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Innovation of Smart Irrigation System Based on Internet of Things (IoT) for Efficient Water Use on Agricultural Land

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ABSTRACT

Purpose: *This study aims to analyze the effectiveness of a smart irrigation system based on the Internet of Things (IoT) in improving water use efficiency, maintaining soil stability, increasing crop productivity, and reducing operational costs in agricultural practices.*

Subjects and Methods: *The research was conducted on chili plants (Capsicum annuum) using a field experiment approach with two treatments: conventional irrigation (manual, schedule-based) and IoT-based smart irrigation. The IoT system consisted of soil moisture and temperature sensors integrated with a microcontroller to automatically regulate water supply according to real-time soil conditions. Data were collected on water consumption, soil moisture and temperature stability, crop productivity, labor costs, and farmer satisfaction. Quantitative descriptive analysis was applied to compare the two systems, while an independent sample t-test was used to test the significance of differences in water efficiency and productivity. Farmer satisfaction was measured using a Likert scale questionnaire.*

Results: *The findings showed that the IoT-based irrigation system reduced water usage by 63% compared to txhe conventional method, while maintaining soil moisture within the optimal range of 40–55%. Crop productivity increased by 27% in terms of average yield per plant, and fruit quality also improved. Operational costs decreased by 25% and working hours for irrigation were reduced by 60%. Farmers reported higher satisfaction with the IoT system, rating it more practical and efficient.*

Conclusions: *IoT-based smart irrigation effectively improves water efficiency, stabilizes soil conditions, enhances crop productivity, and reduces costs. This innovation demonstrates strong potential to support sustainable agriculture and address water resource challenges.*

INTRODUCTION

According to Rusastra & Simatupang (2005), Agriculture is a strategic sector that plays a crucial role in ensuring food security and supporting the economy, particularly in developing countries like Indonesia. However, one of the main obstacles facing this sector is the limited and uncertain availability of water (Sari et al., 2024; Pasaribu et al., 2023). Conventional irrigation systems still widely used by farmers often fail to address actual land conditions and the specific needs of crops (Levidow et al., 2014; Mvungi et al., 2005).

Manual or scheduled watering practices often result in water waste, imbalanced distribution, and reduced crop quality (Qadir et al., 2003). These problems are becoming increasingly complex with increasing pressure from climate change, population growth, and the ever-increasing demand for food. In this context, efforts to improve water use efficiency are urgently needed. Efficiency is not only understood as saving water volume but also as managing water distribution precisely according to crop needs at specific growth stages (Ritchie & Basso, 2008).

Therefore, innovations in irrigation systems are needed that integrate information technology with agricultural cultivation practices. Al-Atawi (2024) said that one approach that has developed rapidly in the last decade is the application of the Internet of Things (IoT), which enables the collection, processing, and use of real-time data to support decision-making.

Theoretically, the application of IoT in agriculture is based on the concept of precision agriculture, a farm management approach that utilizes digital technology to increase productivity, resource efficiency, and environmental sustainability (Getahun et al., 2024; Ahmad & Dar, 2020; Ferrández-Pastor et al., 2016). Precision agriculture emphasizes the use of data as the basis for decision-making, including in irrigation management (Adeyemi et al., 2017).

IoT plays a key role in this concept through the use of sensors, communication networks, and actuator devices that enable continuous monitoring of environmental conditions. Resource efficiency theory also supports the development of this system, emphasizing the importance of optimally utilizing inputs (water, fertilizer, energy) to maximize output (crop yields) without sacrificing sustainability.

Several previous studies have examined the application of IoT to irrigation systems. For example, a study by Soulis et al. (2015) showed that an automatic irrigation system based on soil moisture sensors can reduce water use by up to 30% compared to conventional methods. Another study by Hilali et al. (2022) integrated temperature, humidity, and weather forecast sensors with water pump actuators, which was shown to improve water distribution efficiency.

In Indonesia, several pilot projects have also been conducted to test the effectiveness of IoT in supporting rice and horticultural cultivation (Kaburuan & Jayadi, 2019). These findings demonstrate the significant potential of IoT in increasing productivity while reducing water waste (Undari & Arista, 2024). However, there are research gaps (state of the art) that still need to be explored. First, most studies still focus on the technical aspects of automated irrigation systems without linking them to broader implementation at the farmer level.

Second, previous research has generally been limited to laboratory-scale testing or experimental plots, resulting in limited assessment of their effectiveness in real-world conditions with varying climates, soil types, and farmer socio-economic characteristics. Third, there are limitations in studies of IoT integration with other digital platforms, such as cloud computing and big data analytics, which have the potential to enrich analysis and decision-making processes. This indicates that there is room for the development of IoT-based smart irrigation systems that are not only technically efficient but also adaptive, affordable, and applicable to farmers in the field (García et al., 2020; Nawandar & Satpute, 2019).

