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Research paper

A Novel Methodology for Sustainable Agriculture: IoT-Driven Water Management and Crop Planning Using LoRaWAN

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Abstract

Efficient farming is an advanced and capital-based method of sustainable and clean food production. An IoT and AI-based system with the application of LoRaWAN technology is proposed for efficient environmental monitoring in farming. The system incorporates IoT devices installed in crop fields to provide real-time data visualization, monitoring, and control of key parameters such as temperature, humidity, soil moisture, TDS, and water levels. These sensors are attached to ESP32 microcontrollers with LoRaWAN modules, transmitting data at 915 MHz to ensure low-power, long-range communication. The system attains high accuracy (98.5%) when predicting water requirements, addressing issues like overfitting that are common in standard approaches. Additionally, the system follows an integrated novel methodol-ogy-gy that includes Assessment of the water balance to improve crop planning, and IoT-based optimized irrigation scheduling executed through a LoRaWAN-integrated cloud environment for data storage and visualization. Experimental results confirm the system's higher performance in enhancing water distribution and prediction, resulting in an 8% increase in water use efficiency and a 15% reduction in crop water utilization issues. These results highlight the potential of IoT and LoRaWAN technology to advance water resource management and promote sustainable agricultural practices in rural regions. The system also triggers warnings for low soil moisture, high TDS, and critically low water levels, with sensor data transmitted via LoRaWAN every 120 seconds to provide farmers with real-time insights for improved decision-making.

Keywords: *Water Utilization; Irrigation; IoT; LoRaWAN; Agriculture.*

1. Introduction

Agriculture is the primary source of sustenance and livelihood for many developing countries, India included. However, the sector confronts several difficulties, ranging from limited adoption of technology because of the high cost of use, ineffective water irrigation [1] systems, to the impacts of urbanization and climate change on crop production. Conventional irrigation techniques result in wastage of water, under-watering of crops, and eventually poor yield, which only enhances the hardships of farmers [3]. These challenges pose a significant threat to food security and necessitate the development of new technologies that can increase agricultural productivity while minimizing the impact on the environment.

Smart IoT devices are transforming agriculture by giving farmers the ability to monitor and control in real time environmental factors like soil moisture, temperature, and humidity. The use of IoT sensors in crop cultivation will enable farmers to make data-driven decisions and enhance the use of resources and crop production [2]. Moreover, IoT-based systems can bring a drastic improvement in irrigation, enabling farmers to better control their water utilization, especially for land where there is serious water scarcity.

In this paper, an IoT-based framework is introduced to overcome the challenges of traditional irrigation and crop monitoring. In this system, we used IoT sensors that are deployed in the fields of agriculture to monitor important parameters like soil moisture, temperature, and humidity in real-time. These sensors use LoRaWAN, a low-power, long-range communication protocol, to communicate, providing secure data transmission even in distant locations. It is kept in cloud databases, and farmers are able to view and analyze it to gain actionable information. The system comes with several advantages over conventional systems. First, it reduces human labor usage using automation data gathering and sending. Second, it conserves water by doing so efficiently with correct measurement of soil moisture so that the volume of water for irrigation is calculable. Third, it allows real-time observation and making decisions through a platform like Thingzmate, in which farmers can manage irrigation and gain more yields on their crops.

LoRaWAN's ability to facilitate long-range communication in remote areas, the scalability of IoT sensors, and a cost-effective solution for precision farming. Because it can cater to large plots of agriculture and provide data over long distances, LoRaWAN allows farmers to monitor their fields without incurring expensive infrastructure or manpower in large numbers. It prevents wastage of resources, minimizes the risk of destruction to the crops, and facilitates a greener way of farming.

The convergence of LoRaWAN and IoT in agriculture has already shown positive results in various regions of the globe, where smart agricultural practices have increased efficiency and reduced wastage of resources. IoT-based solutions have been used successfully to remotely track fields of crops, providing farmers with useful information to ensure higher yields. The IoT-SMPLora framework extends these advancements, offering a scalable and reliable option for precision farming. This paper proposed a technique that LoRaWAN-based IoT system effectively improves water and crop management. By virtue of the effective and reliable transmission of data enabled by the utilisation of LoRaWAN, the system supplies accurate and timely data of soil moisture to facilitate farmers in providing water adequately and avoiding excessive or inadequate watering.

The proposed framework maximizes farm production and contributes to sustainable agriculture through the optimization of the utilization of resources and the minimization of environmental impact. Through the use of these advanced tools and techniques, farmers are able to go beyond the constraints of the conventional approach, make more informed choices, and harvest more crops. In this paper, the potential of IoT and LoRaWAN to disrupt agriculture and set the stage for a more productive and sustainable future is emphasized.

The implemented model is discussed as follows: Section II, An overview of research done on IoT, Section III will give complete information about methodology and technique, Section IV discusses the proposed system, Section V tests and results, Section VI concludes the proposed work with future work.

2. Literature Review

In recent years, wireless sensor network-based smart irrigation control systems have been a Craze, and such systems have been applied across many other fields like industry, cities, and residences. Various researchers have discussed the merits of wireless networks in agriculture, e.g., [4], describing a design of a smart system on the basis of an internet of wireless sensors and actuators to manage greenhouse irrigation. Moreover, [5] discusses the energy consumption of the various components of wireless sensor networks, including the main consumers of energy and the improvements in energy efficiency. Kochhar et al. introduce wireless technology for application in communicating with sensors and deciding the rate of transmission of greenhouse crops. Another research article [6] describes an IoT system that developed a smart irrigation system for a large area with the assistance of an LPWAN network and soil temperature, humidity, and air temperature sensors.

