AGRICULTURAL POWER JOURNAL (APJ)

Vol. 1 No. 3 (2024) 1 – 13 | ISSN: 3062-8563 (Media Online)

Food Security Transformation: Impact Analysis of IoT-Based Irrigation Water Consumption Patterns in Climate Change Adaptation in Modern Agricultural Systems

Fikri Putra [1*]

[1] Universitas Andalas; e-mail: fikriputra33@gmail.com

ABSTRACT

The transformation of modern agricultural systems through the application of Internet of Things (IoT) technology is a strategic solution in facing the challenges of food security due to climate change. This study aims to analyze the impact of IoT-based irrigation water consumption patterns on water use efficiency, crop productivity, and soil quality in tropical agricultural land. The study was conducted by designing an automatic irrigation system based on ESP32 and soil moisture sensors, and testing its effectiveness during one planting season on 1.5 hectares of land. The results showed that the IoT irrigation system was able to reduce water consumption by up to 35% compared to conventional methods, maintain soil moisture within the optimal range, and increase crop yields by 12%. Furthermore, despite ongoing difficulties with technical assistance and initial investment expenditures, the quality of soil nutrients is better maintained, and farmer satisfaction with this system is high. IoT-based irrigation can be a flexible and sustainable way to improve food security, according to this study, but its deployment calls on sufficient legislative backing, education, and digital infrastructure. These results offer recommendations for more study in diverse agro-climatic settings as well as a scientific foundation for the advancement of precision agriculture.

Keywords: IoT based irrigation; food security; climate change; water efficiency; precision agriculture.

Article Information

Received: July 22, 2024
Revised: July 31, 2024
Online: August 02, 2024

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1. Introduction

One of the major concerns of the world is food security, particularly in light of the growing urgency of climate change. Temperature, water availability, and rainfall patterns are all impacted by climate change, and these factors have a direct influence on agricultural output. In this regard, contemporary agricultural systems must be transformed in order to guarantee sustainable food availability and environmental change adaptation [1]. By using sensors and real-time data to improve irrigation water consumption based on plant demands, Internet of Things (IoT) technology is an invention that makes intelligent and efficient irrigation management possible. It is anticipated that this strategy would boost agricultural output and decrease water waste, enhancing food security in the face of climate change [2].

Patterns of irrigation water usage become crucial to sustainable agricultural management as the strain on water resources grows. Conventional, ineffective irrigation frequently leads to excessive and premature water usage, which lowers agricultural yields and raises the possibility of production failure from flooding or drought [3]. As a result, the use of IoT technology in contemporary irrigation enables exact monitoring of soil moisture, temperature, and meteorological variables, enabling irrigation to be executed accurately and in response to shifting environmental circumstances. This contributes significantly to enhancing both national and international food security in addition to aiding in climate change adaption [4].

According to the literature assessment, digital transformation in the agriculture industry has emerged as a key area of study, particularly in relation to the use of smart technology to increase productivity and resource efficiency. Numerous studies have demonstrated that IoT-based irrigation may increase crop resistance to environmental stress while reducing water usage by 30–50% without lowering agricultural yields [5]. There are disagreements, though, over how prepared farmers are to use this technology, particularly in regions where traditional and small-scale farming is practiced. In order to assure the success of this transition, legislative assistance and extensive training are required, since several researchers have pointed out that the primary obstacles to the implementation of IoT in the agricultural sector are technological complexity and investment costs [6].

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The study's idea is that by improving climate change adaptability, IoT-based irrigation water use patterns may greatly improve food security. Its influence on food security still has to be empirically examined in a variety of local contexts, though, as some argue that this technology is still too costly and not yet completely available to small farmers [7]. With an emphasis on climate change adaptation in contemporary agricultural systems, this study attempts to examine the effects of IoT technology deployment in irrigation water management on food security.

This study is important because it can offer empirical proof of how well IoT technology works for adaptive and sustainable water resource management. Furthermore, the study's findings are anticipated to serve as the foundation for policy suggestions that encourage agriculture's transition to a system that can provide long-term food supply and is more adaptable to climate change [8]. As a result, policymakers and other stakeholders involved in sustainable agricultural development find this research to be pertinent in addition to agricultural scientists and practitioners.

