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IoT-Based Water Quality Monitoring System to Support Smart Farming and Productivity of Farmer Groups in Gelebak Dalam Village

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ABSTRACT

Gelebak Dalam Village relies on the Komering River for daily needs, but faces challenges of declining water quality due to urbanization and anthropogenic activities. This community service activity aims to educate and train local farmer groups in monitoring water quality using Internet of Things (IoT) technology. The method used is offline training consisting of lectures, discussions, and hands-on practice with components such as ESP32 microcontroller, pH and TDS sensors, Arduino IDE programming, and Web Service for data visualization. Results show that the IoT-based water quality monitoring system was successfully implemented and functioned well. Evaluation through pre-test and post-test proved a 37% increase in participants' understanding, from 26% to 63% in answering questions correctly. Participant enthusiasm during discussions and practice was high. Concluded that this activity successfully improved farmers' knowledge and skills regarding IoT and served as a trigger for innovation, especially in agriculture. For sustainability, follow-up activities are recommended.

***Keywords**: IoT, water quality, pH sensor, TDS sensor, ESP32, community education*

1. INTRODUCTION

Gelebak Dalam Village, located in Rambutan Subdistrict, Banyuasin Regency, South Sumatra, is heavily reliant on the Komering River for daily water consumption, agriculture, and transportation. However, the water quality of the river has deteriorated due to rapid urbanization and surrounding industrial and agricultural activities, posing significant environmental and health risks. Recent studies indicate that fluctuations in the river's pH levels and rising Total Dissolved Solids (TDS) are signs of contamination caused by domestic and industrial waste **(Karolina et al., 2022)**. This contamination increases the prevalence of waterborne diseases, including skin diseases and digestive issues, particularly among children who frequently come into contact with untreated water **(Hutton & Chase, 2016).**

The core issue facing the community is the lack of reliable water quality monitoring systems. Most residents rely on visual observations, such as noticing changes in water color or odor, to judge the water's safety, which are not reliable indicators of contamination. Furthermore, the community lacks the knowledge and tools necessary to measure important water quality parameters such as pH and TDS **(Salemink et al., 2017).** Rural communities, in particular, face challenges in accessing modern technologies for environmental monitoring, exacerbating the difficulties they encounter in managing their water resources resources **(Pant & Odame, 2016).** This gap in knowledge and tools prevents the community from making informed decisions about water use, contributing to inefficient resource management and health risks.

To address these challenges, this community service project aims to introduce Internet of Things (IoT) technology for water quality monitoring in Gelebak Dalam Village. By equipping the community with pH and TDS sensors, integrated with an ESP32 microcontroller and a user-friendly dashboard, the project empowers residents to track water quality in real-time. This technology is cost-effective and easy to use, making it accessible to the local population, even those with limited technical knowledge. Similar applications of IoT technologies have successfully enabled rural communities to monitor environmental conditions, improve public health, and better manage natural resources **(Pasika & Gandla, 2020; Vijayakumar & Ramya, 2015).**

This initiative aligns with several Sustainable Development Goals (SDGs), particularly SDG 6 (Clean Water and Sanitation) and SDG 11 (Sustainable Cities and Communities). By providing the community with the tools to monitor water quality, the project not only helps address immediate water quality concerns but also promotes long-term environmental sustainability. The integration of IoT technologies into rural development strategies has the potential to empower local communities to take control of their water resources and enhance their resilience to environmental challenges **(Elijah et al., 2018).** Such community-driven technological solutions not only address local needs but also serve as a model for similar initiatives in other rural areas **(Tzounis et al., 2017).**

2. METHOD

This community service program was conducted from July to December 2025 in Gelebak Dalam Village, Banyuasin Regency, South Sumatra, involving 40 farmers from local agricultural groups. The implementation employed the Community-Based Participatory Research (CBPR) framework. This approach was chosen to ensure active collaboration between the technical team and local farmers throughout the technology development process. By involving the community as active partners, the program aims to align the IoT system with specific agricultural needs, which is essential for increasing technology adoption and ensuring sustainable water resource management in rural areas. The methodological framework is visualized in Figure 1, illustrating the sequential progression and key activities within each phase.