Therefore, this research focuses on developing an innovative IoT-based smart irrigation system that can improve water use efficiency on agricultural land. By utilizing sensors for soil moisture, temperature, and other environmental conditions integrated through an IoT network, this system is designed to regulate irrigation automatically or semi-automatically according to crop needs. This innovation is expected to address the challenge of limited water resources while simultaneously promoting sustainable agricultural practices.

More specifically, this article aims to: (1) examine the basic concepts and theoretical framework of IoT-based smart irrigation systems, (2) review the results of previous research and identify existing research gaps, and (3) analyze the potential and challenges of implementing this technology in the context of agriculture in Indonesia. Thus, this study is expected to provide theoretical contributions to the development of literature on IoT in agriculture, as well as practical contributions in designing innovative solutions that can be widely implemented by farmers.

METHODOLOGY

Research Type and Approach

This research used a quantitative approach with a field experiment method. This method was chosen based on the research objective, which was to test the effectiveness of an Internet of Things (IoT)-based smart irrigation system compared to a conventional irrigation system. Through field experiments, researchers were able to directly measure the differences in yield between the two irrigation methods under identical land conditions, thus obtaining valid and measurable empirical data.

Research Design

The research design used was a comparative experimental design, comparing two treatment groups. The first group was a control group using a conventional irrigation system based on a fixed schedule, while the second group was an experimental group using an IoT-based smart irrigation system with soil moisture and temperature sensors, and automatic pump control. Both groups were placed under relatively similar conditions, in terms of land area, crop type, soil type, and fertilizer treatment, so any differences could be attributed to the differences in irrigation methods.

Research Variables

The independent variables in this study were the irrigation methods used: conventional irrigation and IoT-based irrigation. The dependent variables encompass several aspects, including water use efficiency, measured by water volume per cycle and weekly total; soil moisture and temperature stability, measured by sensors; plant productivity, measured by harvest weight, fruit number, and yield quality; economic aspects, including operational costs and watering time; and social aspects, including farmer satisfaction with the irrigation system.

Data Collection Techniques

Data collection was conducted using several techniques. First, direct measurements using IoT sensors (soil moisture sensors and temperature sensors) to obtain real-time soil moisture and temperature data. Second, recording the volume of water used in each watering cycle for both conventional and IoT systems. Third, harvest yield calculations included fruit weight, number of fruits per plant, and percentage of good-quality fruit. Fourth, observations of labor time and operational costs incurred for the irrigation process. Fifth, farmer satisfaction questionnaires were completed using a Likert scale of 1–5 to assess their perceptions of the ease and effectiveness of the IoT system.

Data Analysis Techniques

The data obtained were analyzed using quantitative descriptive analysis to illustrate the differences in results between conventional and IoT irrigation systems. This analysis is presented in tables, graphs, and percentage change calculations to demonstrate water use efficiency, humidity stability, productivity, costs, and farmer satisfaction. Furthermore, to test the significance of average differences in certain variables, such as water use and crop productivity, an independent sample t-test was used. Efficiency analysis was conducted by calculating the percentage of water savings, increased crop yields, and reduced operational costs. Meanwhile, satisfaction questionnaire data was analyzed by calculating the average Likert scale score and frequency distribution, thus providing a clearer picture of farmer acceptance of the implementation of an IoT-based smart irrigation system.

RESULTS AND DISCUSSION

The research was conducted on a horticultural crop (red chili) trial plot, comparing a conventional (manual) irrigation system with an Internet of Things (IoT)-based smart irrigation system over a three-month planting period. Observations focused on water use efficiency, environmental conditions (soil moisture and temperature), plant productivity, and economic impact.

Table 1. Average Water Use and Watering Frequency

Parameter	Conventional Irrigation	Smart Irrigation (IoT)	Efficiency/Change

Average water use per cycle (liters)	50	32	Saved 36%
Total water use per week (liters)	350	128	Saved 63%
Watering frequency (times/week)	7	4	More efficient

Results showed that the IoT system significantly reduced water usage. Total weekly water usage dropped from 350 liters to 128 liters. This was because watering was based on actual demand (using a humidity sensor) rather than a fixed schedule in conventional systems. Water efficiency reached 63%.

Table 2. Soil Moisture Conditions and Average Temperature

Parameter	Conventional Irrigation	Smart Irrigation (IoT)	Remarks
Soil moisture (range, %)	20–70% (fluctuating)	40–55% (stable)	IoT more controlled
Soil temperature (°C)	28–35 °C (less stable)	29–32 °C (stable)	IoT maintains stability
Daily moisture variation (%)	±25%	±10%	IoT more consistent

Conventional irrigation systems exhibit highly fluctuating soil moisture, often becoming too dry or too wet. In contrast, IoT systems maintain humidity within the optimal range of 40–55%, resulting in more stable conditions that support plant growth. Soil temperature is also relatively more controlled because humidity levels are not extreme.

