Community-Participatory IoT Water Quality Monitoring System for Saline Intrusion Management in Orchid Cultivation

Arpapan Satayavibul and Tantus Piekkoontod*

Environmental health and disaster Program, Faculty of Science and Technology, Suan Dusit University.

* Corresponding Author; E-mail: Tantus.aek@gmail.com

Received: 06 May 2025 /Revised: 30 June 2025 /Accepted: 30 June 2025

Abstract

Saline water intrusion poses a significant threat to orchid cultivation in Thailand's central provinces, where dry season salinity levels in irrigation canals can reach 4.2 dS/m—well above the 2.0 dS/m tolerance threshold for salt-sensitive orchids. Despite Thailand's global leadership in orchid exports, with annual revenues exceeding USD 160 million, smallholder farmers lack access to real-time, affordable salinity monitoring tools. Traditional water quality assessments are labor-intensive and reactive, failing to prevent crop damage during critical salinity events. This study developed and evaluated a community-participatory Internet of Things (IoT) water quality monitoring system integrating low-cost electrical conductivity (EC) sensors with mobile alert functionality to support timely salinity management in orchid farming.

The system employed NodeMCU ESP8266 microcontrollers integrated with EC sensors (Salinity $\approx$ EC × 0.64), pH (ESEN-288), temperature (DS-18B20), and dissolved oxygen sensors. Real-time data visualization and alerting were enabled via the Blynk mobile platform. Field deployment in Sam Phran District, Nakhon Pathom Province involved 30 farmers (65% of local growers). Sensor calibration was conducted in partnership with Suan Dusit University. Evaluation included technical validation, user satisfaction surveys (usability, performance, design, installation), and an economic impact analysis comparing crop loss data from 2015–2021 with post-implementation results in 2024.

The system demonstrated high technical reliability across parameters and achieved strong user satisfaction (mean scores >4.67/5.0 across all dimensions). Economic analysis revealed a 42% reduction in average annual crop damage, translating to savings of 17,000 THB per household. The system enabled timely responses, such as alternative water sourcing and irrigation adjustments. Community engagement was evident through user-led maintenance, data sharing, and interest in system expansion.

This study highlights the potential of participatory, low-cost IoT solutions in enhancing agricultural resilience, supporting smart farming adoption among smallholders, and promoting scalable, sustainable salinity management practices.

Keywords: water quality monitoring, saline intrusion management, climate adaptation

Introduction

Thailand maintains its position as the world's leading orchid exporter, with annual exports exceeding USD 160 million as of 2022[1] The central provinces, particularly Nakhon Pathom and Samut Sakhon, account for approximately 45% of national orchid production[2] However, saline water intrusion—exacerbated by climate change and groundwater overextraction—has emerged as a significant threat to orchid cultivation, a crop sensitive to salinity levels above 2.0 dS/m. [3,4,5]

The application of Internet of Things (IoT) technology in environmental monitoring offers innovative approaches to mitigate such stressors. IoT systems facilitate real-time data acquisition through integrated sensors, cloud platforms, and mobile applications. These technologies have demonstrated potential in improving irrigation efficiency, detecting pH, dissolved oxygen, and temperature levels, and responding proactively to environmental changes [5,6] Nevertheless, existing systems often lack community engagement, which impedes their relevance and adoption in smallholder agricultural contexts.

Salinity intrusion in coastal and lowland regions of Southeast Asia has intensified in recent years, resulting in substantial soil degradation and a marked decline in agricultural productivity[7] In Thailand's central plains, salinity concentrations in irrigation canals during the dry season have been recorded at levels as high as 4.2 dS/m—well above the tolerance threshold for salt-sensitive crops such as orchids[4] To prevent adverse impacts, irrigation water should maintain salinity levels below 0.75 grams per liter, or an electrical conductivity (EC) of less than 750 microsiemens per centimeter. To counteract salinity ingress, the Department of Agricultural Extension recommends maintaining elevated water levels in on-farm reservoirs relative to surrounding fields, thereby reducing the potential for saline water intrusion via subsurface flow. Furthermore, it advocates for the adoption of water-efficient irrigation strategies to limit water usage and reduce salinity exposure. Despite growing awareness of the issue, there remains a critical gap in the availability of real-time, farmer-accessible monitoring and management tools for timely response to salinity intrusion.