Similarly, [7] modeled and simulated a wireless network of six nodes to represent the relative humidity and temperature of suburban areas through a Long-Rang network (LoRa) at various locations in the city of Ghent (Belgium). It has been used by [8], who developed an optimal LoRa network on the basis of ABC algorithms to reduce Packet Loss Rate (PLR) and forwarding time for approximating the load profiles of a house. This study [9] employed LoRaWAN for designing an energy and water-conserving
greenhouse control system with real-time monitoring of the building.

The research includes the construction of a monitoring system of water flow relative to soil moisture for a specific crop according to smart farming techniques with IoT, with a high degree of accuracy and low usage. At the same time, [10] recommended an operational model of irrigation management, through which measurements of temperature, humidity, light intensity, and soil moisture are obtained on the field with the help of LoRa technology to provide high performance and low human involvement. In [11], an efficient irrigation system improving natural resources like water and energy, and minimizing economic costs, was achieved through an IoT network using a battery-powered network, with a two-hour communication time.

The Climatic parameters, soil moisture, plant health, plant disease, and yield measurement have also been established for the use of IoT technology with wireless networks. Further,[12] presented an overview of the latest advances in LoRa-based wireless sensor network research and how the wirelessly connected sensors need to be powered in challenging areas, noting that such sensors do come with sources of power. This study [13] presented an economical system consisting of a soil moisture sensor, temperature sensor, humidity sensor, and valve actuator in a mesh design managing drip irrigation. Contrariwise, [14] designed an intelligent system for electrical variable measurement to obtain load profiles in homes. Various control systems utilized in irrigation have been proposed. For instance, [15] introduced a microcontroller on fuzzy logic algorithms for drip irrigation. Sudharshan et al. [16] investigated a solenoid valve fuzzy logic control system based on data from temperature, humidity, and soil moisture sensors. Another study [17] applied a greenhouse, garden, and farm management system with an automatic irrigation system to be able to measure crop water requirements and offer historical and real-time data of the farm. This researcher [18] applied an automatic irrigation system with real-time data of soil moisture to estimate the depth of water uptake.

In [19], a system for water utilization monitoring with a focus on how crucial it is to use new technologies like LoRaWAN and sensors to achieve reliable, real-time information on crucial water parameters. Using the LoRaWAN network, the most important advantage is too able to transmit data to the cloud effectively, combining data from multiple sensors in a single packet. Besides, recent studies such as [23] proposed an IoT-based LoRaWAN-based precision irrigation management system with significant improvement in the use of water. A smart watering system based on LoRaWAN was utilized in [24] to offer support for irrigating crops, where real-time responsiveness as well as energy-efficient design are emphasized. Another system [25] presented a hybrid LoRa and NB-IoT monitoring system for smart agricultural management to enable massive deployment with stable performance. In [26], had provided actual design of LoRaWAN infrastructure for soil moisture monitoring and provided practical implementation of long-range IoT applications. In [27], a wireless sensor network was developed for irrigation monitoring on the basis of advanced IoT methods, confirming reduced water loss as well as improved prediction capabilities.

In [20], the development of an intelligent sensor that worked sufficiently for measuring variables in industrial processes was established, and the sensor was discovered to provide safe and precise measurement, becoming an effective tool for monitoring and industrial process control.

Conversely, [21] employed IoT for water monitoring, pointing out that the system can save response time in contrast to manual sampling, is economical, has minimal space requirements, and low-cost implementation. Use of sensors to measure turbidity, temperature, pH, and dissolved solids in different sources of water allows one to instantly record results and predict outcomes based on historical records, in lowering the risks involved with water quality. Finally, [22] conducted experiments to determine the communication performance of the LoRaWAN system, demonstrating how robust it is against interference and noise and how nodes can be placed efficiently between locations. In being cognizant of the consumption in real time, they have come up with a system to regulate and develop savings sustainability strategies. While these studies have shown promising advances in IoT and LoRaWAN-based agricultural systems, most of them focus on localized implementations without addressing large-scale scalability, long-term energy optimization, or affordability in developing contexts. The proposed work will bridge this gap by integrating low-cost local sensors, optimizing the power usage, and further designing a scalable communication network suitable for rural agricultural settings. This critical improvement highlights the novelty of the present approach compared to prior related studies.

3. Methodology

The overall architecture, encompassing the stages, processes, components, methodology, and cloud technology (via the LoRaWAN gateway), forms the foundation for developing the proposed system. The study starts with identifying challenges in existing irrigation and soil monitoring practices, such as inaccurate moisture measurements, inefficient water distribution, and a lack of real-time data accessibility. To address these issues, the proposed system integrates carefully selected hardware and software components tailored to agricultural constraints. Considering the constraints of the agricultural environment, the system architecture is designed to address the needs. The IoT devices are deployed in the field to measure soil moisture, temperature, humidity, TDS, and water level, while the LoRaWAN technology is responsible for transmitting data over long-range and low-power. The system is tested and calibrated for precise prediction and optimal performance. The workflow diagram of the methodology is represented in Figure 1.

