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Utilization of Smart Irrigation Systems to Improve Natural Resource Efficiency in Agriculture: Literature Review

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ABSTRACT

Agriculture plays a vital role in human life, but the sector faces major challenges related to limited natural resources, especially water. Poor water quality and limited water supply are major constraints in agriculture. Smart irrigation systems that use sensor technology and weather data offer an efficient solution for water management in agriculture. By using sensors to monitor soil moisture, temperature, and weather conditions, these systems can optimize water use, reduce waste, and increase agricultural yields. This technology has been proven effective in saving up to 18% of water consumption compared to conventional irrigation. In addition, smart irrigation also increases crop yields through better water management. However, the implementation of this system still faces challenges such as high investment costs and lack of knowledge among farmers, especially in developing countries. Therefore, it is important to provide training and incentives for farmers, as well as develop infrastructure that supports this technology. With the right solution, smart irrigation systems can be an important step in agricultural sustainability, saving natural resources, and improving farmers' welfare.

Keywords: Smart Irrigation, Water Efficiency, Technology, Agriculture, Resource Saving.

INTRODUCTION

Agriculture is a very important sector for human life, not only as a source of food, but also as an economic driver for many countries. However, in recent decades, this sector has faced various challenges, one of which is the limited natural resources, especially water which is the main requirement in agricultural activities. Poor water quality and limited water availability are major challenges. The use of low-quality water, such as treated wastewater, can increase soil salinity and sodicity, which affects crop productivity and soil health (Assouline et al., 2015; Oster, 1994). Inadequate irrigation infrastructure, including damaged or inefficient water channels, hinders effective water distribution to agricultural lands (Kanda & Lutta, 2022).

Smart irrigation systems work by using technology to monitor and control water usage on farmland. Smart irrigation systems often use Internet of Things (IoT) technology and sensors to monitor parameters such as soil moisture, temperature, and weather conditions. These sensors can be connected to nodes to

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implement affordable systems for irrigation management and agricultural monitoring (García et al., 2020; Rawal, 2017). The system can also use communication protocols such as MQTT and HTTP to keep users informed about crop conditions from remote locations (Nawandar & Satpute, 2019).

Some smart irrigation platforms use irrigation models that calculate soil water balance and wet bulb dimensions to determine the best irrigation strategy, especially for drip irrigation systems. These platforms often support a variety of sensors and can be integrated with edge and/or cloud computing systems (Kamienski et al., 2019; Puig et al., 2022). Smart irrigation systems can also use fuzzy logic controllers to calculate input parameters such as soil moisture, temperature, and humidity, and generate motor status outputs. The system can turn off the motor to save power when it rains and prevent damage to crops from unexpected rain (Krishnan et al., 2020).

Smart irrigation systems can reduce water and energy usage by optimizing irrigation schedules based on real-time data and intelligent algorithms. This not only reduces water wastage but also helps in resource conservation and increases crop yields (Nasiakou et al., 2016; Vallejo-Gómez et al., 2023). Thus, this system not only reduces excessive water use but also improves plant health. The use of such technology can improve the sustainability of agriculture in the face of climate change and scarcity of natural resources. It will also have a positive impact on the welfare of farmers who can save costs and increase agricultural yields.

Although smart irrigation systems offer many benefits, challenges in their implementation remain. One is that commercial sensors for irrigation systems are often expensive, making them inaccessible to small farmers. However, the development of low-cost sensors that can be connected to nodes for affordable irrigation systems is underway (García et al., 2020; Puig et al., 2022). The implementation and operation of smart irrigation systems require reliable communication networks. Challenges in communication include technical limitations, environmental factors, data management, human intervention, integration, and cybersecurity (Tsvetanov & Kuzmanov, 2024). Smart irrigation systems use cloud-based data analytics and machine learning algorithms to identify patterns, optimize irrigation schedules, and generate actionable insights for farmers (Murali et al., 2024; Peter et al., 2024).

Smart irrigation system design requires interdisciplinary collaboration and innovative strategies to create robust, scalable and sustainable irrigation solutions (Gulomjonovich & O'g'li, 2024). Smart irrigation systems are vulnerable to cybersecurity threats that can disrupt operations. Therefore, strong security measures are needed to protect data and systems (Tsvetanov & Kuzmanov, 2024). The use of energy-efficient dataloggers and systems that support multiple communication protocols helps in reducing energy consumption and increasing sustainability (Puig et al., 2022).

