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A realtime IoT-mobile-based system for mapping and monitoring water reservoirs of PDAM in Fakfak City

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ABSTRACT

The Regional Drinking Water Company (PDAM) of Fakfak plays a vital role in delivering clean water to the community. However, the current manual approach to monitoring water availability and quality in reservoirs can lead to delays in decision-making related to water distribution. This research aims to design and develop a mobile application integrated with a real-time reservoir mapping and monitoring system, utilizing Internet of Things (IoT) technology. The system employs ultrasonic sensors to measure water levels, pH sensors to assess water quality, and a microcontroller with a communication module to transmit data to a server. This data is then visualized on an Android-based application supported by integrated mapping features. The study follows a Research and Development (R&D) methodology using a prototyping model. The resulting prototype demonstrates the system's ability to provide accurate and real-time insights on water reservoir conditions, thereby enhancing PDAM's capacity for efficient and responsive water distribution planning.

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1. INTRODUCTION

Water resources represent one of the most vital and versatile natural assets, playing a crucial role across various aspects of daily life (Simonovic, 2012). Their significance spans multiple sectors, including agriculture, industry, and household use (Loizou et al., 2019). However, amidst the rapid expansion of industrial and agricultural activities, ensuring the availability of clean and safe water has become increasingly essential due to the heightened risk of water pollution (Zahoor & Mushtaq, 2023).

The availability and distribution of clean water are fundamental needs essential to the well-being of communities (Akhai & Taneja, 2025). As the primary provider of clean water services, the Regional Water Utility Company (PDAM) is expected to deliver op-timal service quality—particularly in monitoring and managing its reservoir systems. In Fakfak Regency, reservoir monitoring is still conducted manually, which often results in delays in identifying issues such as leaks, sensor malfunctions, or discrepancies in water volume. This manual approach can lead to disruptions in water distribution and un-necessary waste of resources.

Advancements in the Internet of Things (IoT) have unlocked significant opportunities to enhance the efficiency of infrastructure monitoring and management systems in real time (Ahmed et al., 2023). By integrating IoT sensors at key reservoir points alongside a mobile-based mapping system, critical data such as water level, pH, temperature, and pressure can be transmitted automatically to a central control unit. This enables early detection of potential issues and supports effective quality control. Moreover, presenting this data through an interactive map within a mobile application empowers PDAM technical personnel to make timely and well-informed decisions, as well as to implement corrective actions swiftly and accurately.

Recognizing the critical importance of clean water management and the growing need for modern monitoring systems, this study focuses on the design and development of a mobile application integrated with a real-time IoT-based mapping and monitoring system for PDAM reservoirs in Fakfak. This innovation is expected to serve as a practical and adaptive digital solution to support clean water management in remote and de-veloping regions such as Fakfak.

To position this research within the broader body of work, it is important to highlight how it differs from previous studies and where its novelty lies. While previous studies in Indonesia and abroad have demonstrated the use of IoT for monitoring either water level or water quality, most of them focus on single parameters or employ web-based dashboards without mobile-based geospatial integration. In contrast, this research combines multiple sensor inputs—ultrasonic for water level, pH for water quality, and temperature monitoring—into a unified IoT system, with real-time visualization directly embedded in an Android-based mapping application. This integration represents a practical advancement, particularly tailored to the operational needs of PDAM in remote regions, thus providing both academic novelty in system design and practical contributions in addressing local water distribution challenges.

2. RESEARCH METHOD

The research adopts a prototype-based system development model, selected for its flexibility in enabling iterative system building and testing (Balci & Nance, 1987). This approach allows continuous refinement through direct involvement of end users, en-suring that the system aligns closely with practical needs and expectations (Ștefan et al., 2024).

The prototyping model implemented in this study consists of the following key stages (Camburn et al., 2017):

a. Needs Analysis
   Observation and interviews were conducted with PDAM Fakfak personnel to identify the specific requirements for the monitoring system.
b. System Design
   This stage involved designing the system architecture, selecting appropriate sensors and microcontrollers, and developing the UI/UX layout for the mobile application. The system uses NodeMCU ESP8266, which is equipped with a 32-bit LX106 microcontroller, 80 MHz clock speed, 64 KB RAM, and integrated Wi-Fi module for wireless data transmission. The hardware components consist of an Ultrasonic Sensor HC-SR04 (range 2–400 cm, accuracy ±3 mm) for measuring water levels and a pH Sensor 4502C (measurement range 0–14 pH, accuracy ±0.1 pH) for assessing water quality.
c. Prototype Development
   An initial working version of the system was built to enable early testing and validation of core functionalities. The software environment integrates Firebase Realtime Database as the cloud server, React Native with Expo framework for the Android application, and Google Maps API for location-based services. The initial working version was developed to validate core functionalities, including data acquisition, transmission, and visualization.
d. Evaluation and Refinement
   The prototype was tested by end users, and feedback was gathered to improve the system through iterative revisions.
e. Final Implementation and Documentation
   A final version of the system was deployed after comprehensive testing, accompanied by complete system documentation for operational and maintenance purposes.