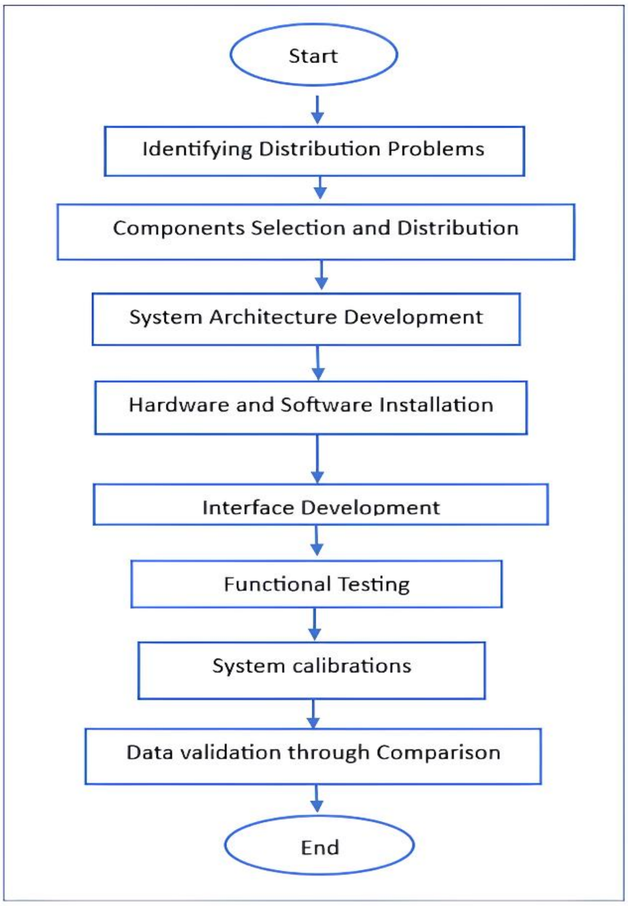

Fig. 1: Workflow Chart.

The proposed system's water requirement prediction module will be accomplished by a supervised machine learning approach that relies on historical soil moisture, temperature, and humidity data. A Random Forest algorithm was chosen because it is robust and less prone to overfitting. We divided the dataset into an 80:20 ratio, with 80% for training and 20% for testing, and used five-fold cross-validation to ensure generalization and reproducibility. This transparency in methodology builds scientific rigor and reliability into the predictive component of this study.

3.1. Component selection

Installation of the new water utilization and distribution monitoring system calls for Thorough component selection using extensive studies of materials in view of cost, application, quality, size, and reliability. Local sensors that measure water utilization parameters were used to minimize costs and design time for the system.

The hardware comprises ESP32 microcontrollers, which connect to sensors like soil moisture, temperature, and humidity sensors to gather environmental data in real-time. LoRaWAN RFM95W modules that work at 915 MHz are used for low-power, long-range communication, allowing data transfer up to a distance of 3 km under open conditions. A LoRaWAN gateway module and an ESP32 microcontroller combine to act as the central hub for receiving and processing data from various sensor nodes. On the software side, the system uses the Arduino IDE for code development of ESP32 microcontrollers and Thingzmate used for LoRaWAN connection and data storage, analysis, and visualization, respectively. All these were selected based on reliability, cost savings, and relevance to agricultural purposes, which makes them easy to integrate and achieve maximum performance under real farming environments. This judicious selection of equipment ensures that the proposed system is cost-effective, efficient, and suitable for application in water utilization monitoring and distribution in agricultural environments. The equipment enables reception and transmission of relevant water utilization data, thereby enabling effective monitoring of significant agricultural parameters in real time.

3.2. System architecture

This architecture is created to overcome the limitations of conventional irrigation and soil moisture observation with the use of IoT and LoRaWAN technologies. The architecture is separated into four layers, each containing a particular function in the pipeline of data collection, transmission, processing, and visualization. Detailed descriptions of each layer are presented below:

The sensing layer constitutes the base of the system that captures real-time environmental information in the agricultural field. This layer is made up of IoT devices with sensors to monitor key parameters like Soil Moisture, that measures volumetric water content within the soil and Temperature that Monitors ambient temp to determine its effect on crop growth, Humidity that monitors air humidity levels to determine evaporation rates and water needs, TDS (Total Dissolved Solids) sensors detect the concentration of dissolved solids in water. These sensors are interfaced to ESP32 microcontrollers, where the raw data from the sensors is processed and ready for wireless transmission. The sensing layer takes care of ubiquitous data collection for precise monitoring of field conditions.

The communication layer enables data transmission from the sensing layer to the cloud, where it is processed further. This layer employs LoRaWAN technology that is best suited for use in agriculture because of its low-power and long-range (up to 3 km in the open) transmission ability. The major components of this layer are the LoRaWAN RFM95W Modules that were integrated with ESP32 microcontrollers to support wireless data transmission. LoRaWAN Gateway that serves as a central gateway, taking input from a number of sensor nodes and sending it to the cloud. The communications layer provides assured and efficient data transfer even in areas far from dense connectivity, like agricultural regions.

The cloud layer acts as the support structure of the system, offering storage, processing, and visualization services. Data received from the communication layer is saved in Cloud, a strong IoT platform that facilitates real-time data analysis and visualization. The major operations of this layer are the Data Storage, where historical and real-time data are saved in the cloud for further analysis, also it provides a smooth and efficient transfer of the data to the cloud.

Stored and processed data can also be graphically presented in the application and visualization layer by the Thingzmate application, providing a user-friendly interface for monitoring water utilization parameters on mobile or other Web-enabled devices. In addition, the predicted soil data is displayed by system dashboards or mobile apps, providing farmers with an easy interface to monitor field conditions. Based on the predictions, farmers can make informed choices about irrigation, fertilizing, and other soil maintenance.

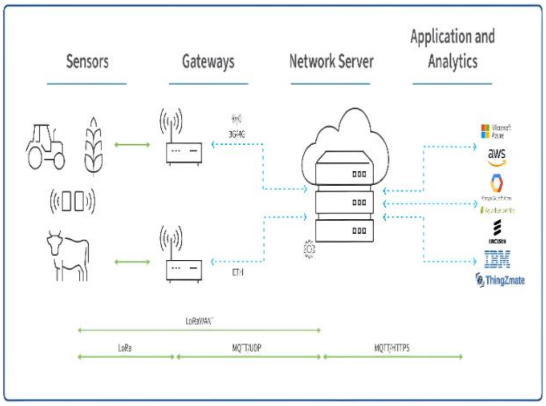

Fig. 2: System Configuration.

