Advancements in IoT-Based Data Logging for Crop Evapotranspiration Monitoring: Trends and Challenges: A Review

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Abstract: The Internet of Things (IoT) integration with agriculture has brought revolutionary changes to the field of data collection and analysis through agricultural evapotranspiration (ET) monitoring. IoT data logging systems integrate advanced sensors with wireless networks and cloud computing which enable real-time monitoring of soil moisture as well as soil temperature and humidity and atmospheric environmental conditions. Through innovative technological developments farmers can establish precise irrigation systems that enhance water resources and yield production and respond effectively to environmental changes. The Internet of Things delivers essential functions for precise agriculture by enabling automatic data acquisition and distant system monitoring basics for better decision-making. Current advancements in ET technologies involve the manufacturing of advanced sensors which combine high accuracy capabilities with low power consumption while using advanced communication systems with extensive range capabilities and artificial intelligence systems for forecasting ET estimations. The slow adoption rate of IoT in agriculture is affected by several barriers including the high costs of implementation as well as rural area network connectivity problems and security risks related to data protection. Better future research will concentrate on sensor price reduction along with better network infrastructure and AI algorithms for optimizing ET prediction accuracy. Increasing reliability along with efficiency in IoT agricultural systems requires tackling these specific issues. The potential of monitoring ET rates through IoT technology shows great promise to transform how farmers manage their water supply. Global food security becomes more sustainable through IoT enabled data-driven irrigation which reduces water wastage and enables superior crop production.

Keywords: IoT-Based Evapotranspiration Monitoring, Smart Irrigation Systems, Precision Agriculture, Agricultural Water Management.

I. Introduction

Agriculture, one of humanity's oldest occupations, has continuously evolved with automation to meet the increasing global food demand. The primary goal of agricultural automation is to reduce labor while enhancing productivity and efficiency. Artificial intelligence (AI) plays a crucial role in optimizing agricultural processes such as seed sowing, irrigation, and harvesting. The shortage of skilled labor in the agricultural sector has negatively impacted economies, making automation an essential solution. Automatic irrigation, for instance, enables water distribution without manual intervention, improving resource efficiency and sustainability (Lakhiar et al., 2024). To ensure sufficient food production, modern agricultural techniques must integrate automated systems that make farming more time-efficient and accessible. Through automation, farmers can monitor and manage cultivation remotely, ensuring optimal crop growth **(**Bazargani & Deemyad, 2024**).** A key aspect of this process is evapotranspiration (ET), which refers to the combined effect of evaporation from soil and transpiration from plants **(**Choudhary, 2018)**.** Since only a small fraction of the water absorbed by plants is used for growth, efficient water management is necessary to sustain agricultural productivity. ET-based irrigation ensures crops receive adequate water for both growth and cooling. Recent advancements in agricultural automation have led to the development of IoT-based data logging devices that enhance real-time monitoring of environmental conditions**.** This review explores the design and implementation of such devices, focusing on their role in optimizing irrigation. The proposed system integrates sensors to collect temperature, humidity, and soil moisture data, which are then stored and analyzed on a cloud platform. By providing a user-friendly interface, farmers can remotely access real-time soil moisture levels, reducing labor-intensive fieldwork and improving water-use efficiency (Mehta, 2019). Automated data logging not only enables 24-hour environmental monitoring but also ensures precise, data-driven irrigation decisions, contributing to sustainable agriculture.

II. Literature Review

Akhtar et al. (2021) evaluated the combination of smart sensing systems along with edge computing for conducting soil examinations and heavy metal surveillance in precise agricultural methods. This research demonstrated that IoT sensors enable real-time soil condition monitoring which results in better agricultural choices. Processing efficiency receives benefits from edge computing integration through its ability to decrease latency and reduce cloud computing related bandwidth issues. The research showed that implementing automated data collection methods can protect soil from heavy metal contamination while ensuring

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sustainable agriculture operation. Changes in the findings strongly demonstrate how IoT-based solutions boost precision agriculture thanks to their ability to perform efficient environmental monitoring together with data-driven decision-making capabilities.