Table 3. Crop Productivity

Parameter	Conventional Irrigation	Smart Irrigation (IoT)	Change
Harvest weight per plant (kg)	1.8	2.3	+27%
Number of fruits per plant	65	84	+29%
Percentage of good-quality fruits	72%	89%	+17%

The implementation of IoT has significantly contributed to increased crop productivity. The average harvest weight per plant increased from 1.8 kg to 2.3 kg (a 27% increase), with more fruit and a higher percentage of high-quality fruit. This is influenced by more precise water distribution and more stable environmental conditions.

Table 4. Economic and Social Impacts

Indicator	Conventional Irrigation	Smart Irrigation (IoT)	Change
Labor operational cost (per season)	Rp1,200,000	Rp900,000	Saved 25%
Irrigation working time (hours/week)	10	4	Saved 60%
Farmer satisfaction level (scale 1–5)	3.2	4.6	Significant increase

From an economic perspective, labor costs have decreased by approximately 25% because the IoT system reduces the need for manual watering. Farmers' watering time has also decreased from 10 hours per week to 4 hours per week. Satisfaction surveys have shown a significant increase, from 3.2 (sufficient) to 4.6 (excellent), as the system is perceived as being convenient, time-saving, and improving yields.

Discussion

Research results show that the implementation of an Internet of Things (IoT)-based smart irrigation system has a significant impact on water efficiency on agricultural land. Data indicate water savings of up to 63% compared to conventional irrigation systems. This aligns with research by Kumar et al. (2020), which confirms that sensor-based automatic irrigation can reduce water waste because watering is carried out according to the actual needs of the plants, rather than based on a fixed schedule. Thus, IoT technology has proven effective in addressing the problem of limited water resources in the agricultural sector.

In addition to efficient water use, the IoT system is also able to maintain soil moisture within a more stable range (40–55%), compared to conventional systems, which fluctuate. This moisture stability is important because it supports optimal conditions for plant growth and reduces the risk of stress caused by excess or insufficient water. These findings are consistent with the theory of precision agriculture, which emphasizes the importance of environmental data in supporting cultivation decisions. Controlled soil moisture has implications for stable soil temperature, which also influences plant physiological processes, such as nutrient absorption and fruit formation.

In terms of productivity, the IoT system has been shown to increase yields by 27% per plant, both in terms of fruit quantity and quality. This improvement can be explained by the link between more controlled environmental conditions and increased plant physiological efficiency. Research by Wheeler et al. (2018) and Palumbo et al. (2021) also shows that sensor-based irrigation management can improve the quantity and quality of horticultural production. Thus, the findings of this study strengthen the evidence that IoT not only saves water but also positively impacts agricultural output.

Economic and social aspects also show significant changes. Reducing the need for watering labor provides cost savings of 25% and reduces farmer workload by up to 60%. This has resulted in increased farmer satisfaction, who perceive the IoT system as more practical and efficient. However, these findings also open up discussion about the limitations of implementation at the smallholder farmer level, such as the affordability of initial installation costs and skills in operating the technology. Therefore, the success of IoT adoption in the field will be greatly influenced by policy support, extension services, and the availability of technological infrastructure.

Overall, this discussion confirms that IoT-based smart irrigation systems are a relevant innovation for addressing the challenges of efficient water use, increased productivity, and reduced operational costs in the agricultural sector (García et al., 2020; Ahmed et al., 2023; Abdelmoneim et al., 2025). However, their implementation needs to consider local conditions, including farmers' socio-economic factors and technological readiness. With policy support and cross-sector collaboration, IoT has great potential to become a sustainable solution for agricultural water management in the era of climate change and increasing global food demand.

CONCLUSION

This research demonstrates that an innovative smart irrigation system based on the Internet of Things (IoT) significantly contributes to improving water efficiency on agricultural land. Trial results show that water usage can be saved by up to 63% compared to conventional methods, with a lower watering frequency while still meeting plant needs. This system has also been shown to maintain soil moisture within the optimal range (40–55%), resulting in more stable environmental conditions and supporting sustainable plant growth. In terms of productivity, the implementation of the IoT system increased yields by an average of 27% per plant, with better fruit quantity and quality compared to manual methods. Positive impacts are also evident economically, with labor costs reduced by up to 25% and watering time reduced by 60%. These findings are reinforced by increased farmer satisfaction with the system's ease and effectiveness. Thus, it can be concluded that the smart irrigation system based on IoT is not only technically efficient but also provides significant economic and social benefits. This innovation has significant potential to support sustainable agriculture, particularly in the face of water scarcity and increasing global food demand. However, the implementation of this technology still requires policy support, infrastructure provision, and assistance for farmers so that it can be implemented widely and optimally.

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