PTI JOURNAL
LPPM Universitas Putra Indonesia YPTK Padang
Lubuk Begalung Highway, Padang, Sumatera Barat, Indonesia
Volume: 13, Issue: 1, Number: 1, Page: 18 - 24, 23/06/2026, e-ISSN: 2685-3914

DESIGN AND IMPLEMENTATION OF A SMART WATER TANK MONITORING SYSTEM FOR OPTIMIZING CAMPUS WATER MANAGEMENT

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Abstract

The growth of the Internet of Things (IoT) is driving the development of monitoring systems capable of improving the efficiency of resource management, including in water management systems. This research aims to develop an IoT-based Smart Water Tank Monitoring system to support the real-time monitoring of water levels on campus. The research employed a Research and Development (R&D) methodology using the ADDIE model, comprising the stages of Analyse, Design, Develop, Implement, and Evaluate. The system developed integrates an HC-SR04 ultrasonic sensor, an ESP32 microcontroller, a local web-based dashboard, LED indicators, and historical data storage. Data collection techniques were carried out through observation, interviews, documentation, and system testing. The data were analysed using quantitative descriptive analysis, Mean Absolute Error (MAE) and Black Box Testing. The results of the study indicate that the system is capable of automatically monitoring water conditions, displaying information in real time, improving the effectiveness of monitoring, and supporting the efficient management of water resources.

Keywords: internet of things, smart water tank monitoring, ESP32, real-time monitoring, water information system

1. **Introduction**

The development of digital technology has driven significant changes in various sectors of life, including the management of technology-based resources and infrastructure. One development experiencing rapid growth is the implementation of the Internet of Things (IoT), a concept that allows various physical devices to be connected via the internet to exchange data automatically and in real time. IoT implementation has been widely used in the industrial, healthcare, agricultural, educational, and environmental monitoring systems sectors because it can improve operational efficiency, reduce human involvement in manual processes, and support faster and more accurate data-driven decision-making. Furthermore, IoT-based systems allow users to directly access information through integrated digital media, thereby increasing the effectiveness of system monitoring and control processes [1][2].

One area requiring an IoT-based monitoring system is water resource management. Water is a vital resource that supports various human activities and plays a key role in supporting the operations of an institution. In educational settings, water is used to support various facilities such as sanitation, canteens, places of worship, parks, and other public facilities. As water demand increases, a management system is needed that can provide fast, accurate, and sustainable information on water conditions. However, in many institutions, water monitoring is still carried out conventionally through manual tank checking. This method has several limitations, such as delayed filling, the risk of tank overflows, inaccurate water condition information, and the lack of historical water usage data to support evaluation of sustainable resource management [3][4].

This problem was also found at the IKIP PGRI Bojonegoro campus. Based on initial observations, there are ten water tanks spread across several campus locations, such as the prayer room, cafeteria, and campus park. The entire water monitoring process is still carried out manually by facility staff. This situation causes several problems, such as overflows several times a week, water shortages that disrupt operational activities, and relatively time-consuming inspection processes. Furthermore, the system used is not yet capable of providing centralized water usage data,

Accepted: 03-03-2026 | Revision: 10-04-2026 | Publication: 23-06-2026 | doi: 10.35134

complicating the evaluation process and making decisions related to effective water resource management.

Various previous studies have developed IoT-based water monitoring systems utilizing ultrasonic sensors, microcontrollers, and internet-based communication technology. Research conducted by Baldeon-Perez et al. developed a water level monitoring system to prevent leaks in reservoirs through the use of sensors and an automatic control system [5]. Other research has shown that IoT-based sensor integration can improve the real-time water condition monitoring process [6]. Furthermore, another study developed a water level monitoring system using IoT-based ultrasonic sensors with the Blynk application [7], while another study developed an IoT-based groundwater tank monitoring and automation system in a hospital environment [8]. These research results indicate that the use of IoT technology can improve monitoring accuracy and the efficiency of water resource management.

