, and the barriers encountered. It highlights the significant contributions of scholars and outlines the challenges and key themes in this field. The perceptions gained from this review can guide future research and policy decisions to promote sustainable agricultural practices. The Python programming language was used as method for performing literature studies on smart irrigation technology because of its capabilities in data extraction, filtering, and analysis using sophisticated libraries such as requests and pandas. This method enables scholars to collect and handle enormous amounts of academic literature, resulting in complete and up-to-date reviews methodically and efficiently.

A significant gap exists in the systematic review of highly cited publications, which can provide useful insights into the most influential research and developing trends in smart irrigation. Highly cited publications frequently represent the research community's collective knowledge and priorities while also making substantial contributions to the subject. However, there is a scarcity of critical evaluations that concentrate solely on these prominent studies, assessing their techniques, conclusions, and implications for future research and policymaking.

2. Background of the study

Agriculture, the foundation of human civilization, faces tremendous difficulties in the twenty-first century. Water scarcity and climate change are two of the most important challenges, threatening global food security and sustainable farming strategies (Younes et al. 2024). As the world's population grows, there is also the need for food, putting further strain on already limited agricultural resources. Traditional irrigation technologies, which account for over 70% of worldwide freshwater withdrawals, are generally inefficient, resulting in significant water waste (FAO, 2017). This inefficiency is especially significant in areas where water is scarce and competition for this valuable resource is fierce.

Climatic variability exacerbates these difficulties by disrupting agricultural cycles and reducing crop output. According to the Intergovernmental Panel on Climate Change (IPCC, 2019), climate change is likely to exacerbate these extreme weather events, posing a considerable risk to agriculture. In this environment, smart irrigation systems have emerged as an important alternative for increasing water efficiency and ensuring the resilience of agricultural activities.

The use of smart irrigation systems is especially important in regions like the African continent, where water scarcity is a major concern. According to Mango et al. (2018), the country's agricultural sector confronts serious water limits, threatening food security and economic stability. Farmers may improve water management, increase crop yield, and contribute to long-term agricultural development by incorporating smart irrigation technologies (Younes et al. 2024). This literature review analysis seeks to provide insights that will help guide future research and policy decisions, enabling the wider implementation of these disruptive technologies.

3. The objectives of the study

- To review the top ten most cited journals on the use of smart irrigation technologies.
- To bring together the study's aims, major findings and identify key themes.
- To Discuss the recommendations made by the researchers
- To learn about the latest trends and technological advancements in farm irrigation systems,
- To evaluate the efficacy of various smart irrigation technologies.

4. Overview of Smart Irrigation Technologies

Systems that maximize water utilization in agricultural fields through the use of different sensors, controls, and algorithms are referred to as smart irrigation technology (Hammouch et al. 2024). With the help of these technologies, crop yields and water management can be increased by delivering the appropriate amount of water at the appropriate time (Karunathilake et al. 2023). These technologies are important because they can save water, cut expenses, and increase agricultural output. South Africa's agricultural concerns include water scarcity, erratic weather patterns, and soil degradation. These difficulties demand novel approaches to ensuring sustainable agriculture practices (Mango et al. 2018). In response to these issues, researchers and institutions are actively researching and developing smart irrigation systems. Adoption of these technologies is motivated by the desire to improve water efficiency and assure food safety.

5. Data extraction method

The systematic literature review was conducted to data mini the 50 highly cited journal papers using a python algorithm. Using the subject "adoption of smart irrigation technologies by farmers," the algorithm was intended to extract 50 highly referenced papers based on citation count, title, and URL after filtering them. We manually selected the top 10 papers based on citation count, recent publications, and relevant information that talks about the related topic. The program is made to bypass websites that demand a premium subscription. The article title, URL, and number of citations are returned as a summary and are shown, as well as being saved in their entirety to a CSV file.

The following python code was intended to use the CrossRef API to retrieve academic publications on a subject of "adoption of smart irrigation technologies by farmers", filter out those that are premium or inaccessible, and then choose and show the top 50 most cited papers. The retrieved data was summarized and stored as a CSV file for future examination. Here is a thorough breakdown of the actions the code took:

The code begins by importing the requests library for sending HTTP queries and the pandas' package for data manipulation and storage.