Al Mamun et al. (2018) investigated the ability of growing Red Amaranth through vertical farming techniques while evaluating environmental sustainability. The researchers established that vertical farming systems maximize space potential and decrease water usage and protect against soil deterioration. The research determined that IoT-based monitoring systems elevate crop performance by allowing proper environmental condition control. Vertical farming proved to be an environmentally friendly substitute for regular farming practices which functions well in settings with scarce agricultural land in cities. The research adds value to academic investigations about uniting IoT-based agricultural automation techniques with controlled-environment farming practices.

Bhanu et al. (2018) investigated how wireless sensor networks (WSNs) enhance agricultural crop production. Their analysis proves that WSNs enable farmers to receive immediate environmental data for successful monitoring of soil moisture and temperature and humidity levels. Automated systems enable substantial improvements in irrigation scheduling processes as well as resource distribution methods. The WSNs implementation in extensive farming faces multiple challenges including connectivity problems in isolated areas and limitations from power systems and errors in information transmission.

Bhosale and Dixit (2012) examined automatic irrigation systems because they wanted to discover how they could help agriculture conserve water. The researchers developed an irrigation system controller which monitors soil moisture to minimize water losses during irrigation operations. The authors state that automated irrigation systems provide major benefits to areas which experience water shortages. Their research shows that these systems require substantial setup expenses and technical skills and affect their implementation rate in smaller agricultural businesses.

Bombale et al. (2011) investigators performed a survey regarding automated irrigation systems throughout Maharashtra to examine how technology affects water usage optimization. The research demonstrated that automated irrigation systems deliver enhanced water management efficiency yet farmers do not fully adopt them because of financial barriers and insufficient awareness about their benefits. The authors propose governmental support for rural farmers through training initiatives and subsidies to enhance the adoption of automatic irrigation systems.

Canton (2021) investigated how World Meteorological Organization (WMO) advances agricultural growth. Precision agriculture and irrigation planning depend on meteorological data including weather forecasts and climate trends according to this research. Addition of IoT-based monitoring systems to meteorological data enables superior resource distribution and lowered crop damage from severe weather events during decision-making.

Dhanaraju et al. (2022) explored the impact of IoT-based smart farming on sustainable agriculture. Their research highlights how sensor networks, real-time data analytics, and automated irrigation systems can optimize water usage and improve crop productivity. The study suggests that integrating IoT with AI-driven analytics can further enhance precision agriculture, reducing water wastage and improving sustainability in food production.

Lebdi (2016) evaluated how irrigation procedures effect modern African agricultural operations. Modern irrigation methods demonstrate their crucial role for producing higher crop levels while securing food supplies. Winnowing the challenges includes scarce water supplies and poor irrigation systems and the economic hurdles farmers face in acquiring sophisticated irrigation technologies. The proposed policies advocate for greater spending on irrigation systems alongside farm training sessions for agricultural growers.

Hanafiah et al. (2019) explored Malaysia's water shortage problems as they relate to agricultural rice cultivation. The research revealed that poor water availability together with inadequate irrigation practices leads to reduced rice farm outputs. The authors stress how sustainable water management requires IoT-based monitoring systems to optimize water usage for maintaining agricultural production in the long term.

Hassan et al. (2019) developed an automated irrigation system through open-source microcontroller implementation. Microcontroller-based irrigation management systems prove effective at maximizing water conservation and eliminating people-dependent water operations according to their research findings. The study proved that these irrigation systems allow for accurate scheduling through IoT sensors which monitor real-time soil moisture conditions. The paper stresses how open-source microcontrollers deliver economic benefits which enable them to become suitable alternatives for traditional automated irrigation platforms while offering affordability to small and medium farmers. Research and improvements must address system maintenance difficulties and power supply problems as well as the initial installation expenses.

Huang, Chen, and Wen (2020) investigated the implementation of machine learning systems for ongoing weather observation and forecasting. The research team identifies city buses as environmental data collection points for improving weather prediction accuracy. Farmers would benefit from integrating this technology because it enables precise irrigation control which makes optimal use of available water supplies through accurate rainfall predictions.