However, a literature review indicates that previous research still has several limitations. Most studies still utilize third-party platforms such as Blynk or cloud services for data storage and visualization. The use of these platforms makes the system dependent on external services, which can limit the flexibility of integration to meet the needs of specific institutions. Furthermore, most of the systems developed still focus on basic monitoring functions and do not yet provide an integrated local dashboard, continuous storage of historical water usage data, or a direct visual indicator system that can assist officers in conducting rapid field monitoring. These limitations indicate a research gap that still needs further development [7][9][10].

Based on these problems and research gaps, this study aims to develop an Internet of Things-based Smart Water Tank Monitoring system using Research and Development (R&D) methods. The R&D method was chosen because this research focuses not only on problem identification but also on systematically producing and evaluating developed products [11][12]. The developed system integrates an ultrasonic sensor as a water level detector, an ESP32 microcontroller as a data processing center, a local web dashboard as a real-time monitoring medium, a three-color LED indicator as a visual warning system, and historical water usage data storage.

This research was conducted to produce a water monitoring system that better suits the operational needs of the campus environment and supports more effective and sustainable water resource use. The contribution of this research lies not only in the development of an IoT-based monitoring system, but also in the integration of a local dashboard, historical data storage, and visual indicators to support decision-making in water management. The research results are expected to provide alternative solutions for technology-based water resource management in educational settings and other sectors.

2. Methods

This study used the Research and Development (R&D) method to develop and evaluate an Internet of Things (IoT)-based Smart Water Tank Monitoring system. The R&D method was chosen because the research is not only oriented towards problem identification but also produces a product that is systematically developed, tested, and evaluated until it can be applied in a real-world environment. The R&D approach allows for a structured development process, from needs analysis to final product evaluation, making it suitable for research focused on technology and information systems development [11,12].

The development model used in this study is ADDIE (Analyze, Design, Develop, Implement, Evaluate). The ADDIE model was chosen because it provides systematic development stages and facilitates a gradual and continuous product development process. This model is widely used in development research because it allows for evaluation at each stage to improve product quality [11].

The first stage, "Analyze," was conducted to identify user needs, the current system's condition, and any issues encountered in monitoring water reservoirs on campus. The needs analysis was conducted through direct observation and interviews with campus facility and infrastructure staff to obtain information regarding the water management process, frequency of water use, and operational challenges encountered.

The Design stage involved designing the system architecture, user interface, data communication flow, database, and hardware and software integration. The Development stage then involved building a system prototype using an HC-SR04 ultrasonic sensor as a water level detector, an ESP32 as the main microcontroller, a local web-based dashboard, LED indicators as a visual warning system, and a database as information storage.

The Implementation phase involves deploying the system on campus to test its performance under real-world conditions. The final phase, Evaluation, is conducted to determine the system's effectiveness through sensor accuracy testing, system function testing, and user evaluation [3,13].

The research was conducted at IKIP PGRI Bojonegoro in the odd semester of the 2026/2027 academic year. The study population consisted of all water reservoirs used on campus. Based on initial observations, there were ten water reservoirs spread across several locations, including the prayer room, cafeteria, park, and other public facilities. The research analysis unit was the water reservoir monitoring system, which encompasses sensor readings, data transmission, data storage, and data visualization on the monitoring dashboard.

The sampling technique used purposive sampling, considering specific characteristics relevant to the research objectives. The research sample consisted of three water reservoirs selected based on several criteria: high usage, high filling frequency, frequent empty or overflowing reservoirs, and representative locations. This technique was chosen because it allowed researchers to obtain samples deemed most relevant to the system's development needs [14]. In addition to the system objects, the research also involved campus facilities and infrastructure officers as respondents who played a role in the product evaluation process.

Data collection techniques included observation, interviews, documentation, and system testing. Observations were conducted to obtain information regarding the condition of the water monitoring system used, reservoir capacity, and water usage patterns. Interviews were conducted with campus facility staff to determine user needs and obtain information on any operational issues. Documentation was used to collect supporting data such as the number of reservoirs, their locations, capacities, and water usage history. Furthermore, system testing was conducted on the developed hardware and software to determine overall system performance [15][16].