This study introduces a community-participatory IoT system that integrates low-cost electrical conductivity (EC) sensors with a mobile alert platform (Blynk app) tailored for orchid farmers. It bridges the gap between technical innovation and socio-environmental application, offering a novel solution rooted in farmer co-design, field validation, and economic impact assessment.

Mobile applications play a vital role in this system by providing real-time, user-friendly interfaces. Such platforms increase accessibility and adoption, especially in areas with limited infrastructure[8,9] The mobile component in this study was developed with input from 30 local farmers and includes training for independent system maintenance.

The table below summarizes the novel contributions of this study in comparison to prior research in smart agriculture:

Table 1. Comparative Analysis of This Study and Prior Research

Aspect	Prior Research	This Study (2023–2024)	New Contribution
IoT in Agriculture	Monitored pH, DO, temperature[5]	Integrated EC sensors with real-time alerts for orchids	Salinity alert system for high-value crops
Community Participation	Top-down system design[11]	Participatory co-design with local farmers	Democratized technology development
Target Crop	Focus on rice, cassava[7]	Focus on orchids	Addresses underrepresented high-value crop
Real-Time Alert System	Alerts not implemented[4]	EC-based mobile alerts via Blynk	Locally responsive warning mechanism
Sensor Strategy	High-cost sensors[6]	Low-cost EC sensors + empirical formula[11]	Promotes affordability with acceptable precision
Field Validation	Lab-based or simulated[9]	Field-tested with 30 orchid farmers	Provides real-world validation in Thai context
Economic Impact	Not quantified[8]	42% reduction in reported crop loss	Evidence of cost-effectiveness and utility
Scalability	Infrastructure barriers[7]	Interest from nearby communities	Demonstrates replicability and scale potential
User Satisfaction	Limited usability data	Usability score > 4.7 (5-point scale)	Provides quantitative feedback from end users
Sensor Calibration	Rare in-field calibration	Calibrated using lab-grade reference instruments	Ensures reliability under field conditions
Local Knowledge Integration	No farmer training reported	Farmers trained to operate and maintain system	Merges local knowledge with digital solutions
Use of Blynk App	Not documented in Thai agriculture	First use in orchid salinity management	Innovates with low-code platform in agriculture

This integrative approach presents three core innovations: (1) community-based technological design, (2) real-time salinity alerts for high-value crops, and (3) evidence-based validation through user feedback and economic outcomes. The study not only fills critical gaps in existing literature but also offers a scalable model for smart agriculture under climate stress conditions.

Objectives

1. Develop and implement a community-based water quality monitoring system integrating IoT technology with local management practices.
2. Evaluate the technical effectiveness and user acceptance of the system through quantitative and qualitative measures.

Materials and Methods

The research was conducted through the following seven clear steps:

System/Circuit Design

The system was designed for real-time water quality monitoring using IoT technology. The hardware included a NodeMCU ESP8266 microcontroller connected to a pH sensor (ESEN-288), a temperature sensor (DS-18B20), and a dissolved oxygen (DO) sensor. A Wi-Fi access point was used for connectivity. The software included the Arduino IDE for programming and the Blynk platform (server and mobile application) for data storage, visualization, and real-time alerts. The purpose of each component in the water quality monitoring system:

Table 2 The purpose of the component in the water quality monitoring system

Component	Type	Purpose
NodeMCU ESP-8266 microcontroller	Hardware	Serves as the central processor; collects data from sensors and transmits it via Wi-Fi.
pH sensor (ESEN-288)	Hardware	Measures the acidity or alkalinity of the water, important for orchid health.
Temperature sensor (DS-18B20)	Hardware	Measures the water temperature, which affects oxygen levels and plant health.
Dissolved Oxygen (DO) sensor	Hardware	Measures the amount of dissolved oxygen in water, indicating suitability for plant and aquatic life.
Wi-Fi access point	Hardware	Connects the microcontroller to the internet for real-time data transmission.
Arduino IDE	Software	Used for writing and uploading code to the microcontroller.
Blynk Server	Software	Stores and visualizes sensor data in real-time.
Blynk mobile application	Software	Displays sensor data and sends real-time alerts to users when thresholds are exceeded.