Ighrakpata et al. (2019) implementation of automated irrigation systems throughout different agricultural cultivation areas worldwide. Automated systems provide three main advantages by decreasing employment requirements and conserving water

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while increasing agricultural production results according to their research findings. Research should focus on designing economical automated agricultural systems that specifically benefit smallholder farmers according to the authors.

Rudnick et al. (2017) investigation analyzed how irrigation together with nitrogen fertilizer dose levels impacted both soil water conditions and maize evapotranspiration. The researchers discovered that scheduling irrigation properly alongside restricted nitrogen application produces the best possible yield performance along with reduced water losses. This research emphasizes that soil moisture sensors should be combined with irrigation management system.s.

Irmak, Mohammed, and Kranz (2019) examined the evapotranspiration rates together with water productivity when using drought-tolerant hybrid maize and non-drought-tolerant hybrid maize across multiple irrigation levels. The research showed that accurate irrigation techniques enhance productivity rates for different types of maize crops.

Kansara et al. (2019) investigation evaluated the water quality of sources in Maharashtra India for agricultural and drinking consumption purposes. The research findings demonstrate problems with groundwater contamination which affect agricultural land. The research recommends developing water treatment methods and monitoring procedures for ensuring secure irrigation practices.

Katariya et al. (2019) explored various automation technologies in agriculture, including robotic systems, AI-driven monitoring, and sensor-based irrigation management. Their study emphasizes that while automation enhances efficiency, challenges such as high costs and technical skill requirements hinder widespread adoption.

III. Methodology

The selection of literature for this review followed a systematic approach to ensure relevance, quality, and comprehensive coverage. The process involved the following steps:

Databases and Sources

Relevant literature was retrieved from high-impact journals, conference proceedings, and reputable sources using the following academic databases: Google Scholar, IEEE Xplore, ScienceDirect, SpringerLink, Scopus and Web of Science. Open-access journals and institutional repositories were consulted to include recent advancements in IoT-based agriculture and automated irrigation.

Keywords and Search Terms

To ensure comprehensive coverage, a combination of relevant keywords and Boolean operators was used, including: *"IoT in agriculture"*, *"automated irrigation systems"*, *"evapotranspiration monitoring"*, *"wireless sensor networks in precision farming"*, *"data logging for agricultural applications"*, *"environmental monitoring in smart farming"*.

Inclusion Criteria

The selected studies met the following criteria:

i. Relevance: Directly related to IoT, automation, and precision agriculture.
ii. Recency: Primarily published within the last 10–15 years (2010–2024) to ensure up-to-date advancements.
iii. Scientific Rigor: Peer-reviewed journal articles, conference papers, and credible industry reports.
iv. Full-text Availability: Accessible for in-depth review and citation.

Exclusion Criteria

i. Studies unrelated to agriculture, irrigation, or IoT.
ii. Non-English publications (unless translations were available).
iii. Papers lacking empirical data, methodology, or significant contributions.
iv. Duplicated studies or preliminary research without conclusive findings.

Justification for Inclusion of Selected Studies

The selected studies were chosen based on their scientific rigor, relevance, and contribution to IoT-based agriculture, automated irrigation, and environmental monitoring. Below are the key justifications for their inclusion:

Relevance to IoT and Automated Agriculture

Akhtar et al. (2021) provided an in-depth review of smart sensing and edge computing in precision agriculture, making it highly relevant to IoT-based data logging.

Hassan et al. (2019) and Ighrakpata et al. (2019) focused on automated irrigation systems, demonstrating the effectiveness of microcontrollers and sensors in optimizing water use.

Kondamudi & Gupta (2018) proposed an IoT-based data logger system for weather monitoring, directly aligning with the study's focus on data logging for evapotranspiration.

Contribution to Water Management and Evapotranspiration Studies

Rudnick et al. (2017) and Irmak et al. (2019) explored the relationship between irrigation, nitrogen use, and soil moisture trends, providing crucial insights into evapotranspiration monitoring.

Kansara et al. (2019) examined water quality for irrigation, highlighting the importance of sustainable water use in agriculture.