The research variables consisted of sensor accuracy, system response time, and user satisfaction level. Sensor accuracy was used to determine the accuracy of ultrasonic sensor readings relative to actual water surface conditions. The error percentage was calculated using Equation (1).

$$Error(\%) = \frac{|\,X_a - X_s\,|}{X_a} \times 100 \qquad (1)$$

Description:

X_a= actual value of manual measurement results
X_s= sensor reading value
The sensor accuracy value is calculated using Equation (2).

$$Accuracy(\%) = 100 - Error(\%) \qquad (2)$$

The system response time is used to measure the time interval between sensor readings and data being displayed on the dashboard. The response time measurement is calculated using Equation (3).

$$T_r = T_o - T_i \qquad (3)$$

Description:

T_r= system response time
T_o= data display time
T_i= data transmission time

User satisfaction was measured using a five-level Likert scale questionnaire that included indicators of ease of use, system appearance, response speed, information quality, and system effectiveness. The satisfaction percentage was calculated using Equation (4).

$$P = \frac{\sum X}{N \times S_{max}} \times 100 \qquad (4)$$

Description:

P= percentage of satisfaction level
X= total respondent score
N= number of respondents
S_{max}= maximum score

Data analysis was conducted using a quantitative descriptive approach and system performance evaluation. Descriptive analysis was used to explain the results of observations, interviews, and the implementation of the developed system. Sensor accuracy was measured using Mean Absolute Error (MAE) to determine the average error of sensor readings relative to actual measurements [17]. The MAE equation is shown in Equation (5).

$$MAE = \frac{1}{n}\sum_{i=1}^{n} |\,X_{a_i} - X_{s_i}\,| \qquad (5)$$

Description:

n = number of tests
X_{a_i}= actual value
X_{s_i}= sensor reading value

In addition, system functionality testing is conducted using the Black Box Testing method to ensure all system functions operate as designed. The system success rate is calculated using Equation (6).

$$Success\ Rate = \frac{N_s}{N_t} \times 100 \qquad (6)$$

Description:

N_s= number of functions successfully executed
N_t= total number of functions tested

Through these methodological stages, the research is expected to produce an IoT-based Smart Water Tank Monitoring system that meets the functionality, accuracy, and user needs aspects and can support more effective and sustainable water resource management.

3. Results and Discussions

In this research, an Internet of Things (IoT) based Smart Water Tank Monitoring System has been successfully developed using an ESP32 microcontroller and an HC-SR04 ultrasonic sensor. The developed system aims to monitor water level conditions in several tanks automatically and in real-time through a web-based dashboard. The system development process was carried out using the ADDIE model which includes the stages of Analysis, Design, Development, Implementation, and Evaluation. The research results include system design, hardware and software implementation, and system testing to ensure all components can function according to user needs. The results of the system development are presented through a Level 0 Data Flow Diagram (DFD), system architecture, monitoring device implementation, and monitoring dashboard display which are explained in the following section.

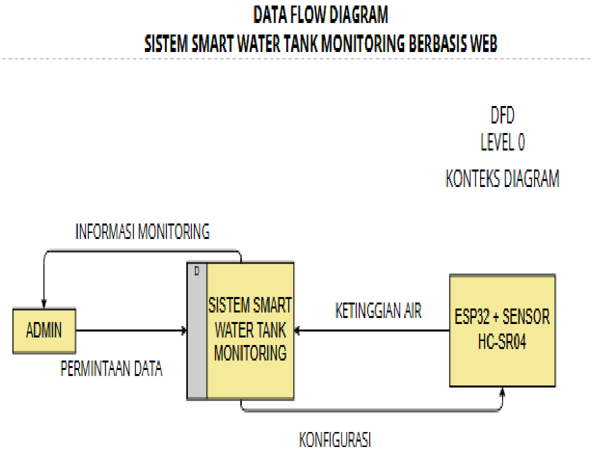


Figure 1. DFD (Data Flow Diagram)