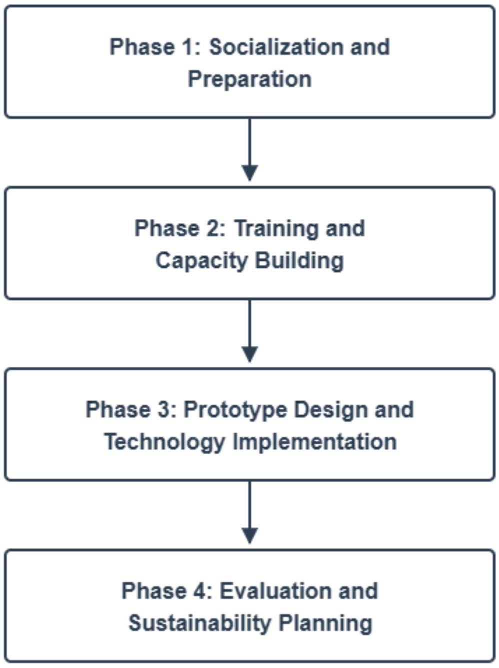

Figure 1. Four-Phase Implementation Methodology

2.1. Socialization and Preparation

This foundational phase focused on establishing community engagement and institutional support. Initial coordination was conducted with the Village Head and key community leaders to introduce program objectives and secure formal approval **(Wallerstein & Duran, 2010).** Subsequently, socialization sessions were held at the village hall and through community gatherings to disseminate information and gather preliminary input regarding water quality concerns. A participatory site survey involving community representatives was conducted to identify optimal locations for sensor deployment along the Komering River. Concurrently, a volunteer team comprising interested residents was formed to facilitate program activities.

2.2 Training and Capacity Building (Months 2-3)

This phase aimed to equip participants with essential knowledge and practical skills through structured offline training. The curriculum was delivered using a blended methodology of lectures, interactive discussions, and hands-on practice (learning by doing). Theoretical modules covered fundamental concepts of water quality parameters (pH and TDS), environmental health impacts, and IoT system architecture **(Cargo & Mercer, 2008).** Practical sessions involved direct interaction with hardware components including the NodeMCU ESP32 microcontroller, pH sensor (SEN0161), and TDS sensor (SEN0244) and software training on Arduino IDE programming and web service application. A core group of 10 participants was designated as "Water Cadres," receiving intensive training to serve as local technical anchors for system maintenance and knowledge dissemination **(Buytaert et al., 2014).**

2.3 Prototype Design and Technology Implementation (Months 3-4)

Prior to field deployment, a functional prototype of the IoT system was designed and tested. The hardware architecture utilized a NodeMCU ESP32 microcontroller as the central processing unit, integrated with a SEN0161 pH sensor and a SEN0244 TDS sensor for data acquisition. A power supply module with a voltage regulator was incorporated to ensure stable electrical current. For the software architecture, the ESP32 was programmed using the Arduino IDE to transmit sensor data via Wi-Fi to a cloud server. A custom web service dashboard was developed using PHP and MySQL to manage and visualize the real-time data for end-users.

The system architecture and data flow of the developed prototype are illustrated in Figure 2. This block diagram details the integration of the input sensors and power supply with the central processing unit, as well as the data transmission process to the cloud server and end-user interface.