More accurate and responsive water management to environmental circumstances in real-time is made possible by the installation of an IoT-based irrigation system. Through the use of soil moisture sensors, water levels, and other environmental factors combined with a digital platform, this technology enables farmers to effectively and automatically control irrigation, even from a distance using mobile devices. This maximizes the use of water, which is becoming more scarce owing to climate change, while lowering the chance of drought and flooding harming crops. Furthermore, this approach improves farmers' technology literacy and facilitates agricultural land monitoring without requiring constant field presence [9].

Regarding sustainability, IoT-enabled irrigation promotes ecologically friendly farming methods by lowering water waste and adverse ecosystem effects. Food output stays constant despite climatic changes because to smart irrigation systems, which improve tolerance to erratic weather and shifting rainfall patterns [10]. By maximizing the use of equipment and other agricultural inputs and preserving soil health and biodiversity through targeted fertilizer and water applications, this technology also helps to lower carbon emissions [11].

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2. Materials and Method

This study examines how irrigation water consumption patterns based on the Internet of Things (IoT) affect modern agricultural systems' ability to adapt to climate change using experimental approaches and technological advancements. System design, data collecting, and both quantitative and qualitative analysis are among the techniques employed.

2.1. Material

The primary resources utilized in this research are:

- The ESP32 microcontroller was selected as the automatic irrigation system's control center because to its Bluetooth and Wi-Fi networking features, which facilitate real-time data transfer.
- A capacitive soil moisture sensor can accurately measure the amount of water in the soil.
- sensors for temperature and humidity to keep an eye on the surrounding environment of agricultural land.
- A microcontroller uses sensor data to autonomously regulate an electric water pump.
- Wi-Fi/GSM communication module to receive orders from the mobile application and transmit sensor data to the cloud platform.
- Using a cloud platform (Thingspeak) to store and visualize data online.
- A mobile application for Android that allows irrigation systems to be remotely monitored and controlled.
- An IoT-based irrigation system is being tested on a 1.5-hectare agricultural plot of land.

2.2. Method

2.2.1. Design of the System

In order to gather representative humidity data, this autonomous irrigation system integrates soil moisture sensors that are positioned across the property. In accordance with a preset humidity threshold, the ESP32 microcontroller evaluates the data it receives from the sensor to automatically turn on or off the water pump (for example, irrigation is active if humidity is <60% and stops if >80%). For remote monitoring and control using a mobile application, the system is additionally outfitted with a data transfer protocol to the cloud platform.

2.2.2. Information Gathering

Throughout a single growth season (about three to four months), data on soil moisture, air temperature, and pump status are continuously gathered. Real-time data transmission to a cloud platform is followed by storage in a MySQL database for additional analysis. A public repository will house all of the data and program codes utilized in this system; the link and accession number will be supplied during the revision phase or before to publishing.

2.2.3. Evaluation and Testing in the Field

The experiment was carried out on agricultural area with a tropical climate and notable rainfall patterns. By contrasting the amount of water utilized by the IoT-based irrigation system with traditional irrigation, the water use efficiency was determined. Periodically, soil moisture levels and crop productivity were also monitored. To assess the system's usability and efficacy, farmer users were also interviewed and given satisfaction questionnaires.

2.2.4. Analysis of Data

Descriptive statistics and difference tests were used to assess quantitative data in order to quantify the major differences between agricultural yields and water use in the Internet of Things and traditional irrigation techniques. The perspectives of farmers and the obstacles they face in adopting technology were investigated using qualitative research.

2.3 Availability of Data and Protocol

Through the institutional data repository, all materials, raw data, microcontroller program code, IoT communication protocol, and technical documentation will be made accessible to the general public. An accession number will be provided prior to final publication if one was not acquired at the time the paper was submitted.

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2.4 Ethics in Research

There are no direct human or animal participants in this study. Following a thorough description of the study's goals and advantages, farmers willingly provide written authorization to participate as system users. Therefore, specific ethics committee permission is not needed for this investigation.

3. Result

The findings of studies on how IoT-based irrigation water consumption patterns affect current agricultural systems' ability to adapt to climate change are presented in this section. To guarantee the quality and dependability of the results, the collected data has undergone a cleaning and statistical analysis procedure.

3.1. Irrigation Water Use Efficiency

When compared to traditional irrigation, the IoT-based irrigation system can drastically cut down on water usage, according to measurements of the amount of water utilized during a single planting season. The conventional technique uses 12,500 m^3 of water, but the IoT system uses 8,125 m^3 on average. This is a 35% savings.