Figure 1 shows a Level 0 Data Flow Diagram (DFD) for the Internet of Things-based Smart Water Tank Monitoring System. This diagram illustrates the data flow between the user, the monitoring system, the HC-SR04 ultrasonic sensor, the ESP32, the MySQL database, and the web dashboard. The ultrasonic sensor reads the water level in each tank, then processes the data by the ESP32 and sends it to the server. The system then stores the data in a MySQL database and displays real-time monitoring information via the web dashboard. Users can view information on the water level, water volume percentage, water condition status, and monitoring history stored in the system. After the system design process was completed using the Level 0 Data Flow Diagram (DFD), the next stage was system implementation. Implementation was carried out by realizing the entire design into integrated hardware and software. The Smart Water Tank Monitoring System was developed using the HC-SR04 ultrasonic sensor as the water level detector, the ESP32 microcontroller as the data processing and transmission center, the MySQL database as the data storage medium, and the web dashboard as the monitoring platform. The system implementation aims to ensure that each component can work in an integrated manner to monitor water conditions in multiple reservoirs in real time. The results of the system implementation are shown in Figure 2 below.

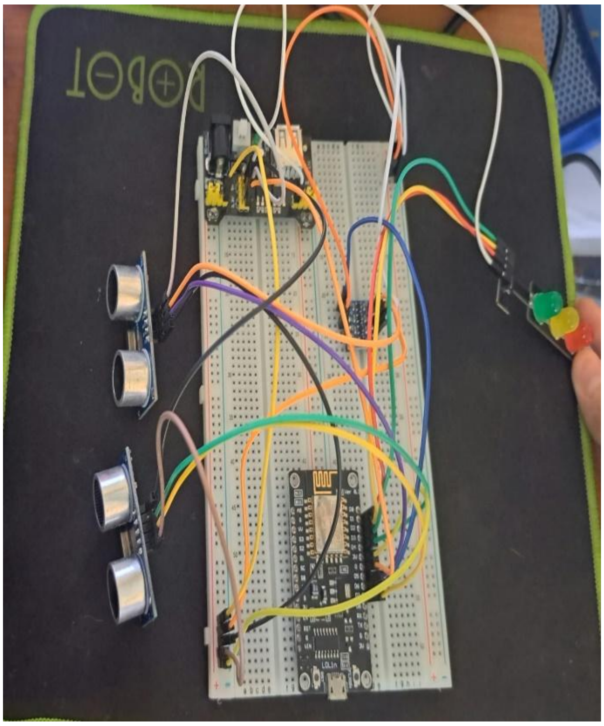


Figure 2. Implementation of the Smart Water Tank Monitoring System

According to Figure 2, the implementation of the Smart Water Tank Monitoring System consists of several interconnected main components: an HC-SR04 ultrasonic sensor, an ESP32 microcontroller, a MySQL database, a web dashboard, and an LED indicator. The ultrasonic sensor measures the water level in the tank. The resulting data is then processed by the ESP32 and sent to the server via a WiFi network. The data is then stored in the MySQL database and displayed in real time on the monitoring dashboard. Furthermore, an LED indicator provides visual notification to show the water level in each tank, making it easier for users to monitor directly. After the system was successfully implemented according to the design, the next stage was the realization of the Smart Water Tank Monitoring device in the form of a ready-to-use prototype. The device implementation was carried out by integrating the HC-SR04 ultrasonic sensor, ESP32 microcontroller, LED indicator, and other supporting components into a single system capable of automatically monitoring water levels. The device implementation results showed that all components functioned according to the design. The physical form of the Smart Water Tank Monitoring device that was developed is shown in the following figure.