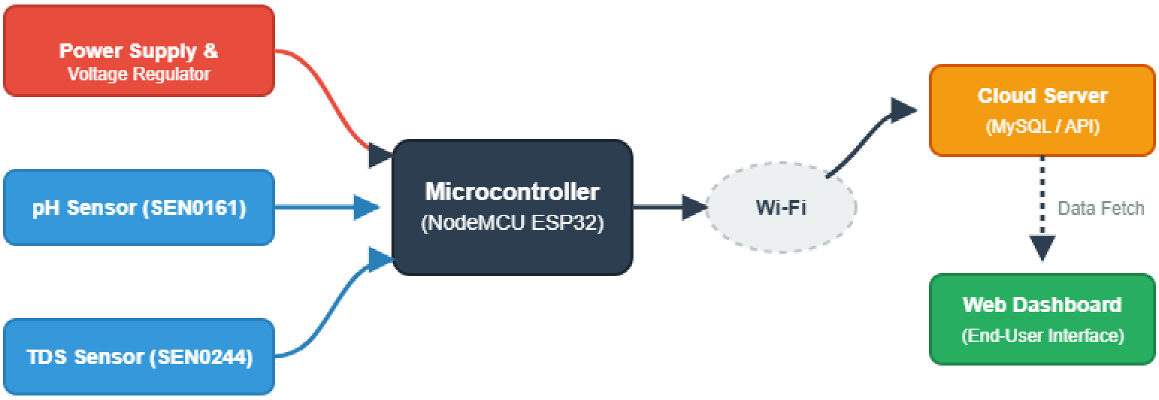

Figure 2. Block Diagram of The IoT-Based Water Quality Monitoring Prototype

The physical design prototype was assembled and housed in a robust, weather-resistant enclosure (Figure 3). The ESP32 microcontroller, voltage regulator, and battery pack were mounted inside, with the pH and TDS sensor probes passed through cable glands for watertight sealing. A 16x2 LCD was mounted on the front panel for local display. The complete assembly underwent calibration using standard buffer solutions (pH 4.0 and 7.0) and a 1413 µS/cm TDS standard solution before field deployment.

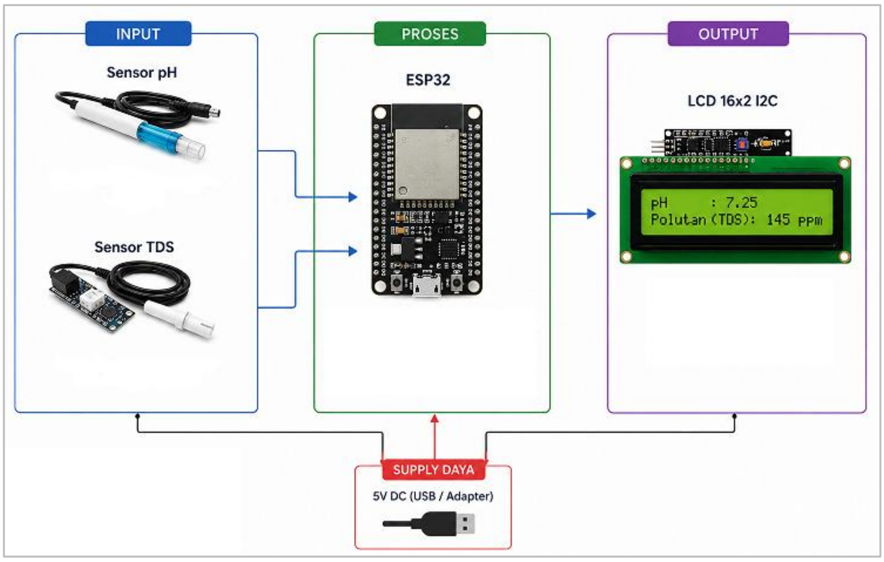

Figure 3. Physical Design Prototype of The IoT Monitoring System

The technological component was deployed in this phase through direct community involvement. The IoT monitoring system consisting of sensors, ESP32 microcontroller, power supply module with voltage regulator, and waterproof housing was installed at a predetermined strategic point on the riverbank. Installation was conducted collaboratively between the technical team and community volunteers **(Encinas et al., 2017).** System calibration was performed using standard buffer solutions to ensure measurement accuracy, followed by comprehensive end-to-end testing to validate data transmission stability and dashboard functionality. A custom web service application was developed using PHP and MySQL to display real-time pH and TDS values, historical trends, and visual alerts, with accessibility optimized for both desktop and mobile devices to enhance user engagement **(Al-Fuqaha et al., 2015).**