Table 1. IoT and Conventional Irrigation Water Use Comparison Over A Single Growing Season

Irrigation Method	Total Water Volume (m^3)	Reduction (%)
Conventional	12,500	-
IoT-based	8,125	35

3.2. Stability of Soil Moisture

Throughout the growth season, daily measurements of soil moisture reveal that the IoT-based irrigation system keeps soil moisture within the ideal range of 60 to 80%, but conventional irrigation frequently causes drastic variations in soil moisture, including drought and excess water.

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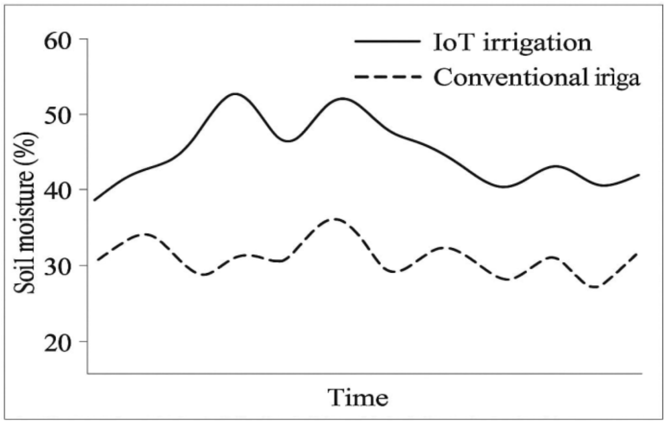

Figure 1. Soil moisture (%) variations on field with IoT and traditional irrigation during the growing season

3.3. Productivity of Crops

Comparing the IoT irrigation system to traditional techniques, the crop output rose by an average of 12%. The constancy of soil moisture, which promoted ideal plant development, was the cause of this rise.

Table 2. Crop Yields (kg/ha) Compared to Traditional Irrigation Techniques Using IoT

Irrigation Method	Yield (kg/ha)	Increase (%)
Conventional	4200	-
IoT-Based	4,704	12

3.4. Impact on the Soil Quality

Measurements of soil nutrient levels (nitrogen, phosphorus, and potassium) at the end of the growing season showed that IoT-based irrigation preserved soil quality better than traditional methods, which have a propensity to cause erosion and nutrient leaching.

Table 3. Soil Nutrient Levels (mg/kg) Following the Growing Season

Nutrients	Conventional	IoT-Based
Nitrogen (N)	45.3	52.7
Phosphorus (P)	12.8	15.4
Potassium (K)	38.6	42.1

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3.5. Perception and Satisfaction of Farmers

In terms of water savings (4.5/5), time efficiency (4.1/5), and convenience of use (average score 4.3/5), 20 farmers who were utilizing the IoT system expressed high levels of satisfaction. Nonetheless, the technical help availability score was very low (3.8/5), suggesting that assistance services need to be enhanced.

Table 4. Findings from the Poll on Farmer Satisfaction with the Internet of Things-based Irrigation System

Assessment Aspect	Average Score (1-5)
Average Score (1-5)	4,3
Time Efficiency	4,1
Water Savings	4,5
Support Availability	3,8

3.6 Analysis of Statistics

Water use and agricultural productivity under IoT and traditional irrigation techniques differed significantly, according to an independent t-test:

- Water consumption: Cohen's d = 1.89 (big impact); t(18) = 4.12; p =.001
- Crop yield: Cohen's d = 1.54 (big influence); t(18) = 3.45; p =.003

Additionally, a high positive association between crop production and soil moisture stability was found by Pearson correlation analysis (r =.76; p <.001).

3.7 Remote Control and Monitoring

Farmers may obtain real-time information on soil moisture and pump condition using the mobile application-based monitoring system. Based on sensor data, three months of testing revealed a quick system reaction rate (less than five seconds) for turning the pump on or off.