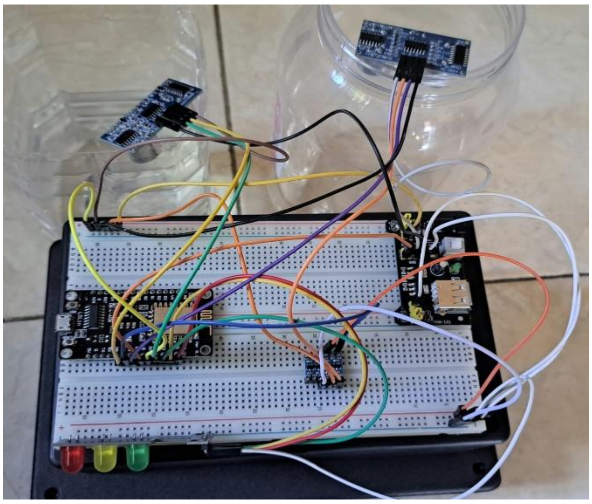
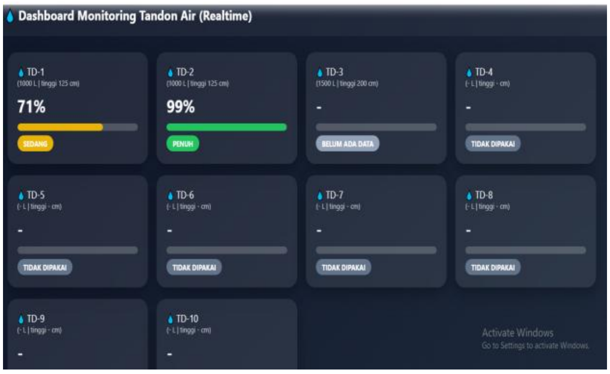


Figure 3. Device Implementation Results

Figure 3 shows the implementation results of the developed Smart Water Tank Monitoring device. The device consists of an ESP32, an HC-SR04 ultrasonic sensor, an LED indicator, a power supply, and other supporting modules installed in the water tank. The sensor is used to measure the distance from the water surface to the sensor, thereby obtaining information about the water level in the tank. All components work in an integrated manner to support the automatic and real-time monitoring process. In addition to the hardware implementation, this research also produced a web-based monitoring dashboard that serves as a visualization of real-time water level data in the tank. The dashboard was developed to facilitate users in obtaining information about water conditions without having to visit the tank in person. Through this dashboard, users can monitor the water level, water volume percentage, water condition status, and the time of data readings sent by the system. Furthermore, the dashboard is equipped with a data history feature that allows users to view a track record of water conditions over a specific period. The results of the monitoring dashboard implementation are shown in the following figure.



Dashboard Monitoring Tandon Air (Realtime)

TD-1
(1000 L | tinggi 125 cm)
71%
SEDANG

TD-2
(1000 L | tinggi 125 cm)
99%
PENUH

TD-3
(1500 L | tinggi 200 cm)
-
BELUM ADA DATA

TD-4
(- L | tinggi - cm)
-
TIDAK DIPAKAI

TD-5
(- L | tinggi - cm)
-
TIDAK DIPAKAI

TD-6
(- L | tinggi - cm)
-
TIDAK DIPAKAI

TD-7
(- L | tinggi - cm)
-
TIDAK DIPAKAI

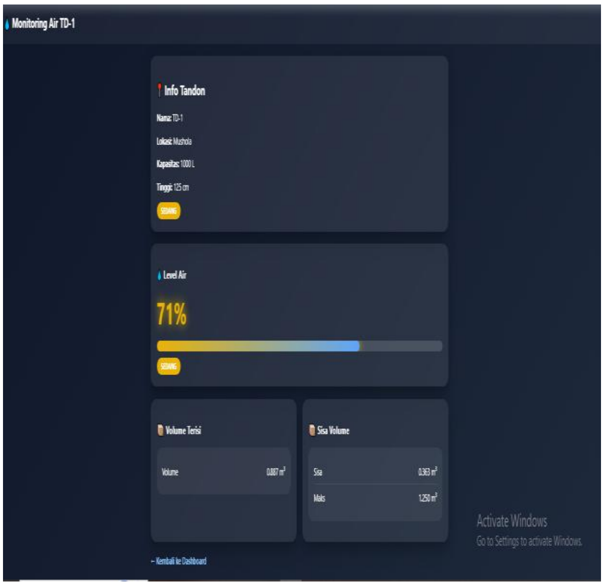
TD-8
(- L | tinggi - cm)
-
TIDAK DIPAKAI