Step 1: This configures the base URL for the CrossRef API, which will be used to retrieve scholarly papers:

```
import requests
import pandas as pd
# CrossRef API base URL
CROSSREF_API_URL = "https://api.crossref.org/works"
# Function to check: premium subscription on an papers
def is_premium_paper(doi):
    url = f"https://doi.org/{doi}"
    try:
        response = requests.get(url)
        if response.status_code != 200:
            return True  # 200 responses is a premium or inaccessible papers
    except Exception as e:
        print(f"Error checking article DOI {doi}: {e}")
        return True
    return False
```

After submitting a request to the DOI URL. This status code (200) indicates that the request was completed successfully. When the code determines whether a document is premium or inaccessible, it initiates a request to the paper's DOI URL. If the response status code is 200, it indicates that the paper is accessible and not premium. If the status code is not 200, it indicates that the document is either premium or inaccessible, and it is therefore eliminated from the results.

Step 2: The following is a Function to Fetch Papers from CrossRef API:

```
def fetch_papers(topic, rows=100):
    params = {
        'query': topic,
        'rows': rows,
        'sort': 'score',
        'order': 'desc'
    }
    response = requests.get(CROSSREF_API_URL, params=params)
    if response.status_code == 200:
        return response.json()['message']['items']
    else:
        print(f"Error fetching papers: {response.status_code}")
        return []
```

The above section of the function retrieves a list of papers ordered in descending order of relevance score by sending a request with the supplied topic to the CrossRef API. The list of documents is returned if the request is approved. This parameter sets the number of search results to retrieve from the CrossRef API. When searching for papers on the topic, the algorithm seeks up to 100 results to ensure a complete list of relevant studies.

Step 3: The next body of the function is used to Sort and Filter Papers based on Number of Citations:

```
def filter_and_sort_papers(papers, top_n=50):
    filtered_papers = []
    for paper in papers:
        doi = paper.get('DOI')
        citation_count = paper.get('is-referenced-by-count', 0)
        if not is_premium_paper(doi):
            filtered_papers.append({
                'title': paper.get('title', [''])[0],
                'doi': doi,
                'citation_count': citation_count
            })
    # Sort articles by citation count in descending order and get the top N papers
    sorted_papers = sorted(filtered_papers, key=lambda x: x['citation_count'], reverse=True)
    return sorted_papers[:top_n]
```

The DOI, title, and number of citations for publications that are available are gathered by the above function of step 3, which also removes premium papers. The top N papers (the default is 50) are then chosen after the papers are sorted by citation count in descending order.

Step 4: the next Function body was used to Get Top Cited Papers on a Topic**:**

```
def get_top_cited_papers(topic):
    papers = fetch_papers(topic)
    top_papers = filter_and_sort_papers(papers)
    return top_papers
```

The top cited papers are returned by the above function of step 4, which first calls fetch_papers to obtain a list of papers pertaining to the specified topic. It then calls filter_and_sort_papers to filter and sort the articles based on the number of citations.

Step 5: Call function get_top_cited_papers passing the topic and Convert to DataFrame for better readability:

```
get_top_cited_papers =
get_top_cited_papers("adoption of smart
irrigation technologies by farmers")
df = pd.DataFrame(get_top_cited_papers)
print(df)
df.to_csv('get_top_cited_papers.csv',
index=False)
```

The last step is get_top_cited_papers function which is called to return the data of the topic "farmers' adoption of smart irrigation technologies." The resulting list of top-cited publications is converted to a pandas DataFrame for easier reading and stored as a excel CSV file.

6. Criteria for Inclusion and Exclusion

- Criteria for included data: scholars' peer-reviewed articles, conference papers, and theses on smart irrigation systems.
- Criteria for excluded data: Studies not related to smart irrigation or older than 10 years.

7. Method for identifying key themes

The content of the selected studies was examined to discover key themes and recommendations. Thematic analysis was utilized to organize the data into recurring topics such as IoT integration in agriculture, water use efficiency, sustainable farming techniques, and technical breakthroughs. The top ten most referenced journals were included, along with the objective of each study, major conclusions, and total number of citations. The recommendations and the outcomes of each study were also analysed in order to provide a thorough picture of the current state of smart irrigation technologies and their adoption.

8. Results of top ten journal

Table 1 describes the ten most highly cited journals on farmers' use of smart irrigation technologies, as well as the study objectives, findings, and number of citations for those works.