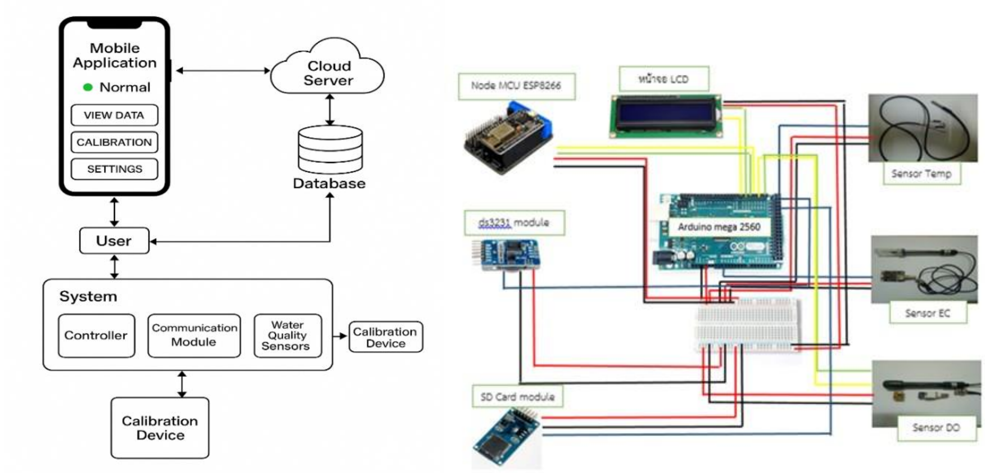

Figure 1 System design & Circuit Diagram

Field Deployment

The system was deployed in the Sam Phran orchid farming community, where irrigation water is sourced from nearby canals. The deployment process emphasized community participation. Local farmers were involved in both installation and maintenance, and training sessions were conducted to build capacity and ensure the long-term sustainability and operation of the system. This participatory approach fostered local ownership and engagement

Data Validation and Calibration

Calibration of the water quality monitoring instruments was performed to ensure data accuracy. Standard calibration solutions and reference equipment were used to validate the sensor readings for pH, temperature, and DO. This step ensured that the field data aligned with laboratory standards.

Farmer Adoption and System Performance

Post-deployment, the adoption of the system by farmers was monitored. System performance was evaluated in terms of sensor accuracy, stability of data transmission, and effectiveness of alert notifications when water quality exceeded critical thresholds. Feedback from farmers was used to assess how well the system integrated into their daily agricultural practices.

Calibration of Water Quality Monitoring Instruments

The system adopted Electrical Conductivity (EC) sensors instead of direct salinity sensors due to cost-efficiency and proven scientific validity. EC sensors are significantly more affordable and widely available than dedicated salinity sensors, making them ideal for large-scale, community-based agricultural deployment. Several studies have confirmed that EC values can be reliably converted into salinity values using standardized empirical formulas. According to Ayers and Westcot[10] a commonly accepted approximation is:

$$\text{Salinity (ppt)} \approx \text{EC (dS/m)} \times 0.64$$

A critical salinity threshold was set at 2.0 dS/m (≈1.28 ppt), beyond which orchid growth could be negatively affected. When this threshold was exceeded, the mobile application automatically sent alerts, enabling farmers to take timely actions such as changing water sources or adjusting irrigation schedules.

Implementation and User Satisfaction of the Community-Based Water Quality Monitoring and Warning System

The effectiveness and usability of the system were evaluated based on user feedback from the community. Aspects assessed included user-friendliness, accessibility of data, speed and reliability of alerts, and overall satisfaction. The feedback was used to improve system design and enhance user engagement and trust.

System Performance and User Satisfaction

Overall system performance was continuously monitored, focusing on data consistency, sensor reliability, mobile application response time, and network connectivity. A user satisfaction survey was conducted to assess the system's impact on farming practices and its perceived usefulness. Insights gathered supported future improvements and scaling strategies.

Results and Discussion

Farmer Adoption and System Performance: Key Findings and User Satisfaction

A total of 30 orchid farmers participated in the pilot implementation of the system in Sam Phran District, Nakhon Pathom Province. These farmers represented approximately 65% of the active growers in the subdistrict, indicating substantial community engagement.