2.1. Research Design

2.1.1. Rapid Design Modeling

Rapid design modeling involves the creation of flowcharts and block diagrams to visu-alize the system workflow and application structure. In this study, the system design flow integrates the use of NodeMCU ESP8266, Ultrasonic Sensor HC-SR04, and a pH Sensor as the primary hardware components.

2.1.2. Prototype Construction

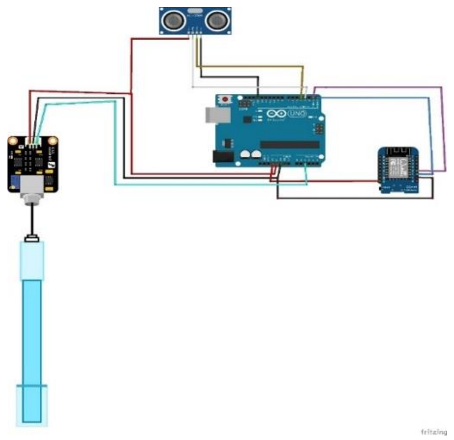


Figure 1. Prototype Design

Based on the initial system design, this stage focuses on constructing the prototype by outlining the hardware workflow and assembling the required components. It involves designing how each part of the system interacts, including the integration of sensors, microcontroller, and communication modules necessary for the device to function as intended.

2.1.3. Block Diagram

Figure 2 illustrates how each sensor provides input data to the mapping system based on measurements taken from the water reservoir. The Ultrasonic Sensor HC-SR04 is used to determine the water level in the reservoir, while the pH sensor measures the water's acidity to assess its suitability for consumption. Once the water level and pH values are measured, the data is transmitted via the NodeMCU ESP8266 module and received by an Android application, which immediately displays the measurement results in real time.

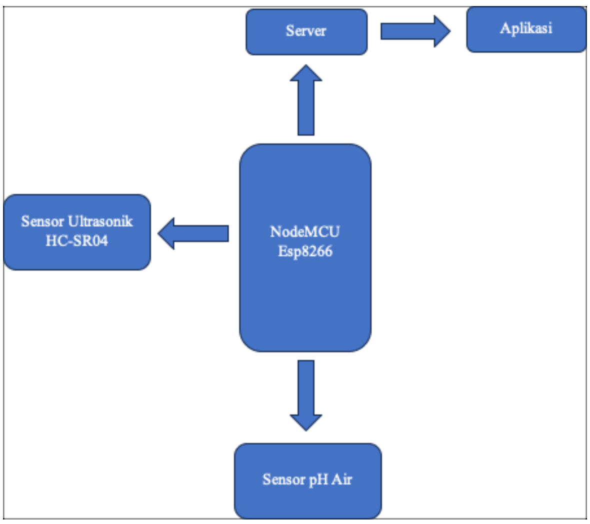


Figure 2. Block Diagram

2.1.4. Application Flowchart

Figure 3 illustrates the application flow when the device is powered on. The NodeMCU ESP8266 initializes and controls both the Ultrasonic Sensor HC-SR04 and the Water pH Sensor. These sensors measure the water level and detect the pH value within the res-ervoir. The measured data is continuously updated and transmitted in real time to the Android application, where the results are displayed dynamically.

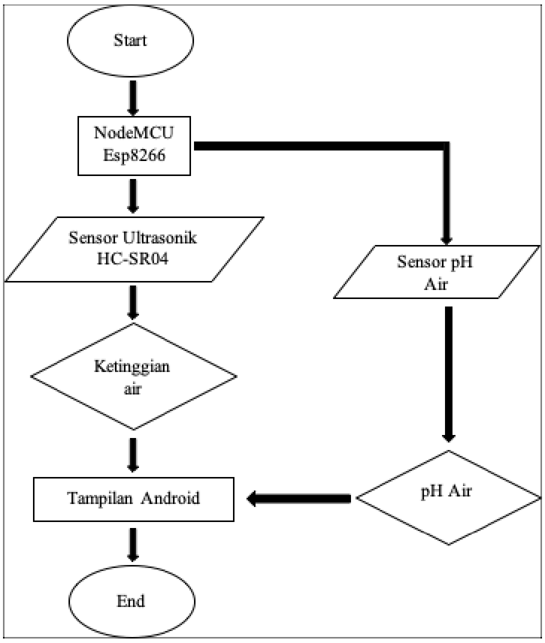


Figure 3. Application Flowchart

2.2. Functional Requirement of the PDAM Fakfak Reservoir Application

Functional requirements define the procedural capabilities that the application must perform, as well as the type of information it must generate and manage (Malan & Bredemeyer, 2001). These requirements outline the core functionalities necessary for the system to operate effectively and meet user expectations.