TD-9
(- L | tinggi - cm)
-

TD-10
(- L | tinggi - cm)
-

Figure 4. Monitoring Dashboard Display

Figure 4 shows the monitoring dashboard used to monitor water conditions in several reservoirs. The dashboard displays the reservoir identity, water volume percentage, water condition status, and the data reading time. This information is automatically updated based on data sent by the ESP32, allowing users to monitor water conditions in real time without having to visit the reservoirs themselves.



Monitoring Air TD-1

Info Tandon

Nama: TD-1

Lokasi: Mushola

Kapasitas: 1000 L

Tinggi: 125 cm

SEDANG

Level Air

71%

SEDANG

Volume Terisi

Volume 0.887 m³

Sisa Volume

Sisa 0.363 m³

Maks 1.250 m³

Figure 5. Monitoring Dashboard Implementation Results

According to Figure 5, the monitoring dashboard displays water condition information from several reservoirs connected to the system. The information displayed includes reservoir identity, water level, water volume percentage, water condition status, and the time of the most recent data reading. This data is automatically updated based on ultrasonic sensor readings sent by the ESP32 to a MySQL database. The dashboard is designed to be simple and easy to understand, allowing users to monitor water conditions quickly and accurately. In addition to displaying real-time data, the dashboard also provides historical monitoring information that can be used as evaluation material for water resource management. With this monitoring dashboard, the water condition monitoring process is more effective, efficient, and structured compared to the manual monitoring method previously used. After the system development and implementation process was completed, the next stage was an evaluation of the research instrument used. This evaluation was conducted through instrument content validation to ensure that each statement item aligns with the measured indicators and can be used as a valid data collection tool. Instrument content validation was conducted by two experts, assessing aspects of indicator suitability, item representativeness, language clarity, statement relevance, and general validity. The results of the instrument content validation are used as a basis for determining the suitability of the instrument before it is used at the research data collection stage.

Table 1. Validation of instrument content

Description	Value
Number of Statements	18
Number of Respondents	2
Score Influenced	171
Maximum Score	180
Percentage	95%
Category	Very Valid

$$P = \frac{Score\ Obtained}{Maximum\ Score} \times 100\%$$

$$P = \frac{171}{180} \times 100\%$$

$$P = 95\%$$

The instrument content validation results were conducted by two experts on 18 statement items used in the study. Based on the assessment results, a total score of 171 was obtained out of a maximum score of 180. The instrument validity percentage was calculated using the feasibility percentage formula by comparing the total score obtained to the maximum score. The calculation results showed a value of 95%. Based on the assessment criteria used, this value is included in the "Very Valid" category. This result indicates that the research instrument is in accordance with the measured indicators, has good language clarity, and is suitable for use as a data collection tool in research. After the research instrument was declared valid and suitable for use, the next stage was data collection from system users. User testing was conducted to determine the level of practicality of the Smart Water Tank Monitoring System based on user experience when using the system directly. The assessment was carried out through a questionnaire covering aspects of system quality, information quality, visual appearance, and system usability. The results of the user assessment were used to determine the extent to which the system can be accepted and utilized in monitoring water tank levels on campus.