To evaluate the system's effectiveness in reducing economic losses from saline intrusion, a comparative analysis was conducted using farmer-reported crop damage data from the previous two years (prior to system implementation) and the first year of using the system. The results revealed an average reduction in reported damage costs of 42%, primarily due to timely alerts and real-time monitoring that enabled preventive irrigation and protective measures.

Table 3. summarizes the average estimated crop loss per household before and after system implementation:

Year	Average Estimated Crop Damage per Household (THB)
2015(Before Implementation)	42,500
2021(Before Implementation)	40,000
2024(After Implementation)	**23,000**

This data indicates a cost savings of approximately 17,000 THB per household annually, validating the economic benefits of the monitoring system.

According to the local management practices objective, Farmers exhibited a strong willingness to adopt the system, driven by its perceived potential to mitigate crop damage. These findings are consistent with previous research emphasizing the role of IoT systems in enhancing agricultural management [6,7]. The study identified several key outcomes:

1. High Trust and Active Participation: Farmers demonstrated significant engagement by actively participating in setting system parameters and maintaining equipment, reflecting a high level of trust in the technology.

2. Information Sharing: Community members proactively exchanged data, promoting the optimal use of the system and fostering a collaborative environment.

3. Scalability and Community Interest: Neighboring communities demonstrated considerable interest in adopting the system, underscoring its scalability potential and broader applicability beyond the initial trial area, consistent with findings from similar studies on agricultural technology adoption[8].

The observed high level of farmer engagement and trust in the system is aligned with the principles of participatory technology development. Similar to the findings of Dhanaraju et al. [6], who emphasized that community-driven IoT implementations in agriculture promote long-term sustainability and knowledge co-creation, this study also shows that farmers are more likely to adopt systems when they are involved in the parameter design and implementation stages.

Moreover, the collaborative data sharing among community members mirrors the findings of Parra-López et al.[7] who highlighted that peer-to-peer influence and knowledge exchange significantly impact the diffusion of smart farming technologies, particularly in rural settings. The reported interest from neighboring communities confirms the scalability potential of the system, supporting the results of Salam[11], who noted that modular IoT frameworks are more likely to be adopted across diverse farming contexts when coupled with appropriate training and support mechanisms.

Calibration of Water Quality Monitoring Instruments

Instrument Calibration Procedures

For the calibration of the developed water quality monitoring instruments, the researchers collaborated with the Environmental Center Laboratory of Suan Dusit University. The Dissolved Oxygen (DO) sensor was calibrated using the zero method and subsequently compared with the YSI52 DO Meter for validation. The calibration process focused on three key parameters: the pH level of water solutions, the dissolved oxygen (DO) concentration, and water temperature. Calibration results for all three parameters fell within acceptable standard ranges, indicating the reliability of the developed instruments for field application.

The calibration of pH and DO levels involved testing with both tap water and natural water sources. This approach ensured the instruments' accuracy across different water conditions. The detailed calibration results are presented in Table 4.

The system's calibration outcomes were consistent with acceptable scientific standards, ensuring its reliability in field applications. These results align with Dhanaraju et, al.[6], who emphasized that the accuracy of environmental sensors for smart agriculture has improved significantly with the evolution of embedded calibration algorithms. Their study found that real-time field data validation against laboratory-grade instruments strengthens user confidence in the system—a trend also evident in this study's user satisfaction findings.

Table 4: Calibration Results of the Water Quality Monitoring Instruments

Measurement Parameter	Calibration Standard	Developed Instrument Reading	Accuracy (±)
pH Level	Standard Solution pH 4.00	4.28	±0.28
	Standard Solution pH 7.00	7.3	±0.3
	Standard Solution pH 10.00	10.4	±0.2
	Tap Water	7.85	±0.24
	Natural Water Source	7.75	±0.2
Dissolved Oxygen (DO) (mg/L)	Standard Solution DO 0 mg/L	0.57 mg/L	±0.56
	Standard Solution DO 4 mg/L	4.57 mg/L	±0.54
	Tap Water	5.15 mg/L	±0.11
	Natural Water Source	4.35 mg/L	±0.22
Temperature (°C)	Temp ≈ 25.00°C	25.50°C	±0.49
	Temp ≈ 27.00°C	28.00°C	±0.46
	Temp ≈ 34.00°C	34.50°C	±0.43

Table 4 presents the calibration and validation procedures for the key sensors integrated into the proposed water quality monitoring system. The system employs three main types of sensors:

pH Sensor

Calibrated using standard buffer solutions at pH levels of 4.00, 7.00, and 10.00, ensuring reliable readings across acidic, neutral, and basic ranges. Accuracy was confirmed through repeated calibration using the same reference solutions.