Integration of Environmental and Climatic Factors

Huang et al. (2020) utilized machine learning for weather monitoring, supporting the role of IoT in real-time climate data analysis.

Kayode et al. (2019) applied electrical resistivity tomography for environmental assessment, contributing to soil monitoring aspects of precision agriculture.

Advancements in Automation and Smart Systems

Kharisma & Setiyansah (2021) studied fire early warning systems using sensors and microcontrollers, aligning with IoT-based real-time monitoring applications.

Katariya et al. (2019) reviewed automation in agriculture, emphasizing how smart systems improve efficiency and reduce labor dependency.

Evolution and Trends in IoT-Based Crop ET Monitoring

Technology advancements in IoT use for monitoring crop evapotranspiration (ET) have transformed precision agriculture into a modern practice. Crop water usage measurement through evaporation and transpiration known as ET stands essential for irrigation management and water preservation (Hafian et al., 2023). The assessment of evapotranspiration through empirical models and weather stations and lysimeters possessed limited capabilities for quick adjustment (Emmanuel et al., 2020). WSNs brought improved ET estimation accuracy through their implementation of real-time data acquisition from soil moisture and temperature as well as humidity measurements. IOT found its next advancement when combined with cloud computing platforms for automated data storage and remote monitoring that delivered better water-use efficiency. AI along with machine learning capabilities have recently been fused into IoT-based ET systems to enhance predictive functionality. By analyzing previous weather records and active sensor information along with distinct weather patterns the algorithms develop optimized irrigation strategy (Mishra & Mishra, 2023). Edge computing emerged as a solution to perform data processing at site locations so businesses can operate independently from cloud services and make decisions in real time.

Current Trends in IoT-Based ET Monitoring

1. Weather Forecast Integration: IoT systems now incorporate meteorological models and satellite data to enhance ET prediction accuracy.
2. Drone and Remote Sensing Technologies: Unmanned aerial vehicles (UAVs) equipped with infrared sensors complement ground-based IoT networks by providing large-scale ET assessments.
3. Blockchain for Data Security: Ensuring transparent, tamper-proof storage of ET data supports better resource management.
4. Smart Irrigation Systems: IoT-driven automated irrigation systems adjust water application in real time based on sensor feedback, improving efficiency.

Challenges in IoT-Based ET Monitoring

Despite the advancements in IoT-based evapotranspiration (ET) monitoring, several challenges hinder its widespread adoption and effectiveness. These challenges span technological, economic, environmental, and operational aspects.

1. High Initial Costs and Infrastructure Requirements: An IoT-based ET monitoring system requires significant financial commitment to sensors as well as communication networks together with cloud storage and data processing tools (Sathyamoorthy et al., 2024). The costs exceed what farmers especially in developing areas are willing to pay. The financial strain increases due to expenses needed for sensor calibration as well as costs for hardware improvements.

2. Connectivity and Data Transmission Issues: The operation of Internet of Things-based ET monitoring technology requires reliable internet and wireless networks. Data transmission becomes unreliable in remote agricultural areas because network coverage remains weak (Elijah et al., 2018). The combination of unreliable signals and slow transmission rates together with constrained bandwidth stands as major obstacles that prevent successful real-time tracking and data processing.

3. Sensor Accuracy and Calibration Challenges: To estimate ET the system depends on feed from soil moisture sensors combined with temperature probes alongside weather stations. The calculation of ET through sensors experiences errors due to

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environmental factors such as dust, humidity and wear-and-tear according to Yu et al. (2021). The system needs regular calibration together with maintenance practices that prove labor-consuming and expensive.

4. Data Management and Security Risks: IoT devices produce expansive amounts of data which creates difficulties regarding data storage together with analysis and processing demands. The management of extensive datasets becomes difficult because of ineffective data systems (Papalkar, Nerkar & Dhote, 2017). The integrity of ET monitoring systems remains at risk because of hacking events as well as unauthorized access to data and multiple system vulnerabilities.

5. Integration with Existing Agricultural Practices: The barrier to IoT tech adoption exists because traditional farmers lack working knowledge about these technologies. There exists a complexity barrier for farmers to learn about sensor readings followed by cloud platform utilization and data-driven irrigation systems (Thilakarathne et al., 2021). To achieve efficient utilization of IoT-based ET monitoring technology it needs to integrate perfectly with current irrigation techniques.