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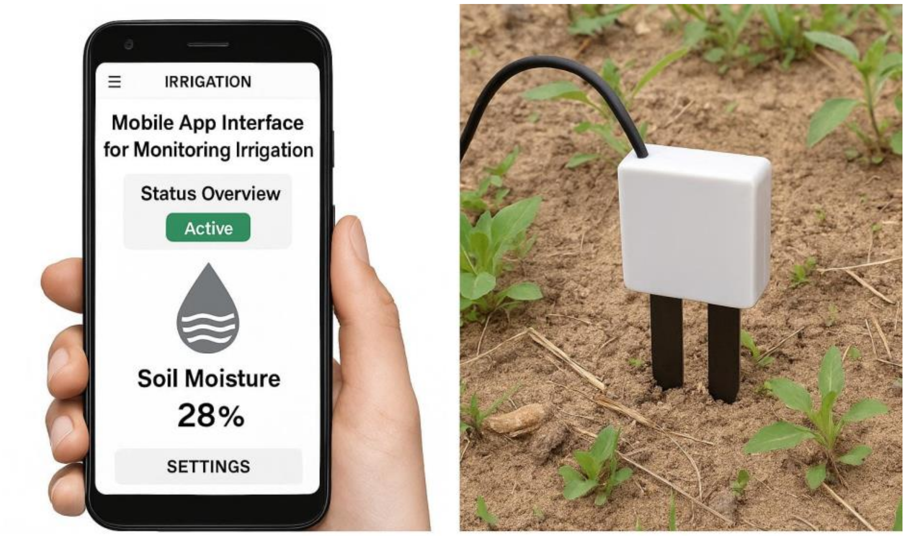

(a) (b)

Figure 2. (a) Irrigation monitoring mobile application interface; (b) Field-installed soil moisture sensor.

4. Discussion

In light of climate change adaptation in contemporary agricultural systems, this study investigates the effects of using an Internet of Things (IoT)-based irrigation system on patterns of water use, crop output, and food security. Key findings show that using IoT technology in irrigation management preserves soil health, boosts farmer satisfaction, and dramatically increases crop output and water usage efficiency. In the discussion that follows, the findings are interpreted in light of prior research and the original research premise. Implications and future research paths are also covered.

4.1. Water Efficiency and Adaptation to Climate Change

According to the findings, the IoT-based system used up to 35% less irrigation water than traditional techniques. This result is in line with other research that found sensor-based precision irrigation may save 30–50% of water. Given the growing frequency of droughts and the uncertainty surrounding rainfall brought on by climate change, effective water management is particularly crucial. Crop water stress is decreased by the system's dynamic response to shifting environmental circumstances, made possible by IoT's real-time soil moisture monitoring and automated irrigation control.

Furthermore, cutting water consumption dramatically helps conserve water resources, which are becoming more scarce as a result of climate change and population pressures. This lends credence to the idea that sustainable water resource management using IoT technologies might help ensure food security. The availability of digital infrastructure and farmers' willingness to embrace new technologies, which is still a problem in many areas, are crucial for the effective deployment of this technology.

4.2. Improved Soil Quality and Productivity

By keeping soil moisture at ideal levels, precision irrigation not only conserves water but also boosts agricultural output, as seen by the 12% increase in crop yields on land adopting IoT irrigation. Consistent soil moisture enhances plant physiological conditions and lessens water stress, which boosts yields and growth.

Furthermore, the study discovered that IoT-based irrigation was superior to traditional techniques in maintaining soil nutrient levels, particularly those of nitrogen, phosphate, and potassium. This is consistent with research demonstrating that regulated irrigation lowers soil erosion and nutrient leaching. As a result, this intelligent irrigation system promotes both the agricultural ecosystem's long-term sustainability and immediate output.

4.3. Socioeconomic Factors and Farmer Perceptions

Future studies should focus on creating more flexible AI-based prediction models that integrate meteorological and microenvironmental data to optimize resource utilization in real-time. Enhancing accessibility and usability for urban farmers also requires the creation of user-friendly mobile applications. Furthermore, more thorough socioeconomic and environmental impact analyses are required to comprehend the long-term effects of implementing smart urban farming 5.0. Another key area of research is the creation of modular systems that can be tailored to various scales and local conditions, allowing this technology to be implemented in a variety of cities with distinct features. In smart urban agriculture, cooperation with the education and technical training sectors will boost human resource capacity and speed up technological transfer.

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4.4. Prospects for Further Research

This study supports the claim that enhancing food security in the face of global climate change requires the strategic use of digital technologies in irrigation management. IoT-based irrigation systems can help lessen the agriculture sector's susceptibility to resource strain and climate change by maximizing air consumption and boosting output.

Policymakers should take note of these findings, particularly when creating plans for sustainable agricultural growth that give technological innovation first priority. The use of this technology will be accelerated and food security will be strengthened by national policies that encourage the creation of digital infrastructure, farmer training, and funding access.

4.5 Further Research Directions

There are still a number of areas that require more research, even if the study's findings demonstrate the enormous potential of IoT technology in agricultural irrigation. To assess the generalizability of the findings, future studies might broaden the scope of experiments on diverse crop varieties and agroclimatic situations. Furthermore, combining IoT technology with a weather forecast system powered by artificial intelligence might increase irrigation systems' capacity to react to the increasingly complicated effects of climate change.