However, although this technology promises many benefits, further research is needed to evaluate its effectiveness in various environmental and socio-economic conditions. Therefore, it is important to conduct a more comprehensive study on how this technology can be widely applied in various regions by considering local conditions. This aims to ensure that smart irrigation systems can provide maximum benefits for farmers and the environment. In addition, the implementation of smart irrigation systems can

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open up opportunities for further research related to the integration of technology with other agricultural sectors, such as soil management and fertilization. This technology can be integrated with a data-based agricultural management system to create a more efficient and environmentally friendly agricultural ecosystem. For example, by combining soil moisture data and analysis of plant nutrient needs, farmers can regulate irrigation and fertilization more accurately. This integration will significantly increase agricultural productivity and reduce the waste of natural resources.

Overall, the use of smart irrigation systems can be an important step in increasing the efficiency of natural resource use in agriculture. This technology is not only useful for overcoming the problem of water scarcity, but can also improve agricultural yields and reduce negative impacts on the environment. Therefore, it is important to conduct a more in-depth literature review on the application of smart irrigation systems in various regions. This study is expected to provide useful recommendations for natural resource management policies in the agricultural sector in the future.

METHOD

This study uses a literature review approach to explore the use of smart irrigation systems in improving natural resource efficiency in the agricultural sector. This study aims to analyze various studies, articles, and other literature sources that are relevant to the topic of smart irrigation, water use efficiency, and its impact on agricultural sustainability. The literature used includes research from scientific journals, books, government reports, and other related publications that have been published in recent years. The literature selection process is based on relevance, source credibility, and the quality of information provided, with a focus on research that examines smart irrigation technology in various agricultural conditions.

The data collection process began with a literature search using various scientific databases, such as Google Scholar, ScienceDirect, Springer, and JSTOR. Keywords used for the search included terms such as "smart irrigation systems," "water efficiency in agriculture," "sustainable agriculture," and "irrigation technology." Literature selection was carried out by prioritizing articles that focused on the use of smart irrigation technology in the context of natural resource efficiency, especially water, and how this system can improve agricultural productivity and sustainability. Articles to be analyzed were selected based on the year of publication between 2019 and 2024. Then the articles were evaluated based on quality criteria, such as the methodology used, relevance to the topic, and contribution to existing knowledge.

Next, the selected articles are analyzed in depth to identify important findings related to the implementation of smart irrigation systems. This analysis includes an evaluation of the type of irrigation technology used, how the technology can reduce water waste, and its impact on agricultural yields. In addition, the author will also assess various factors that affect the effectiveness of smart irrigation systems, such as climate factors, crop types, and soil conditions. This analysis aims to identify patterns that can be used to recommend the implementation of smart irrigation systems in various agricultural conditions.

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In this literature review, the author will also identify the challenges faced in implementing smart irrigation systems, both in terms of technology, economy, and social. Some of the challenges that are often discussed in the related literature include high initial investment costs, lack of knowledge among farmers, and the need for integration of irrigation systems with other agricultural technologies. The author will highlight various solutions or recommendations provided in the research to overcome these challenges, including the role of government policies, education and training for farmers, and technological advances that can reduce these obstacles.

The results of this literature review will be summarized to provide a clearer picture of the potential and challenges in implementing smart irrigation systems to improve the efficiency of natural resources in agriculture. The author hopes that through this review, it can provide a significant contribution to the development of smart irrigation technology in the agricultural sector and provide insight for policy makers and agricultural industry players to design more effective strategies in managing natural resources sustainably.

RESULT AND DISCUSSION

RESULT

This study examines the utilization of smart irrigation systems based on literature reviews taken from various scientific sources to determine their impact on the efficiency of natural resource use, especially water, in agriculture. The following are the results of various studies that have been analyzed.

1. Efficient Water Use

Based on various studies that have been analyzed, the implementation of smart irrigation systems significantly reduces water waste. One of the main benefits of this technology is its ability to provide the right amount of water according to plant needs, leading to savings in critical water resources. Data from several studies show that the use of smart irrigation can reduce water consumption by up to 18% compared to conventional irrigation systems that do not use sensors and automation.(Marazky, 2018).

Smart irrigation systems equipped with soil moisture sensors, as well as weather data-based systems, have been shown to reduce water waste that often occurs in conventional irrigation. Soil moisture sensors directly monitor soil moisture and adjust the amount of water applied based on the specific needs of the crop. This significantly reduces the amount of water wasted, which is especially important in areas with limited water supplies.

2. Increasing Agricultural Yields

The implementation of smart irrigation not only has an impact on water savings, but can also increase agricultural yields. Several studies have shown that with more optimal water management, plants get the moisture they need to grow better, leading to increased yields. The results of the study showed an increase in yields ranging from 18% to 25% in various types of crops.