4. Developed system

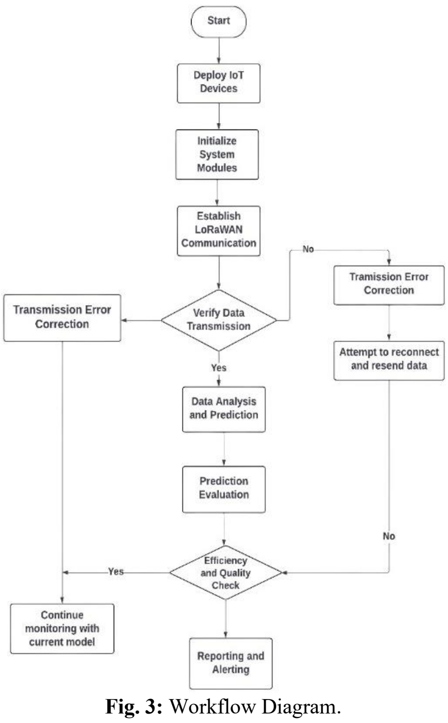

Fig. 3: Workflow Diagram.

Algorithm: Efficient Farming Environmental Monitoring and Prediction System

```
Start
Deploy IoT Devices
Deploy sensors in crop fields to monitor temperature, humidity, soil moisture, TDS, and water levels.
Initialize System Modules
Connect each sensor to ESP32 microcontrollers equipped with LoRaWAN modules.
Establish LoRaWAN Communication
Configure devices to transmit data over 915 MHz frequency using the LoRaWAN protocol.
Transmission Verification
Check if sensor data is successfully transmitted to the gateway.
If transmission is successful:
Forward the data to the cloud platform, such as Thingzmate.
Else:
Transmission Error Correction.
Attempt to reconnect and resend data.
Data Visualization
Display real-time sensor data on the monitoring dashboard via the cloud platform.
Data Analysis and Prediction
Analyse collected data to predict water requirements using a trained ML model.
Model Evaluation
Display water levels predicted on the monitoring dashboard.
Efficiency and Quality Control
Check prediction accuracy and water usage efficiency.
If prediction accuracy is ≥ 98.5% and the water usage efficiency has improved
Continue monitoring with the current model.
Else:
Retrain or fine-tune the ML model to address the overfitting or inaccuracy.
Reporting and Alerting
Notify farmers if anomalies or inefficiencies are detected also generate water usage reports.
End
```

The interval Forecasting for soil moisture and water levels plays a main role in the accuracy model's predictions. Real-time Intervals enable irrigation planning and resource allocation. This improves the usage of water and also supports sustainable farming decisions.

4.1. Hardware deployment

In the crop field, ESP32 boards with LoRaWAN modules were installed, each of which was attached to humidity, temperature, moisture, and water level sensors. This sends the data to the IoT cloud server for real-time storage and display at the control station, which is humidity-shielded (As shown in Figure 4). This network utilizes the 915MHz frequency, and the data is sent to the cloud.

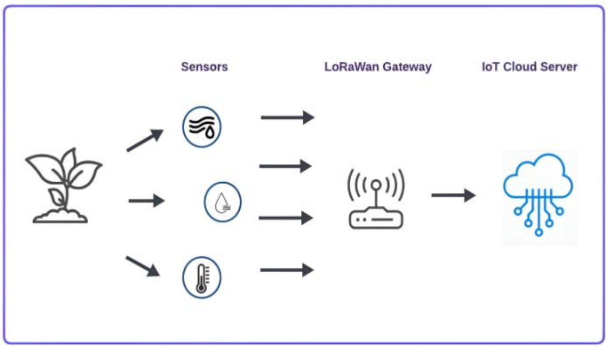

Fig. 4: Sensor Distribution.

The topology of the network was utilized, where monitoring nodes are connected directly to a gateway (see Figure 5). This setup also supports efficient communication between nodes as well as less power consumption by the nodes. A segmented addressing scheme was implemented, where every gateway and node is given a unique identifier for efficient routing of data and for the effective delivery of packets. It shows how differentiation at the data link level and routing of data over multiple nodes in the field network were realized.

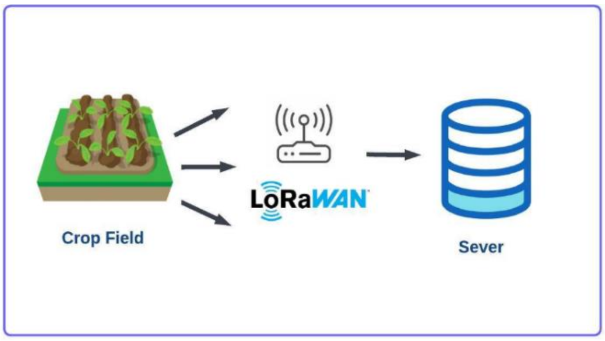

Fig. 5: LoRaWAN Network in Crop Field

The LoRaWAN gateway was placed purposely to provide full coverage across the supervised area. The gateway collects data from the sensors, and for processing and analysis, it proceeds to a cloud platform. After obtaining the components and testing, the sensors are connected to the ESP32 microcontroller (as shown in Figure 6).