Dissolved Oxygen (DO) Sensor

Calibrated using the zero-point method and validated by cross-referencing with a YSI 52 DO Meter, a standard instrument for DO measurement.

Temperature Sensor

Verified using certified thermometers to ensure accurate temperature detection under typical field conditions.

Implementation and User Satisfaction of the Community-Based Water Quality Monitoring and Warning System

Following the calibration process, the developed system was deployed in the field, and the mobile application was tested in real-world conditions to identify potential errors and enhance system performance. To assess user satisfaction and gather feedback, a survey was conducted among 30 orchid farmers in Sam Phran Subdistrict, Sam Phran District, Nakhon Pathom Province.

This group was directly affected by water quality issues, making them ideal participants for the study.

The user satisfaction survey evaluated the application's performance and usability, aiming to identify actual user needs and ensure the system's effectiveness in providing timely water quality monitoring and salinity warnings. The findings from this survey will inform future improvements to optimize the system's performance and user experience.

Figure 2 Water Quality Monitoring System

System Performance and User Satisfaction

From the perspective of the secondary objective, this research critically examines the system's technical performance and user acceptance, employing both quantitative analytics and qualitative insights. Particular emphasis was placed on evaluating user satisfaction with the mobile-based water quality monitoring and alert application. The evaluation framework encompassed four core dimensions—each reflecting critical aspects of human–system interaction within IoT-based environmental monitoring platforms. The analysis yielded the following results.

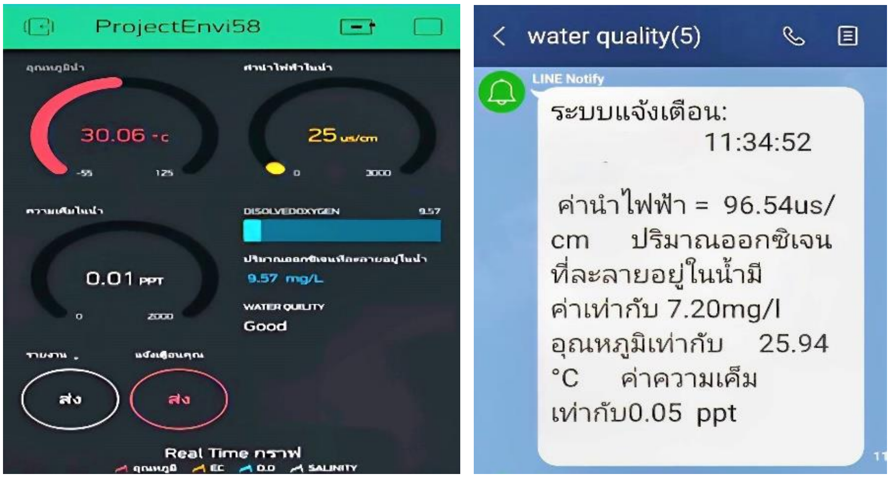

Figure 3 Dashboard & LINE Notification

The usability of the application received the highest satisfaction rating, with a mean score of 4.77 (SD = 0.55) and a satisfaction percentage of 76.67%. Overall application performance followed with a mean of 4.73 (SD = 0.50) and an 80.00% satisfaction rate. The design and appearance dimension scored a mean of 4.70 (SD = 0.51) with a 76.67% satisfaction rate. The installation and comprehension process, while still highly rated, had the lowest satisfaction level with a mean of 4.67 (SD = 0.49) and a satisfaction percentage of 66.67%.