Table 1: Top ten highly cited journals

Author	**Purpose of the Study**	**Findings**	**No. of citations**
Nawandar and Satpute, 2019	to create a sophisticated, low-cost Internet of Things module for smart irrigation systems.	The designed module increased agricultural fields' water use efficiency at a reasonable cost.	293
Krishnan et a. 2020	to use fuzzy logic and the Internet of Things to build a smart irrigation system.	Water waste was decreased by the system's effective management of irrigation schedules based on real-time soil moisture data.	254
Dhanaraju et al. 2022	to investigate smart farming using the Internet of Things for sustainable agriculture.	Resource management and agricultural productivity were greatly enhanced by IoT-based technologies.	254
Koech and Langat, 2018	to examine developments, obstacles, and chances for increasing Australia's irrigation water use efficiency.	highlighted a range of techniques and technologies to improve water efficiency, with a particular emphasis on precision irrigation.	239
Bwambale et al. 2022	to examine intelligent irrigation monitoring and control methods for increasing precision	It was discovered that agricultural yields and water use efficiency were greatly	238

	agriculture's water use efficiency.	increased using IoT-based monitoring systems.	
Madushanki et al. 2019	to examine how IoT is being used in smart farming and agribusiness in order to promote urban greening.	Better resource management and urban greening initiatives resulted from the deployment of IoT in agriculture.	235
Kpadonou et al. 2017	to examine how various on-farm water and soil conservation technologies are being used in the Sahel region of West Africa.	In dryland areas, use of water and soil conservation technologies increased agricultural output and resilience.	204
Qazi et al. 2022	to conduct a comprehensive evaluation of next-generation smart agriculture powered by AI and IoT.	identified the main obstacles and upcoming developments in agricultural IoT and AI applications.	184
Vaishali et al. 2017	to create an Internet of Things-based mobile integrated smart irrigation management and monitoring system.	The solution improved user accessibility and control by enabling effective irrigation management using mobile interfaces.	180
Obaideen et al. 2022	to give a summary of Internet of Things-based smart irrigation systems.	Smart irrigation systems powered by the Internet of Things increased crop yield and water management.	158

9. Identified Themes:

Theme 1: Integration of IoT in Agriculture

All then highly cited publications emphasize the use of the Internet of Things in agriculture to improve efficiency and productivity. Most studies focused on integrating IoT into agricultural practices to improve efficiency and productivity. IoT technology offer real-time monitoring and control of irrigation systems, giving farmers critical information on soil moisture, weather conditions, and crop health. Nawandar and Satpute, (2019), developed a low-cost IoT module for smart irrigation, demonstrating improved water use efficiency. This data-driven strategy enables precise irrigation scheduling, which reduces water waste and increases crop yields. Krishnan et al. (2020) used IoT and fuzzy logic to create smart irrigation programs that were effectively managed using real-time soil moisture data.

Theme 2: Water use efficiency

Enhancing water use efficiency is a crucial topic, and numerous studies concentrate on smart irrigation technologies and techniques to maximize water usage. In order to reduce water use efficiency in smart irrigation systems, Garcia et al. (2018) coupled irrigation scheduling with solar energy output. More strategies and technologies were examined to increase water efficiency. According to Bwambale et al. (2022), crop yields and water use efficiency were shown to be greatly increased by IoT-based monitoring systems. While Koech and Langat (2018), highlighting precision irrigation technologies, they reviewed developments in irrigation water use efficiency.

Theme 3: Sustainable Farming

The significance of resource management and sustainable farming practices has been highlighted in most of these ten studies. The goal of sustainable farming is to satisfy present agricultural demands without endangering the capacity of future generations to satisfy their own (Kpadonou et al. 2017; Garcia et al. 2018; Dhanaraju et al. 2022). It includes actions that are socially conscious, economically feasible, and environmentally sound. The adoption of small-scale irrigation farming as a climate-smart agriculture technique that raises household income was covered by Mango et al. (2018). IoT-based smart farming was used by Dhanaraju et al. (2022) to investigate sustainable agriculture, demonstrating notable gains in resource management and productivity. While Kpadonou et al. (2017) examined how dryland areas used soil and water conservation measures to increase agricultural output and resilience. The necessity for sustainable agricultural techniques to provide long-term productivity and environmental protection is a recurrent issue in studies.

Theme 4: Technological Advancements
Numerous articles address the technological developments in smart irrigation systems such as IoT, artificial intelligence (AI), fuzzy logic, and mobile interfaces that are augmenting the potential of intelligent irrigation systems. In order to improve user accessibility and control, Vaishali et al. (2017) developed a mobile integrated smart irrigation management system. Qazi et al. (2022) reviewed smart agriculture that is AI-enabled and IoT-equipped, noting potential obstacles and emerging trends. IoT-based solutions that improve smart irrigation through real-time monitoring and automated changes, lowering water usage and enhancing crop health, were the topic of studies by Nawandar and Satpute, (2019) and Krishnan et al. (2020). The three main technologies advancing smart irrigation innovation are IoT, AI, and precision agriculture. These technologies offer notable gains in agricultural yield, sustainability, and water use efficiency. To optimize the advantages of these technologies, however, issues like excessive prices, intricate technical requirements, and the requirement for thorough farmer training must be resolved (Vaishali et al. 2017; Nawandar and Satpute, (2019); Qazi et al. (2022).