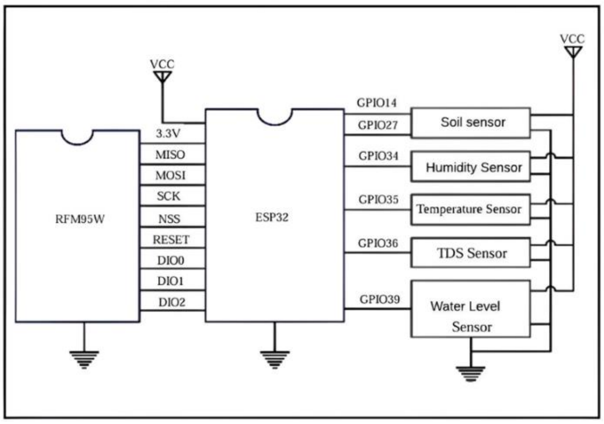

Fig. 6: Convergence of ESP32 and LoRaWAN Module.

For water distribution, data is transmitted to the cloud through an ESP32 interfaced with water level sensors loaded with LoRaWAN modules.

Fig. 7: ESP32 Development Board Layout.

4.2. Software deployment

The programming of this system of software development for water distribution and quality monitoring was separated into various interdependent components. Initially, to develop the ESP32 micro-controllers, the programming of the sensor nodes was taken care of using the Arduino IDE. The code implemented involved the initialization, data processing to transform analog reading into useful values, and setup of the different sensors (temperature, humidity, moisture, TDS sensor, and water level sensors), as well as the setup of the LoRaWAN communication, including the RFM95W module initialization. Packaging and transmitting data via LoRaWAN were an important portion of the code.

The gateway's configuration was another major component of the Software implementation. The LoRaWAN gateway on the ESP32 was configured by installing and setting up the LoRa Gateway Bridge software, establishing the connection to the cloud, and tuning significant parameters like frequency, spreading factor, and bandwidth. Integration with the cloud involves creating an application for handling device data (such as device registration, generation of security keys, and configuration of payload decoders to properly decode the received data). Thingzmate cloud was used to implement the visualization of the data (Illustrated in figures 8, 9, 10, and 11). Channels were created for each measured parameter, and graphs and Widgets were set up to show the data in real-time, offering an intuitive and user-friendly interface to end users. Figs. 8–11 present the real-time monitoring capability of the proposed system using the visualizations generated on the Thingzmate platform. These figures show the stability of communication, consistent sensor responsiveness, and accurate data transmission of the different parameters, like soil moisture, leaf moisture, temperature, EC, and pH. Smooth data acquisition and minimum latency during cloud synchronization prove that LoRaWAN communication is operational with integrity and is reliable under real field conditions. Collectively, these visualizations give evidence for the effectiveness of the system in continuous real-time environmental data monitoring and support the quantitative analysis presented later in the Results section.

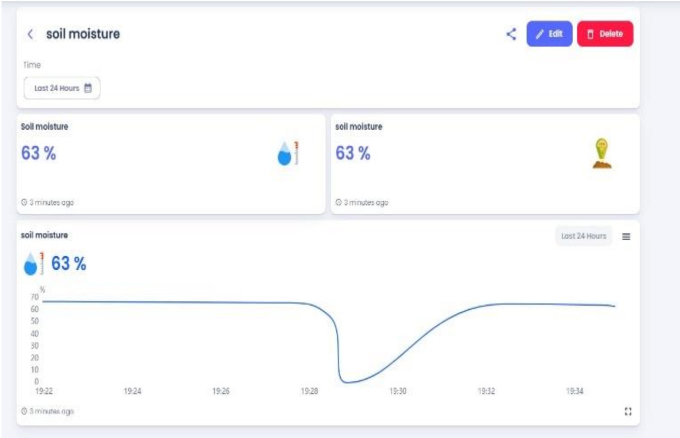

Fig. 8: Moisture Signal Monitoring.

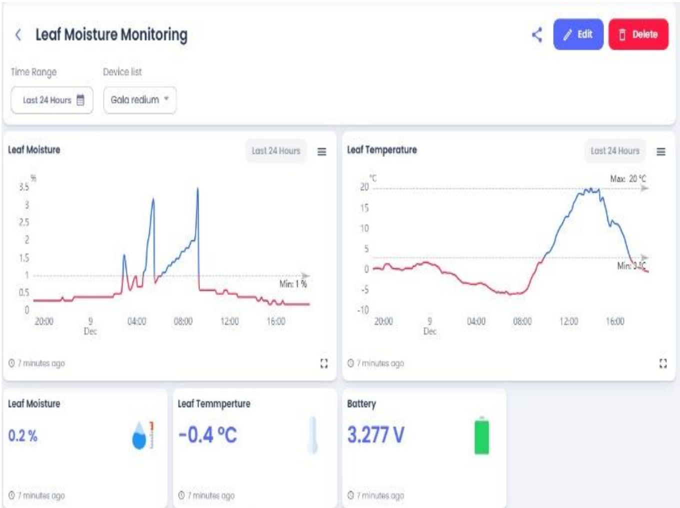

Fig. 9: Leaf Moisture Signal Monitoring.

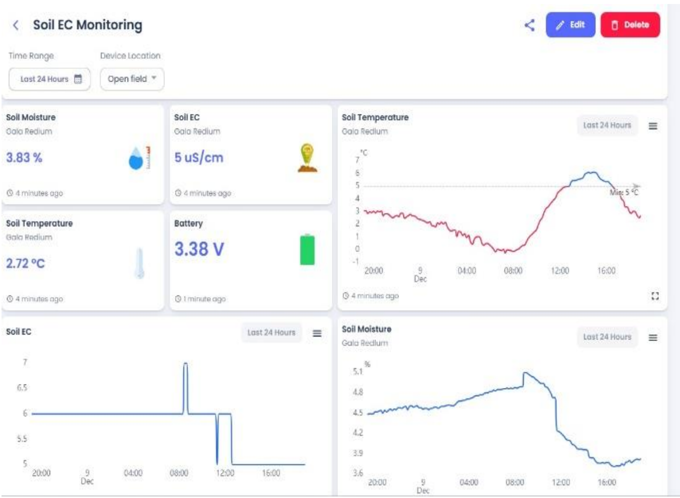

Fig. 10: Temperature and EC Signal Monitoring.