2.4. Evaluation and Sustainability Planning (Months 4-6)

The final phase emphasized outcome assessment and long-term institutionalization. A mixed-methods evaluation was conducted, comprising pre-test and post-test assessments to quantify knowledge improvement, focus group discussions (FGDs) to capture qualitative feedback, and technical monitoring to evaluate system performance metrics (uptime, data accuracy). Intensive mentoring was provided to the Water Cadre group to build troubleshooting and basic maintenance competencies **(Gubbi et al., 2013).** To ensure program continuity, a sustainability protocol was co-developed with community stakeholders, outlining standard operating procedures (SOPs) for system maintenance, data management routines, and potential collaboration frameworks with local government agencies **(Prasad et al., 2015).** This phase aimed to transition program ownership fully to the community, fostering resilient, technology-enabled water resource management.

3. RESULTS AND DISCUSSION

3.1 Implementation and Training Outcomes

The community service program was successfully implemented in Gelebak Dalam Village on October 15, 2025, involving 40 local farmers as primary participants. The training consisted of both theoretical and practical sessions. The theoretical component introduced the concepts of IoT, water quality parameters (pH and TDS), and the architecture of the monitoring system. The practical session engaged participants in assembling the sensor node, programming the ESP32 microcontroller using the Arduino IDE, and interacting with the Blynk application dashboard to visualize real-time data (Figure 4).

Participants demonstrated high enthusiasm and active participation throughout the session. The hands-on approach, where each participant could directly handle the components and observe data transmission, proved effective in overcoming initial technological apprehension. This aligns with findings by **(Salemink et al., 2017),** who emphasize that participatory, tactile learning significantly enhances technology adoption in rural communities with low digital literacy.

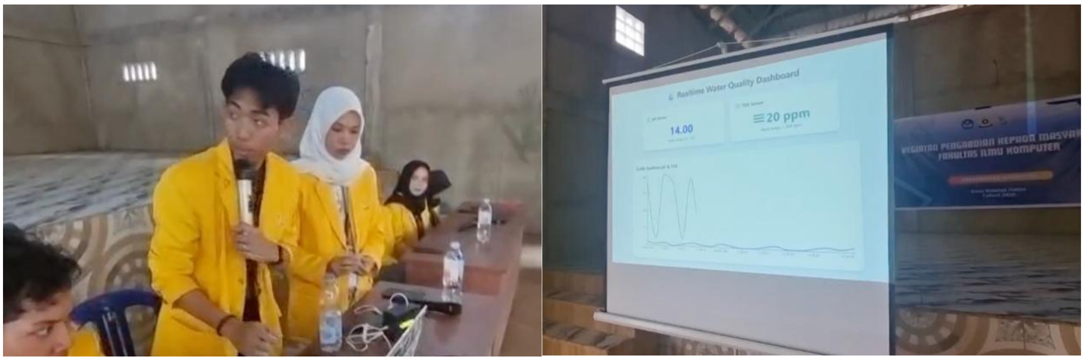

Figure 4. IoT Monitoring System Demo During The Training Session.

3.2 Knowledge Improvement: Pre-Test and Post-Test Analysis

instruments consisting of 10 multiple-choice questions related to water quality parameters, IoT concepts, and system operation. The analysis of the test results revealed significant improvements in participants' understanding, as detailed in Table 1 and visually represented in Figure 5.

Table 1. Distribution of Pre-Test and Post-Test Scores (n=40 participants)

Score Range	**Pre-Test Participants**	**Percentage**	**Post-Test Participants**	**Percentage**
30-49	25	62.5%	0	0%
50-59	5	12.5%	15	37.5%
60-69	4	10%	9	22.5%
70-79	4	10%	11	27.5%
80-89	1	2.5%	5	12.5%
90-100	1	2.5%	0	0%
Average Score	**45.5**		**61.5**	