10. Recommendations

In order to augment the uptake and efficacy of smart irrigation technology, it is advisable to allocate resources towards research and development, furnish farmers with financial assistance, and foster awareness and educational initiatives. It is the responsibility of policymakers to establish favourable conditions for the adoption of these technologies (Vaishali et al. 2017; Qazi et al. 2022; Dhanaraju et al. 2022). Together, the ten studies that were analysed show how revolutionary IoT and related technologies may be in agriculture, especially when it comes to smart irrigation systems. These systems can greatly increase water use efficiency, support sustainable agriculture practices, and boost overall output by utilizing real-time data and cutting-edge technologies (Jabbari et al. 2024).

The recurrent themes emphasize the significance of technology breakthroughs, sustainability, water use efficiency, and IoT integration. The study' recommendations emphasize the necessity for reliable data security protocols, integration with renewable energy sources, and scalable, affordable solutions. All things considered; the research suggests that IoT-enabled smart irrigation systems present viable answers to some of the most urgent problems facing the agricultural industry (Jabbari et al. 2024). To guarantee that the advantages of these technologies are broadly available and long-lasting, future research should keep addressing these issues and looking into new avenues for collaboration (Li et al. 2024). Further research is required to examine affordable options for small and medium-sized farms as well as the integration of intelligent irrigation systems with renewable energy sources, such as solar power.

11. Challenges of implementing smart irrigation technologies

High upfront costs and economic barriers: One of the major problems in integrating smart irrigation technologies is the high initial cost of these systems. Small-scale farmers may find the cost of installing IoT-based sensors, automated irrigation controllers, and related infrastructure excessively high. For example, Kpadonou et al. (2017) found that the expense of purchasing and maintaining these technologies can be a significant disincentive, particularly in underdeveloped countries where financial resources are limited. Furthermore, ongoing costs, such as maintenance and prospective technical support, increase the overall cost burden, making it difficult for farmers to maintain these systems in the long run.

Technological complexities and lack of skills: Smart irrigation technologies are not widely adopted due to their technical complexity and a lack of skills. Many farmers, especially those in rural or underdeveloped areas, may lack the technical abilities required to run and troubleshoot this complex equipment effectively. According to Qazi et al. (2022), integrating AI and IoT in agriculture demands a specific level of technical skill that is not always available in farming communities. Training and technical assistance are critical, but they might be inconsistent and insufficient, resulting in inefficient technology utilization and potential system failures.

Internet Connection Issues and Infrastructure: Smart irrigation systems rely heavily on real-time data transmission and remote monitoring, therefore dependable infrastructure and connectivity are essential for their proper operation. However, many rural communities confront substantial hurdles in this regard, such as limited internet access and inconsistent power sources. According to Mango et al. (2018), infrastructural deficiencies can severely limit the performance of smart irrigation technology by disrupting automated operations through intermittent data transfer and power outages. To address these infrastructural concerns, governments and private sector parties must make significant investments and work together.

12. Evaluation of the reviewed studies

The methods used in the evaluated research are diverse and typically robust, offering significant understanding into the implementation and impact of smart irrigation technologies. However, the quality of the data varies, with some studies being more thorough and scientifically established than others. When evaluating the findings, keep in mind possible limitations such as generalizability, scope, technological and economic restrictions, and data collection biases (Hammouch et al. 2024). Future study should attempt to solve these constraints by integrating more diverse and long-term studies, investigating cost-effective and scalable solutions, and guaranteeing the inclusion of various climatic and socioeconomic circumstances.

13. Conclusion

The studies consistently show that the adoption of smart irrigation technologies by farmers is influenced by a combination of economic, environmental, and educational factors. Economic benefits, such as increased profitability, food security and reduced water usage, are significant motivators. Barriers like high initial costs and lack of technical knowledge hinder adoption, particularly among small-scale and less educated farmers. Government policies and support mechanisms, such as subsidies and training programs, are crucial in promoting adoption. Additionally, the role of technology providers and the increasing awareness of climate change are important drivers. To enhance adoption rates, tailored strategies that address financial, educational, and demographic differences are necessary. Future study should attempt to solve these constraints by integrating more diverse and long-term studies, investigating cost-effective and scalable solutions, and guaranteeing the inclusion of various climatic and socioeconomic circumstances.

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