Table 1. Functional Requirement

User	Description
User	User Functionality : 1. View Reservoir Locations 2. Find Nearest Location 3. Route Navigation 4. Search Reservoir by Map 5. View Reservoir List with Images 6. View Water Level Data 7. View Application Description
Staff	Staff Functionality: 1. Login to application 2. Add, Edit, Delete reservoir data 3. View water level, pH Data, Images, and Reservoir Map 4. View Staff Lists and Details 5. View Historical Water Status by Reservoir 6. Add New Reservoir
Admin	Admin Functionality : 1. Login to the application 2. View total number of staff 3. Add new staff 4. Edit, delete staff 5. Search staff by name

2.3. System Testing

To ensure the system’s performance and reliability, three testing methods were applied:

a. Sensor Accuracy Test

The Ultrasonic Sensor HC-SR04 and pH Sensor 4502C were tested by comparing their readings with standard measurement tools (a ruler for water level and a calibrated digital pH meter). The accuracy was calculated based on the percentage error between sensor readings and reference values.

b. Data Response Speed Test

The communication performance was evaluated by measuring the time delay between data acquisition at the sensor and its display on the mobile application. This was done by recording timestamp logs at both the NodeMCU and Firebase server levels.

c. Application Reability Test

The Android application was tested by PDAM staff to evaluate stability, usability, and reliability under real operational conditions. Stress testing was also conducted by simulating multiple reservoir data inputs simultaneously to examine application consistency.

3. RESULTS AND DISCUSSIONS

The real-time mapping and monitoring system for PDAM reservoirs in Fakfak City was developed using the C programming language through the Arduino IDE environment. For the development of the Android application, Visual Studio Code was used as the primary editor, utilizing JavaScript as the programming language, supported by the React Native framework.

3.1. Hardware Assembly Results

The following table presents the hardware connection layout, detailing the pin config-urations used in the Mapping and Monitoring System for PDAM Reservoirs in Fakfak City:

Table 2. Hardware Pin Configuration Scheme

No	Component	NodeMCU Pin Used	Function
1	Ultrasonic Sensor HC-SR04	D5 (Trig), D6 (Echo)	Measures water level in reservoir
2	pH Sensor	A0	Detects water adicity (pH level)
3	VCC (Power Supply)	3V3	Powers sensors
4	GND (Ground)	GND	Common ground for all components

The following figure shows the assembled hardware setup of the Mapping and Monitoring System for the PDAM Reservoir.

(a) (b)

Figure 4. This figure illustrates the assembled hardware of the system: (a) Top view of the hardware configuration; (b) Front view of the hardware configuration.

3.2. Application Interface Results

This section presents the interface of the mobile application developed for the PDAM Reservoir Mapping and Monitoring System. The application displays sensor data such as water level and pH in real time, and provides interactive features such as location mapping, reservoir lists, and navigation tools to assist technical staff in monitoring operations efficiently.

3.2.1. Home Page Interface

Figure 5 displays the index or home page of the application. This is the first screen users encounter before performing any other activity. The home page includes several key elements designed to facilitate monitoring, such as a list of reservoir locations, a feature to find the nearest location, and a search menu for locating specific reservoirs.

Figure 5. Home Page

3.2.2. Reservoir List Interface

Figure 6 shows the Reservoir List interface, which displays information about all reservoirs that have been registered in the application.

Figure 6. Reservoir List

3.2.3. Reservoir Detail Menu

This page displays reservoir monitoring data, including: tank height, current water level, date and time, photo and location of the reservoir, as well as real-time pH measurement values.