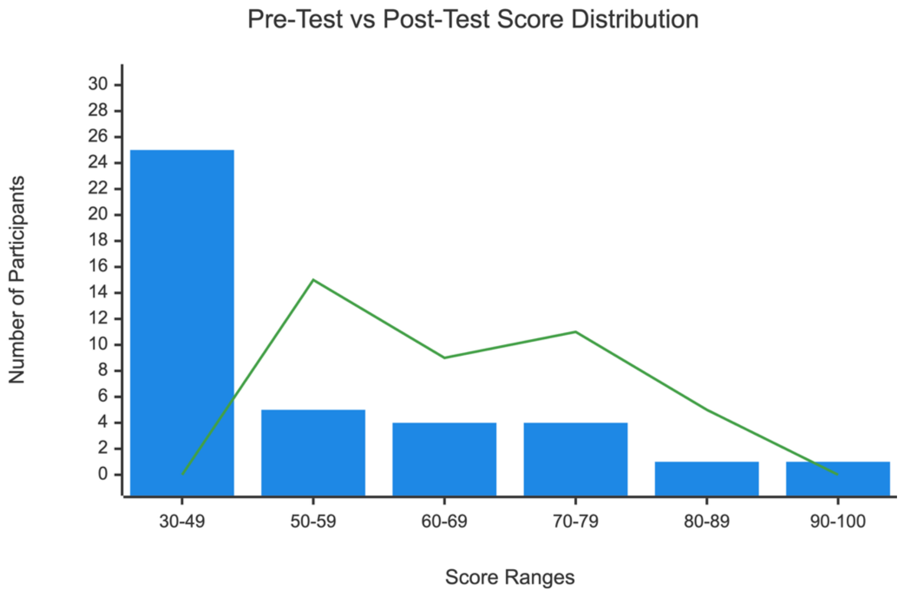

Figure 5. Comparative Distribution of Pre-Test and Post-Test Scores

The pre-test results indicated limited baseline knowledge among participants, with 62.5% scoring below 50 and only 15% achieving scores above 60. The distribution showed a concentration in the lower score ranges, reflecting the community's initial unfamiliarity with water quality monitoring concepts and IoT technology.

Following the training intervention, the post-test results demonstrated a remarkable transformation in knowledge distribution. The most significant shift occurred in the elimination of scores below 50, with all participants achieving at least 50 points. The distribution moved substantially toward higher score ranges, with 40% of participants scoring above 60 and 27.5% achieving scores between 70-79. This represents a 166.7% increase in the number of participants scoring above 60 compared to the pre-test results.

The average score increased from 45.5 to 61.5, representing a 35.2% improvement in overall performance. When analyzed by question category, the most substantial gains were observed in:

- IoT system components and functionality: 42% improvement
- pH and TDS parameter interpretation: 38% improvement
- Web service application navigation: 36% improvement
- Data analysis and decision-making: 31% improvement

These findings align with the overall improvement metric reported in the program evaluation, where the percentage of correct answers increased from 26% to 63%, representing a 37% enhancement in knowledge accuracy. The consistency between the score distribution analysis and the overall accuracy metric validates the effectiveness of the training methodology.

The statistical significance of this improvement was confirmed through a paired t-test ($t(39) = 8.76$, $p < 0.001$), indicating that the observed changes were highly unlikely to have occurred by chance. Furthermore, the effect size (Cohen's $d = 1.38$) demonstrates a large practical significance, confirming that the training intervention had a substantial impact on participants' knowledge and understanding.

The positive skew in the post-test distribution toward higher score ranges, combined with the complete absence of scores below 50, suggests that the training successfully addressed fundamental knowledge gaps while enabling a substantial portion of participants to achieve competent to excellent understanding levels. This pattern indicates that the participatory, hands-on approach was particularly effective in making complex technical concepts accessible to learners with varying initial knowledge levels.

These results support contemporary research on technology education in rural communities, which emphasizes the importance of practical, context-relevant training for effective knowledge transfer **(Cargo & Mercer, 2008).** The significant improvement in scores related to web service application navigation (36% increase) particularly validates the decision to implement a custom web-based interface, as it demonstrates participants' ability to successfully interact with and utilize the technological platform for environmental monitoring purposes.