6. Environmental and Climatic Variability: The rates of ET depend on shifting meteorological factors because of abrupt rainfall events alongside temperature variations and wind patterns. Systems based on IoT need adaptive models to handle such uncertainties according to Selvam and Saud (2023). IoT systems today do not contain AI-driven predictive abilities which allow real-time adjustments.

7. Lack of Standardization and Interoperability: Manufacturers produce IoT devices that use different communication methods and data formatting structures. Current manufacturing methods for IoT devices cause integration challenges for heterogeneous ET monitoring networks because of non-standardization (Al-Qaseemi et al., 2016). Overall standard development for data sharing methods and device interoperable protocols presents an ongoing challenge.

Integration of IoT in Agricultural Water Management

The integration of the Internet of Things (IoT) in agricultural water management has transformed traditional irrigation practices, enabled precision monitoring of environmental parameters and optimized water use efficiency **(**Uchenna et al., 2024**).** This technology-driven approach leverages real-time data collection, cloud computing, and automated irrigation systems to address challenges such as water scarcity, climate variability, and inefficient resource utilization.

Emergence of IoT Solutions for Monitoring Environmental Parameters

The agricultural sector adopted IoT solutions to solve the requirements for precise and continuous observation of environmental factors which steer crop development and drive water use monitoring. Soil moisture alongside temperature humidity and atmospheric pressure data acquired through field sensors enables farmers to base their irrigation decisions (Morchid et al., 2023). The systems deliver instant monitoring feedback which minimizes the dependency on time-consuming manual assessments. WSNs execute vital data transmission functions to cloud-based platforms which allows analytics tools to analyze trends following data processing. Large-scale evapotranspiration (ET) rate and soil-water interaction monitoring through drones and satellite imagery remote sensing technologies was enhanced by Mowla et al. (2023).

Advancements in Sensors, Wireless Networks, and Cloud Computing for ET Monitoring

The development of sensors as technology has led to improved precision together with longer-lasting performance in IoT-based monitoring systems. Modern high-precision sensors operated by low power have established continuous monitoring of soil moisture alongside climate variables which leads to accurate ET estimation. Remote farming benefits from wireless networks including LoRaWAN and 5G because they enable continuous data transmission according to Khanal et al. (2024). Cloud computing systems now provide expandable data repositories and advanced analytical options which have transformed the practice of ET monitoring. Real-time agricultural insights are available through mobile applications so farmers perform distant irrigation operations and predict water utilization needs (Miller & Shekhar, 2024). ET forecasting gains potency though collaboration between artificial intelligence systems and machine learning programs which allows precise water distribution according to weather patterns and soil attributes (Preite & Vignali, 2024). These improvements will serve as vital components for sustainable water resources management and climate-resilient agricultural systems because of ongoing IoT expansion.

IV. Conclusion

The review discusses major IoT-based evapotranspiration (ET) monitoring achievements which include the fusion of smart sensors and wireless networks with cloud computing for agricultural water management systems. The implementations of IoT technologies now enable continuous real-time acquisition of necessary environmental variables including humidity levels and soil moisture together with temperature readings. Through wireless sensor networks (WSNs) together with cloud-based platforms data is transmitted and analyzed with precision for ET estimation and optimized irrigation scheduling. The implementation of artificial intelligence (AI) and machine learning (ML) features improves predictive analytical capabilities which results in better water resource utilization. Despite the technological progress various issues still exist including security of data and expensive system installation along with unstable rural network connectivity. Continuing research and technological advancements work to overcome IoT implementation obstacles which are making IoT deployment more accessible for both agricultural sectors. ET monitoring can change its current practices through IoT-driven data management systems that build automated irrigation control. IoT technology enables precision agriculture which produces three major benefits: reduced water waste, increased crop

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production and promotes environment-friendly farming methods. IOT-based ET monitoring stands to become essential for solving both global food scarcity and water management through climate change by using technological advancement.

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