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Table 1. Increasing Agricultural Yields with Smart Irrigation

No	Literature Sources	Types of Plants	Technology Used
1	Gupta et al. (2019)	Paddy	Soil moisture sensor, automation
2	Wang et al. (2020)	Tomato	Sensor-based irrigation
3	Chen et al. (2021)	Potato	IoT based irrigation system
4	Kumar et al. (2023)	Soya bean	Humidity monitoring system

This increase in agricultural yields is influenced by the ability of smart irrigation systems to maintain optimal soil moisture, which is essential for plant growth. In several studies, Internet of Things (IoT)-based technology used to monitor soil moisture and climate conditions in real time has been shown to help farmers manage irrigation more efficiently, leading to higher and better yields.

3. Challenges in Implementing Technology

Although smart irrigation systems offer many benefits, there are a number of challenges in their implementation. One of the main issues is the high initial investment costs. Small and medium farmers often find it difficult to access this technology due to the high cost of equipment and the need for skilled maintenance systems. In addition, there is still a knowledge gap among farmers on how to operate smart irrigation systems.

Table 2. Challenges in Implementing Smart Irrigation Systems

No	Challenge	Explanation	Impact
1	High Initial Investment Costs	mart irrigation systems require a fairly large initial investment.	Restricting smallholder farmers' access
2	Lack of Farmer Knowledge	Farmers often do not know how to operate these systems efficiently.	Suboptimal use
3	Infrastructure Limitations	Limited access to infrastructure that supports irrigation technology	Hindering the distribution of technology
4	Dependence on Technology	Reliance on data and stable connectivity can be a problem in remote areas.	Operational instability

The main challenges are investment costs and the need for farmer training. To overcome this, it is important for the government to provide subsidies or incentives that can reduce initial costs. In addition, improving infrastructure and intensive training for farmers can reduce the knowledge gap and ensure that smart irrigation systems can be used optimally.

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DISCUSSION

This study examines the use of smart irrigation systems that use sensor-based technology and weather data to improve water efficiency and increase agricultural yields. Based on various research results that have been analyzed, smart irrigation systems have been proven to have a significant impact on saving natural resources, especially water, and increasing agricultural yields. However, the implementation of this system also faces a number of challenges that need to be overcome so that its benefits can be optimally felt by farmers, especially in developing countries.

1. Water Use Efficiency in Smart Irrigation

One of the main benefits of smart irrigation systems is their ability to save water usage. Many studies have shown that this technology can significantly reduce water waste compared to conventional irrigation systems. According to research byMenne et al. (2022), the use of soil moisture sensors in smart irrigation has proven to be more efficient in water distribution. In addition, the use of smart irrigation can reduce water consumption by up to 18% compared to conventional irrigation systems that do not use sensors and automation.(Marazky, 2018).

This technology ensures that water is only supplied when needed, avoiding the waste that often occurs in traditional irrigation systems. In areas facing water shortages, such as in some parts of the Middle East and Africa, this technology provides a very useful solution to maintain agricultural sustainability.

2. Increasing Agricultural Yields

In addition to water efficiency, smart irrigation systems also contribute to increased agricultural yields. This technology helps plants obtain optimal moisture for their growth, which in turn increases crop yields. In a study conducted bySingh et al. (2023), the use of sensor-based irrigation on crops shows an increase in crop yields. This technology allows farmers to set irrigation schedules according to changing weather conditions, so that plants get the ideal amount of water.

In addition, research byChen et al. (2021)showed that the application of an Internet of Things (IoT)-based irrigation system to potato plants can increase yields by up to 25%. The system monitors soil moisture in real-time and regulates watering based on the data obtained, ensuring that plants receive optimal moisture throughout their growth cycle.

3. Challenges in Implementing Smart Irrigation Systems

Although smart irrigation systems show great potential in improving agricultural efficiency and yields, there are several challenges in their implementation. One of the biggest challenges is the high initial investment cost. Smart irrigation systems require significant investment in equipment such as sensors, automation devices, and other supporting infrastructure. This is often a barrier for small and medium farmers, especially in developing countries with limited funds.

According toKumar et al. (2023), another challenge faced is the lack of knowledge among farmers on how to operate smart irrigation systems. Although this technology is designed to simplify irrigation management, many farmers are not trained to use the tools efficiently. For example, in some parts of India, many farmers struggle to adopt smart irrigation technology due to lack of training and supporting infrastructure.

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CONCLUSION

This study shows that smart irrigation systems, which use sensor-based technology and weather data, have a significant impact on improving water use efficiency and agricultural yields. These systems are able to reduce water waste by providing the right amount of water according to crop needs, which is very important for areas facing water shortages. However, the implementation of these systems also faces several challenges, especially high initial investment costs and lack of knowledge among farmers. This is a barrier for small and medium farmers in developing countries. Therefore, to ensure the successful adoption of this technology, it is important to provide adequate training for farmers and government support, such as subsidies or incentives to reduce initial investment costs. With the right solution, the benefits of smart irrigation systems can be maximized by farmers, increasing the efficiency of natural resource use and agricultural productivity in a sustainable manner.

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