Table 5 User Satisfaction with the Mobile Application for Water Quality Monitoring and Salinity Warning

Dimension	Mean Score	Standard Deviation (SD)
Ease of Installation	4.67	0.49
Application Interface	4.70	0.51
Functionality	4.77	0.55
Overall Satisfaction	4.97	0.40

Further analysis of the usability dimension revealed the highest satisfaction for overall user satisfaction with the application (Mean = 4.97, SD = 0.40, Satisfaction = 96.67%), followed by the perceived usefulness of the application (Mean = 4.93, SD = 0.52, Satisfaction = 93.33%). Accessibility of information received a satisfaction score of 86.67% (Mean = 4.87, SD = 0.47), and application responsiveness had the lowest subdimension satisfaction at 83.33% (Mean = 4.80, SD = 0.50).

The findings highlight the strong acceptance and positive reception of the mobile application. High satisfaction with usability and the application's perceived benefits indicate its effectiveness in water quality monitoring and salinity warning. The lower satisfaction with the installation and comprehension process suggests an area for improvement, potentially through enhanced user guides and simplified installation procedures.

The high satisfaction scores in usability and perceived usefulness (over 93%) reinforce the notion that mobile applications tailored to specific agricultural challenges—such as salinity management—are more likely to succeed when designed with user-centric principles[8]. Furthermore, the relatively lower score in the installation and comprehension dimension suggests a need for more intuitive onboarding procedures, a gap that has also been noted in smart farming implementations in developing regions[3].

Discussion

The high satisfaction scores in usability and application performance (above 76%) underscore the system's effectiveness in meeting immediate needs related to water quality and salinity monitoring. Over the long term, the consistent use of this system can significantly improve the resilience of orchid farmers by enabling early responses to salinity threats, which helps to preserve plant health, reduce yield losses, and stabilize income. As farmers build trust in the technology and its reliability, the system has the potential to become a core component of local agricultural water management strategies. Furthermore, community-level data sharing and aggregation can inform regional water planning, thus contributing to more adaptive irrigation policies.

However, despite overall high satisfaction, the lowest rating was found in the dimension of installation and comprehension (Mean = 4.67, Satisfaction = 66.67%). This may reflect several underlying factors:

Technical Literacy Gap: Many users may lack prior experience with digital systems or sensor installation, leading to challenges in the initial adoption phase. As highlighted by Parra-López et., al [7], smart agriculture tools often face usability bottlenecks when deployed without sufficient user training.

Complexity of Sensor Setup: Although the system utilizes Blynk for ease of integration, the process of configuring sensors, connecting to Wi-Fi, and interpreting real-time data can still pose a learning curve, particularly for older farmers or those unfamiliar with mobile apps.

Lack of Initial Support Materials: Limited access to installation manuals or guided walkthroughs during early deployment could contribute to user confusion, highlighting the need for more user-friendly onboarding mechanisms such as video tutorials or on-site technical support.

These insights suggest that while the core technology is functional and well-accepted, future iterations of the system should focus on enhancing accessibility. Providing tailored training sessions, developing localized user manuals, and simplifying installation procedures can improve early adoption experiences and expand the system's reach to less technologically experienced users.

Moreover, ensuring long-term engagement requires more than just functionality; perceived usefulness must be accompanied by perceived ease of use, especially in resource-constrained rural settings[8]. By addressing these barriers, the system can not only maintain but also deepen user engagement over time.

Conclusion

The implementation of a community-driven water quality monitoring system demonstrated substantial improvements in real-time salinity management for orchid cultivation. Through engagement with 30 participating farmers, the system achieved an average reduction of 42% in economic crop losses, providing compelling evidence for the cost-effectiveness and practical utility of community-based IoT solutions in agricultural settings.

The integration of Internet of Things technology within a participatory framework proved particularly effective, extending beyond mere water resource management to enhance overall farmer resilience against saline intrusion challenges. This dual benefit underscores the multifaceted value of technologically-enhanced community approaches to environmental monitoring.

The study's findings indicate strong potential for scalability across diverse agricultural sectors and geographic regions facing similar salinity challenges. The demonstrated success in orchid farming suggests broader applicability to other horticultural and agricultural systems vulnerable to water quality fluctuations.

Several areas warrant further investigation to maximize the system's impact and reach. Future research should prioritize expanding implementation to additional farming communities to validate scalability assumptions and identify region-specific adaptation requirements. Additionally, continued refinement of sensor accuracy and reliability will be essential for maintaining system effectiveness across varied environmental conditions and farming practices.