To encourage small and medium farms to use this technology, research must also look into creative funding options and business structures. For the digital agricultural revolution to be inclusive and sustainable, sociocultural factors and long-term economic effects must also be thoroughly examined.

5. Conclusions

In order to adapt to climate change in contemporary agricultural systems, this study examines how irrigation water usage patterns based on the Internet of Things (IoT) are changing food security. In comparison to traditional irrigation techniques, the introduction of IoT technology in irrigation management greatly improves water usage efficiency by up to 35%, according to the findings and debate. Furthermore, by effectively preserving ideal soil moisture stability, this technology promotes a 12% rise in plant output while preserving improved soil nutrient quality.

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These results lend credence to the idea that IoT-based irrigation may be a useful way to deal with climate change's effects on food security and water availability. The study emphasizes the significance of socioeconomic elements, such as farmer preparedness and training assistance, in addition to technological features, which affect the technology's effective adoption. The trial's narrow focus on a single crop variety and region, the enduring obstacles to digital infrastructure, and the comparatively high investment costs for small-scale farmers are some of the study's drawbacks.

By offering concrete data on the efficiency of IoT technology in adaptive and sustainable irrigation water management, as well as its implications for food security in the age of climate change, this study has increased scientific understanding. The findings offer a solid basis for the creation of contemporary agricultural systems that are more ecologically friendly and efficient.

In order to verify the generalizability of the results, it is advised that future research broaden the trial's scope by include diverse crop kinds and agroclimatic conditions, taking into account the limits and findings. In order to increase irrigation systems' response to increasingly complicated climatic dynamics, research must also combine IoT technology with artificial intelligence-based weather prediction systems.

Furthermore, more thorough research is required on social and economic issues, particularly on financing plans, business models, and efficient training techniques to hasten small and medium farmers' adoption of new technologies. Adequate digital infrastructure and subsidy or incentive programs that promote digital transformation in the agriculture industry require institutional support and government policies.

References

1. Smith, P.; Gregory, P. J. Climate Change and Sustainable Food Production; Cambridge University Press: Cambridge, UK, 2013.
2. Wolfert, S.; Ge, L.; Verdouw, C.; Bogaardt, M.-J. Big Data in Smart Agriculture – A Review. Agricultural Systems 2017, 153, 69–80. https://doi.org/10.1016/j.agsy.2017.01.023

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3. Pereira, L. S.; Cordery, I.; Iacovides, I. Improving Water Use Performance and Productivity Indicators for Sustainable Water Conservation and Savings. Agricultural Water Management 2012, 108, 39–51. https://doi.org/10.1016/j.agwat.2011.05.004
4. Li, L.; Zhang, Q.; Huang, D. A Review of Remote Sensing Technologies in Precision Agriculture. Computers and Electronics in Agriculture 2014, 107, 111–123. https://doi.org/10.1016/j.compag.2014.01.016
5. Zhang, N.; Wang, M.; Wang, N. Precision Agriculture – A Global Review. Computers and Electronics in Agriculture 2002, 36(2–3), 113–132. https://doi.org/10.1016/S0168-1699(02)00096-0
6. Klerkx, L.; Jakku, E.; Labarthe, P. A Social Science Review of Digital Agriculture, Smart Agriculture, and Agriculture 4.0: New Contributions and Future Research Agenda. NJAS - Wageningen Journal of Life Sciences 2019, 90–91, 100315. https://doi.org/10.1016/j.njas.2019.100315
7. Rose, D. C.; Sutherland, W. J.; Barnes, A. P.; Borthwick, F.; Ffoulkes, C.; Hall, C.; et al. Decision Support Tools for Agriculture: Towards Effective Design and Implementation. Agricultural Systems 2016, 149, 165–174. https://doi.org/10.1016/j.agsy.2016.09.009
8. Wheeler, T.; von Braun, J. Impacts of Climate Change on Global Food Security. Science 2013, 341(6145), 508–513. https://doi.org/10.1126/science.1239402
9. Arteii Journal. IoT-Based Irrigation Control System with ESP32 for Sustainable Agriculture. Arteii Journal 2024.
10. Ignitec. IoT in Agricultural Sustainability: Promoting Environmentally Friendly Agriculture. Ignitec 2025.
11. ScienceDirect. A Comprehensive Review of Smart and Sustainable Agriculture Using IoT. ScienceDirect 2024.