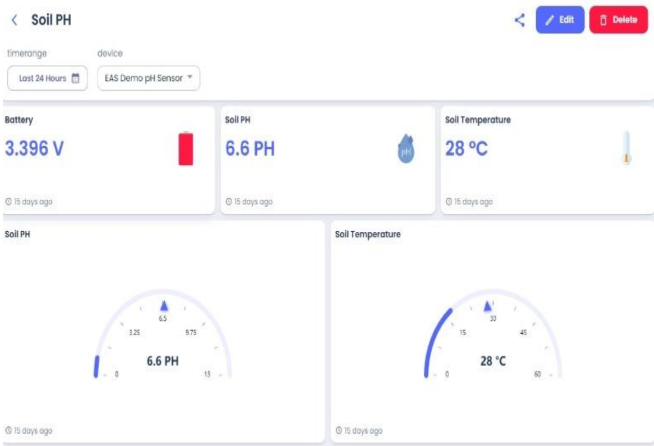

Fig. 11: pH Signal Monitoring.

5. Test and Results

Fig. 12: Implementation site: Rural land, Coimbatore, Tamil Nadu. Figure Exhibits Experimental Set-Up for Selected Crops. The Proposed IoT Platform is Used to Stabilize the Water Utilization.

Several extensive tests were performed to evaluate the developed system's performance and its reliability. The results were also compared with laboratory measurements: the sensor's accuracy was ±3% for pH, ±4% for moisture, ±6% for TDS, and ±5% for temperature. These deviations are Suitable for applications in the field of monitoring and providing a reliable foundation for decisions regarding water utilization.

Table 1: Sensor Calibration

Sensor	Reference	Before Calibration	After Calibration
	4	3.85	3.98
pH	7	6091	7.02
	10	9.83	9.97
	0.5	0.45	0.49
Moisture	1	0.92	0.98
	1.5	1.38	1.47
	300	285	295
TDS	600	570	590
	900	860	885
	5	4.6	4.9
Temperature	10	9.3	9.8
	20	18.7	19.5

LoRaWAN range testing was a critical part of the system's feasibility testing in the rural environment. They gave a data transmission success rate of 98.5% at a distance of up to 3 km in open spaces, which validated the viability of LoRaWAN technology for monitoring systems placed in vast areas where traditional communication technology does not exist. You need a lot more because aspects like communication cannot be influenced by geology, vegetation, and buildings from the surrounding environment.

Table 2: Range Tests

Distance to Gateway (Km)	Signal Strength (RSSI, dBm)	SNR (dB)	Network Status
0.5	-65	9	Correctness
1	-85	6	Correctness
2	-90	4	Correctness
3	-100	1	Moderate Correctness
4	-110	-1	Recurring failure

For verification of the results and to evaluate the error handling under more stringent conditions, supplementary testing is advised to be carried out under various conditions, for example, sites with high-density vegetation, terrain with undulations, and areas with mid-range infrastructure. This would allow for a measure of how the system performs under a wider set of conditions, providing additional insight into how efficient the system performs under poor conditions and accumulating data to back arguments for application elsewhere in rural contexts.

Latency testing was also favorable, with a mean latency of 5 seconds from sensor reading to display on the cloud and a maximum latency of 12 seconds under heavy network load. Such low latency allows near-real-time monitoring so that rapid response to fluctuations in water utilization or distribution is possible.

Table 3: Latency Tests

Distance to Gateway (Km)	Transmission time (ms)	Arrival Time (ms)	Complete response time (ms)
0.5	50	100	150
1	60	150	210
2	80	200	280
3	70	220	290
4	90	300	390

The proposed system was tested over an extended period of 30 days for its reliability. The system achieved 98.5% data transmission success with only 1.5% packet loss during the experiment, as shown in Table IV. The reliability pertains to enabling uninterrupted water resource monitoring, which is paramount to ensure.

Table 4: Reliability Tests

Distance to Gateway (Km)	Total Packets Sent	Packages Received	Lost Packages	Success Rate (%)
0.5	1000	995	5	99.5
1	1000	975	25	97.5
2	1000	990	10	99
3	1000	985	15	98.5
4	1000	945	55	94

The results of these tests confirmed that the system can offer accurate and reliable water utilization and distribution monitoring in crop fields (Table V). The implementation of this system has played a major role, rendering farmers and local authorities more capable of making conservative decisions regarding water management and utilization. As a result, crop water utilization problems have reduced by 20% and water use efficiency has risen by 15%. These results indicate the potential of the developed system to significantly enhance water resource management in agricultural fields by way while also verifying its functionality.

Table 5: System Impact

Metric	Pre-testing	Post-testing	Optimization
Water optimization	70%	85.6%	8%
Crop Water Management Issues	22 Occurrences / Month	16 Occurrences/ Month	-15%
Irrigation Latency Issues	24 Hours	4 Hours	-75%

The discussion on the experimental results evidences the strong impact of the proposed system, in particular, to reduce irrigation latency and improve the efficiency of water resource management. Nevertheless, some open questions, such as sensor placement strategies to ensure uniform data coverage in large agricultural fields, could be optimized, along with the development of energy-efficient modules to support the operation in off-grid rural settings.