Table 2. User Questionnaire Calculation

Description	Score
Number of Statements	13
Number of Respondents	2
Score Influenced	118
Maximum Score	130
Percentage	90,77%
Category	Very Valid

$$P = \frac{Score\ Obtained}{Maximum\ Score} \times 100\%$$

$$P = \frac{118}{130} \times 100\%$$

$$P = 90{,}77\%$$

Based on the results of the user questionnaire, a total score of 118 was obtained out of a maximum score of 130, resulting in a percentage of 90.77%. Based on the assessment criteria used, this score is included in the "Very Valid" category. These results indicate that the developed system is easy to use and is able to provide the information needed by users clearly. Users also assessed that the monitoring dashboard has a simple, easy-to-understand display and is able to present water level information in real-time. In addition, the multi-tank monitoring and historical data storage features are considered to help users monitor water conditions more effectively and efficiently compared to the manual monitoring method previously used. The developed system was also evaluated by experts to determine the level of system feasibility from a technical and functional aspect. Expert validation aims to assess the suitability of the system to user needs, the reliability of available features, ease of use, and the quality of the developed interface display. The assessment was conducted using instruments that had been declared valid in the previous stage. The results of the expert validation were used as a basis for determining the level of feasibility of the Smart Water Tank Monitoring System before its wider implementation. The results of the expert validation are presented in Table 3.

Table 3. Expert Validation Calculation

Description	Score
Number of Statements	20
Number of Respondents	2
Score Influenced	168
Maximum Score	200
Percentage	84%
Category	Very Valid

$$P = \frac{Score\ Obtained}{Maximum\ Score} \times 100\%$$

$$P = \frac{168}{200} \times 100\%$$

$$P = 84\%$$

Based on the results of the system expert validation conducted by two validators, a total score of 168 was obtained out of a maximum score of 200, resulting in a percentage of 84%. Based on the assessment criteria used, this value is included in the "Very Valid" category. These results indicate that the developed web-based Smart Water Tank Monitoring System has met the aspects of system product quality, system feasibility, and system practicality well. The validators assessed that the system is able to display water level monitoring data in real-time, has a good level of accuracy in reading and processing sensor data, and can present clear information through the monitoring dashboard. In addition, the integration between the HC-SR04 ultrasonic sensor, ESP32 microcontroller, MySQL database, and web dashboard is considered to have run according to the designed function. Thus, the developed system is declared valid and suitable for use as a medium for monitoring water levels in reservoirs in the campus environment. The results of the evaluation that has been carried out indicate that the developed system has a high level of validity, feasibility, and practicality. The integration of ESP32, HC-SR04 ultrasonic sensor, MySQL database, web dashboard, and multi-tank monitoring features supports real-time water condition monitoring. Therefore, the developed system can be used as a more effective water level monitoring solution compared to manual monitoring methods. Further research conclusions are presented in the following section.

4. Conclusions

This research successfully developed an Internet of Things-based Smart Water Tank Monitoring system using the ADDIE Research and Development (R&D) model. The developed system integrates an HC-SR04 ultrasonic sensor, an ESP32 microcontroller, a local web-based dashboard, LED indicators, and historical data storage to support real-time water level monitoring. The development results demonstrate that the system is capable of automated monitoring and data transmission, thereby helping to improve the effectiveness of water reservoir management on campus.

Empirically, this research demonstrates that implementing an IoT-based monitoring system can help reduce delays in detecting water conditions, minimize the risk of empty or overflowing reservoirs, and expedite monitoring processes previously performed manually. Theoretically, this research strengthens the application of IoT concepts in the development of water resource monitoring systems through the integration of hardware and software into a single, interconnected system. A novel finding in this research lies in the development of a system that combines a local web-based dashboard, historical data storage, and integrated visual indicators to support decision-making.

From an economic perspective, the developed system has the potential to reduce water waste, lower operational costs resulting from manual monitoring processes, and improve resource efficiency. Further research is recommended to develop a system integrating cloud computing technology, artificial intelligence (AI), and water usage prediction features to create a more adaptive and intelligent monitoring system. Furthermore, the system can be expanded on a broader scale with a wider number of sensors and implementation locations to achieve higher levels of accuracy and flexibility.

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