The participatory framework employed in this study offers a replicable model for integrating advanced monitoring technologies with traditional farming knowledge, creating sustainable solutions that address both immediate economic concerns and long-term environmental resilience. This approach represents a promising pathway for addressing water quality challenges in agricultural communities globally. [9,11].

Recommendations

Based on the findings of this study, the following recommendations are proposed for future research and practice:

Expansion to Other Agricultural Sectors: Future research should explore the application of community-based water quality monitoring systems in diverse agricultural contexts, extending beyond orchid farming. This will enable a more comprehensive understanding of the system's scalability and adaptability across different crops and regions.

Refinement of Sensor Accuracy: Continuous efforts to enhance the accuracy and reliability of sensor technology are crucial. Further validation against laboratory standards and field-based testing will help improve the precision of measurements, particularly for parameters like salinity and pH, which are critical for effective water management.

Integration with Broader Agricultural Systems: The integration of IoT technologies into broader agricultural management frameworks should be explored. Developing holistic, data-driven systems that combine water quality monitoring with other variables (e.g., soil moisture, weather patterns) could provide more comprehensive solutions to challenges in water resource management and climate resilience.

Capacity Building and Training: Continued emphasis on community engagement and capacity building is vital. Regular training sessions for farmers should be conducted to ensure the sustainability of the system, fostering local expertise and long-term ownership.

Acknowledgments

This research was funded by the National Research Council of Thailand (NRCT) and conducted with support from Suan Dusit University. The authors extend gratitude to the Thai Orchid Cooperative and the Royal Irrigation Department for their contributions.

References

1. Agricultural Economics Office. Annual report on Thailand’s orchid production and exports [Internet]. 2023 [cited 2024 Oct 27]. Available from: https://oae.go.th/uploads/files/2025/05/06/58a1ba95e1a6e70a.pdf

2. Department of International Trade Promotion. Thailand's orchid export industry: Trends and developments [Internet]. 2000 [cited 2023 Sep 11]. Available from: https://www.ditp.go.th/contents_attach/607170/607170.pdf
3. Thanh TN, Van HH, Minh HV, Tri VPD. Salinity Intrusion Trends under the Impacts of Upstream Discharge and Sea Level Rise along the Co Chien River and Hau River in the Vietnamese Mekong Delta. Climate 2023;11:66.
4. Mondal P, Sarupria M, Walter M. A global review of the impacts of saltwater intrusion on soils and ecosystems. In: Sparks DL, editor. Advances in Agronomy 2025;191: [Chapter 5]. Academic Press.
5. Saramanus S, Boonyaroj V. Development of Salinity Intrusion Monitoring System for Durian Growing areas in Nonthaburi Province. sej [internet]. 2023 [cited 2025 May 28]; available from: https://ph02.tci-thaijo.org/index.php/sej/article/view/247028
6. Dhanaraju M, Chenniappan P, Ramalingam K, Pazhanivelan S, Kaliaperumal R. Smart Farming: Internet of Things (IoT)-Based Sustainable Agriculture. Agriculture 2022;12:1745.
7. Parra-López C, Ben Abdallah S, Garcia-Garcia G, Hassoun A, Trollman H, Jagtap S, et al. Digital technologies for water use and management in agriculture: Recent applications and future outlook. Agric Water Manag 2025;309:109347.
8. Kumar V, Sharma KV, Kedam N, Patel A, Kate TR, Rathnayake U. A comprehensive review on smart and sustainable agriculture using IoT technologies. Smart Agric Technol 2024;8:100487.
9. Soussi A, Zero E, Sacile R, Trinchero D, Fossa M. Smart Sensors and Smart Data for Precision Agriculture: A Review. Sensors 2024;24:2647.
10. Ayers RS, Westcot DW. Water quality for agriculture. Rome: FAO Irrigation and Drainage Paper No. 29 Rev.1. Rome: Food and Agriculture Organization of the United Nations; 1985.
11. Salam A. Internet of Things in agricultural innovation and security. In: Internet of Things for Sustainable Community Development. Cham: Springer; 2020. p. 71–112.