Though the integration of machine learning for automated irrigation presents a potentially useful research direction, proper algorithms and data requirements need to be outlined. Algorithms like Random Forest, SVM, or LSTM networks may be used for processing historical soil moisture, temperature, and climatic data for predictive irrigation. Beyond applications at a rural level, the same framework may be used for urban farming and greenhouse management, where precision monitoring and regulated irrigation are equally important. In this way, the proposed IoT-driven system would be more scalable, sustainable, and adaptable to different contexts.

The signal visualizations of Figures 8–11 complement the quantitative findings with the confirmation of the practical stability of sensor readings and the responsiveness of the LoRaWAN communication link. Seamless data flow from the field sensors to the cloud interface underlines the capacity of the system for real-time decision support in irrigation management.

In addition, challenges such as device maintenance under harsh field conditions and cost implications for large-scale deployment in resource-constrained regions should be addressed to strengthen the system's long-term sustainability and adoption potential. While experimental validation was conducted at a single rural site in Coimbatore, Tamil Nadu, the proposed system architecture is adaptable to various agricultural conditions. Through recalibration of sensors and fine-tuning of LoRaWAN parameters such as transmission power and spreading factor, the framework can be extended to diverse climates, soil types, and crop varieties, ensuring scalability and broader applicability.

6. Conclusion

The water utilization and distribution system monitoring system based on LoRaWAN implemented in this study has been a cost-effective and efficient solution for addressing water management problems in the agricultural sector. Employing precise sensors and LoRaWAN technology has offered a well-built real-time monitoring solution by preventing the infrastructure issues prevalent in rural areas. This study addresses a specific gap in the literature, which is the limited availability of cost-effective, long-range IoT-based water management systems for developing regions. The proposed system integrates locally available sensors with low-power LoRaWAN communication and can overcome financial and technical barriers restricting the adoption of precision agriculture technologies in resource-constrained environments. The system maintained reliable operation within a 3 km range under open field conditions, which would cover most of the demand in agriculture. The dependability of the system, as illustrated by a 98.5% data propagation success rate and an average latency of 250 ms at 3 km, highlights the use of the system in water resource management. These findings confirm that the system provides a novel balance between communication range, reliability, and affordability, making it particularly suited for deployment in geographically dispersed rural

farms. This paper has presented a LoRaWAN-based model that practically shows scalability without any expensive network infrastructure, and hence, it contributes to a measurable advancement in IoT-enabled agricultural systems.
Applications of this system have led to an increase in irrigation water management, which has improved the sustainability of agriculture. Particularly, it registered an improvement of 8% in water use as well as a 15% decrease in crop water utilization incidents. Further, the 75% decrease in problem reaction time facilitates more proactive water resource management. Besides, this project also demonstrates not just technical success but also shows how technology can be used to remedy key problems in rural areas and improve the quality of life and farm production. Besides ensuring better technical performance, the system has economic benefits in reduced operational cost and improved yield efficiency, while its modular design will enable adaptation across crops and regions. Integrating the system with a machine learning-based automation irrigation system is to be done in the future, so it can anticipate and prevent water utilization issues, and offer water and crop optimization new possibilities. Finally, this project opens the way to introducing new technology into agriculture, helps to secure local territories, and ensures global food security and environmental sustainability. Further research will explore socio-economic impacts, adoption potential, and scalability to reinforce the role of IoT-driven systems in sustainable and globally relevant agriculture.

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Conflicts of Interest

The authors declare that they have no conflicts of interest in this work.

References

[1] M. Dholu and K. A. Ghodinde, "Internet of Things (IoT) for Precision Agriculture Application," 2018 2nd International Conference on Trends in Electronics and Informatics (ICOEI), Tirunelveli, India, 2018, pp. 339-342, https://doi.org/10.1109/ICOEI.2018.8553720.

[2] T. Wiangtong and P. Sirisuk, "IoT-based Versatile Platform for Precision Farming," 2018 18th International Symposium on Communications and Information Technologies (ISCIT), Bangkok, Thailand, 2018, pp. 438-441, https://doi.org/10.1109/ISCIT.2018.8587989.

[3] Xiao, Lei & Guo, Lejiang. (2010). The realization of a precision agriculture monitoring system based on wireless sensor network. CCTAE 2010 - 2010 International Conference on Computer and Communication Technologies in Agriculture Engineering. 3. 89 - 92. https://doi.org/10.1109/CCTAE.2010.5544354.

[4] Christos Goumopoulos, Brendan O'Flynn, and Aquiles Kameas, “Automated Zone-Specific Irrigation with Wireless Sensor/Actuator Network and Adaptable Decision Support,” Computers and Electronics in Agriculture, vol. 105, pp. 20-33, 2014. https://doi.org/10.1016/j.compag.2014.03.012.

[5] Đoko Banđur et al., “An Analysis of Energy Efficiency in Wireless Sensor Networks (WSN) Applied to Smart Agriculture,” Computers and Electronics in Agriculture, vol. 156, pp. 500-507, 2019. https://doi.org/10.1016/j.compag.2018.12.016.

[6] Iván Froiz-Míguez et al., “Design, Implementation and Empirical Validation of an IoT Smart Irrigation System for Fog Computing Applications Based on LoRa and LoRaWAN Sensor Nodes,” Sensors, vol. 20, no. 23, pp. 1-33, 2020. https://doi.org/10.3390/s20236865.

[7] Thomas Ameloot, Patricio Van Torre, and Hendrik Rogier, “Variable Link Performance Due to Weather Effects in a Long-Range, Low Power LoRa Sensor Network,” Sensors, vol. 21, no. 9, pp. 1-22, 2021. https://doi.org/10.3390/s21093128.