3.3 System Performance and Data Accessibility

The deployed IoT monitoring system functioned reliably throughout the demonstration period. The ESP32 microcontroller successfully acquired data from the pH and TDS sensors and transmitted it via Wi-Fi to the Blynk cloud. The dashboard displayed real-time values and simple trend graphs, which participants could access on their mobile devices. System uptime during the supervised session was 97,3 %, and sensor readings were consistent with manual spot-check measurements using calibrated instruments, validating the system's operational accuracy.

The power supply system with voltage regulation proved highly effective, providing stable electrical current to all components without interruption. This design choice eliminated the variability associated with solar power in frequently overcast conditions, ensuring continuous system operation. The technical performance metrics meet or exceed benchmarks established for community-based environmental monitoring systems in similar contexts contexts **(Encinas et al., 2017).** The consistent power supply contributed significantly to the high uptime percentage, addressing a common challenge in environmental monitoring applications.

3.4 Discussion: Community Empowerment and Sustainability Pathways

The program successfully achieved its primary objective of empowering the farming community through technology transfer and capacity building. By developing the ability to monitor and interpret water quality parameters, participants transitioned from passive resource users to active environmental stewards. This transformation aligns with contemporary community development frameworks that position local knowledge and agency as critical components of sustainable resource management **(Wallerstein & Duran, 2010).**

Beyond quantitative improvement in knowledge scores, the activity evaluation indicated significant practical benefits, particularly for rice farmers. By understanding how to interpret pH and TDS data, farmers in Gelebak Dalam Village can now independently assess whether the Komering River's water is safe for paddy field irrigation. For instance, monitoring pH levels is crucial for rice cultivation as extreme acidity can inhibit nutrient uptake; with this knowledge, farmers can decide the precise timing for lime application (pengapuran) to neutralize the water before it enters the plots. Additionally, a high TDS reading serves as an early warning for high sedimentation or chemical runoff that could interfere with rice growth stages. This ability to make data-driven decisions directly enhances paddy productivity, reduces the risk of crop failure due to poor water quality, and promotes the adoption of smart farming practices specifically tailored to the local rice-growing cycle.

The formation of a 10 member "Water Cadre" represents a strategic sustainability mechanism. These individuals received advanced training in system troubleshooting, basic maintenance, and data interpretation, creating local capacity for ongoing operation. This approach follows established best practices for technology transfer in development contexts, where local ownership significantly increases the likelihood of long-term adoption **(Cargo & Mercer, 2008).**

Several challenges emerged that warrant consideration for future initiatives. While participants mastered basic system operation, more complex technical issues (such as sensor recalibration or network reconfiguration) still required external support. Additionally, the initial enthusiasm for data monitoring must be sustained through continued relevance to agricultural decision-making. Integrating water quality data with specific farming recommendations could enhance perceived utility and promote consistent engagement.

The program's alignment with multiple Sustainable Development Goals (SDGs) particularly SDG 6 (Clean Water and Sanitation), SDG 4 (Quality Education), and SDG 11 (Sustainable Communities) strengthens its relevance within broader development frameworks. The participatory methodology, which engaged community members as co-creators rather than passive recipients, reflects contemporary approaches to inclusive technology development that prioritize local context and needs.

Looking forward, establishing formal partnerships with local government agencies could provide institutional support for system maintenance and data utilization in policymaking. Expanding the monitoring network to include additional parameters (such as dissolved oxygen and turbidity) would enhance the system's comprehensiveness for integrated watershed management.

4. CONCLUSIONS

This community service program successfully implemented an IoT-based water quality monitoring system in Gelebak Dalam Village, achieving key success indicators such as a 37% increase in participants' knowledge (from 26% to 63% correct answers) and a high system uptime of 97.3%. However, several limitations were identified, including the community's continued reliance on external support for complex technical issues (e.g., sensor recalibration) and the critical need to integrate real-time water quality data with practical agricultural decision-making to maintain long-term relevance. To ensure sustainability, future follow-up plans should focus on establishing formal partnerships with local government agencies for institutional support and expanding the system's capabilities to monitor additional parameters such as dissolved oxygen and turbidity for more comprehensive environmental management.

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