[8] A. Cano-Ortega, and F. Sánchez-Sutil, “Performance Optimization LoRa Network by Artificial Bee Colony Algorithm to Determination of the Load Profiles in Dwellings,” Energies, vol. 13, no. 3, pp. 1-29, 2020. https://doi.org/10.3390/en13030517.

[9] Ritesh Kumar Singh et al., “Leveraging LoRaWAN Technology for Precision Agriculture in Greenhouses,” Sensors, vol. 20, no. 7, pp. 1 17, 2020. https://doi.org/10.3390/s20071827.

[10] Poonam S. Jakhotiya et al., “Application of Lorawan Technology in Farm for Irrigation System” International Journal of Creative Research Thoughts, vol. 9, no. 8, pp. 1-8, 2021.

[11] André Gloria et al., “Water Management for Sustainable Irrigation Systems Using the Internet-of-Things,” Sensors, vol. 20, no. 5, pp. 1 14, 2020. https://doi.org/10.3390/s20051402.

[12] Višnja Križanović et al., “An Advanced Energy-Efficient Environmental Monitoring in Precision Agriculture Using LoRa-Based Wireless Sensor Networks,” Sensors, vol. 23, no. 14, pp. 1-34, 2023. https://doi.org/10.3390/s23146332.

[13] Nestor Michael Tiglao et al., “Agrinex: A Low-Cost Wireless Mesh-Based Smart Irrigation System,” Measurement, vol. 161, 2020. https://doi.org/10.1016/j.measurement.2020.107874.

[14] F. Sanchez Sutil, and Antonio Cano Ortega, “Smart Public Lighting Control and Measurement System Using LoRa Network,” Electronics, vol. 9, no. 1, pp. 1-28, 2020. https://doi.org/10.3390/electronics9010124.

[15] A.R. Al-Ali et al., “IoT Solar Powered Smart Agricultural Irrigation System,” Journal of Electronic Science and Technology, vol. 17, no. 4, pp. 1-14, 2019. https://doi.org/10.1016/j.jnlest.2020.100017.

[16] N. Sudharshan et al., “Renewable Energy Based Smart Irrigation System,” Procedia Computer Science, vol. 165, pp. 615-623, 2019. https://doi.org/10.1016/j.procs.2020.01.055.

[17] Neha K. Nawandar, and Vishal R. Satpute, “IoT based Low Cost and Intelligent Module for Smart Irrigation System,” Computers and Electronics in Agriculture, vol. 162, pp. 979-990, 2019. https://doi.org/10.1016/j.compag.2019.05.027.

[18] Renkuan Liao et al., “Development of Smart Irrigation Systems Based on Real-Time Soil Moisture Data in a Greenhouse: Proof of Concept,” Agricultural, Water Management, vol. 245, 2021. https://doi.org/10.1016/j.agwat.2020.106632.

[19] Waheb A. Jabbar et al., “Development of LoRaWAN-based IoT System for Water Quality Monitoring in Rural Areas,” Expert Systems with Applications, vol. 242, pp. 1-18, 2024. https://doi.org/10.1016/j.eswa.2023.122862.

[20] Tahera Kalsoom et al., “Advances in Sensor Technologies in the Era of Smart Factory and Industry 4.0,” Sensors, vol. 20, no. 23, 2020. https://doi.org/10.3390/s20236783.

[21] Samini Subramaniam et al., “WQMS: A Water Quality Monitoring System Using IoT,” Proceedings of the 2019 2nd International Conference on Computational Intelligence and Intelligent Systems, pp. 177-182, 2019. https://doi.org/10.1145/3372422.3372429.

[22] Juan Pablo Morales-Alvarez et al., “LoRaWAN Water Consumption Monitoring System,” Pädi Scientific Bulletin of Basic Sciences and Engineering of the ICBI, vol. 11, pp. 183-189, 2023. https://doi.org/10.29057/icbi.v11iEspecial2.10686.

[23] J. A. S. K. Jayasinghe, et al, "Enhancing Agricultural Efficiency with IoT-Enabled Precision Irrigation Management Using LoRaWAN Technology," 2024 IEEE 16th International Conference on Computational Intelligence and Communication Networks (CICN), Indore, India, 2024, pp. 69-75, https://doi.org/10.1109/CICN63059.2024.10847478.

[24] S. Gitahi, D. M. Kaburu, I. N. Oteyo and S. Kimani, "A Model Implementation of Internet of Things (IoT)-based Smart Watering System for Crops using LoRaWAN," 2023 IST-Africa Conference (IST-Africa), Tshwane, South Africa, 2023, pp. 1-8, https://doi.org/10.23919/IST-Africa60249.2023.10187864.

[25] Yin, Wentong & Huang, Lihua & Wang, Xiaoliang & Yin, Wenda. (2024). Research on Intelligent Agricultural Environment Monitoring System Based on LoRa and NB-IoT Technology. 1-6. https://doi.org/10.1109/ASIANCON62057.2024.10837778.

[26] Gómez, E.P.S., Yoo, S.G. (2024). LoRaWAN Infrastructure Design and Implementation for Soil Moisture Monitoring: A Real-World Practical Case. In: Franco, L., de Mulatier, C., Paszynski, M., Krzhizhanovskaya, V.V., Dongarra, J.J., Sloot, P.M.A. (eds) Computational Science – ICCS 2024. ICCS 2024. Lecture Notes in Computer Science, vol 14838. Springer, Cham.

[27] Yogesh Kumar Kushwaha, Amrita joshi, et al..,(2024) , Development of a Smart irrigation monitoring system employing the wireless sensor network for Agricultural Water management, Vol 26, issue 12, Journal of Hydro informatics (2024) 26 (12): 3224–3243. https://doi.org/10.2166/hydro.2024.241.