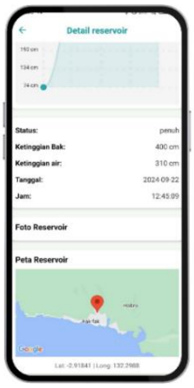
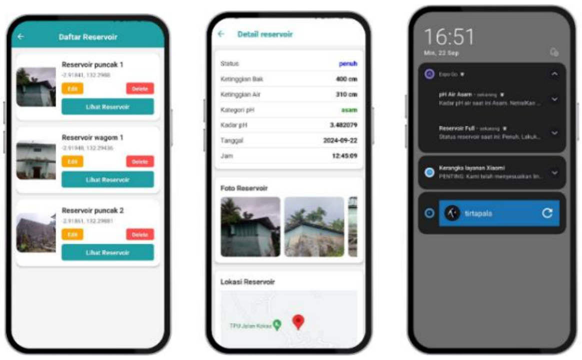


Figure 7. Reservoir Details

3.2.4. Reservoir Status Page

This page provides several features such as view, edit, and delete reservoir data to assist PDAM officers in managing water conditions more effectively. The system includes a notification feature that alerts officers when the reservoir is full. Notifications will also be triggered if the water's pH level is outside the predefined safe range.



(a) (b) (c)

Figure 8. Reservoir Status Interface : (a) List of Reservoirs; (b) Page to edit or delete reservoir data; (c) Notification regarding reservoir status

3.2.5. Add Reservoir Page

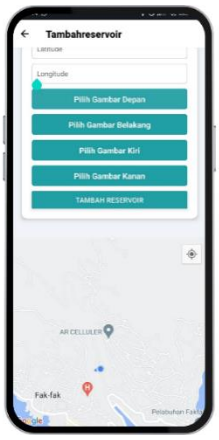
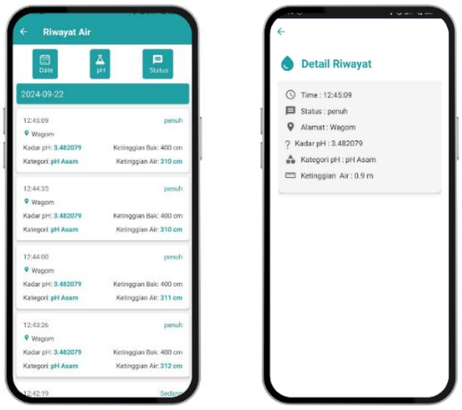


Figure 9. Add Reservoir Page

This page allows PDAM officers to add a new reservoir to the system. Required data includes: reservoir name, latitude, longitude, front photo, rear photo, left-side photo, and right-side photo. Once all data is entered correctly, a map marker will appear at the corresponding coordinates.

3.2.6. History Page

This page allows PDAM officers to view the historical data of each reservoir. The data includes previous monitoring records such as water level and pH measurements. The history can be filtered based on date, water status, or pH category to facilitate analysis and tracking of reservoir conditions over time.



(a) (b)

Figure 10. History display in the application: (a). History List; (b) History Details

3.3. Testing Results

The application testing was carried out using the black box testing method, in which the application was tested based on its functionality (Sholeh et al., 2021).

Table 3. Testing Results

No	Feature	Expected Output	Result
1	User identification	Users can log in based on their role (admin, staff, user)	Success
2	Reservoir Mapping	Map correctly displays the location of reservoirs	Success
3	Realtime monitoring	Water level and pH data are displayed correctly	Success
4	Notification	Application can display notifications related to reservoir status	Success
5	Data History	Application can display history data based on the provided search filters	Success
6	Add, edit, delete reservoir data	Application can add, edit, and delete specific reservoir	Success

3.4. Performance Evaluation

Beyond functional testing, quantitative performance analysis was conducted to validate the accuracy and responsiveness of the system. The Ultrasonic Sensor HC-SR04 was compared with manual water-level measurements using a calibrated measuring stick. The average deviation recorded was 1.4 cm, corresponding to an accuracy rate of 96.8%. Similarly, the pH Sensor 4502C was evaluated against a laboratory-grade digital pH meter, yielding an average deviation of ±0.2, or an accuracy rate of 94.5%.

System response time was also measured by recording the interval between data acquisition at the sensor and visualization on the Android application. On average, the end-to-end delay was 2.1 seconds, which demonstrates that the system fulfills the criteria for real-time monitoring. Furthermore, notification reliability testing showed that alerts were successfully triggered in 97% of test cases when water level and pH thresholds were exceeded.

3.5. User Acceptance Test

A user acceptance test (UAT) involving five PDAM Fakfak personnel was conducted to evaluate usability and satisfaction. Using a Likert scale (1–5), participants rated the system on various aspects. Results indicated that 92% of users agreed that the application was easy to operate, particularly highlighting the interactive reservoir mapping and search features. Additionally, 88% of participants confirmed that the system significantly reduced the time required to identify reservoir issues compared to the manual method. Overall, the UAT results demonstrate that the system not only meets technical requirements but also provides tangible operational benefits to PDAM staff.

4. CONCLUSION

The mapping and monitoring system for PDAM Fakfak water reservoirs enables real-time supervision of reservoir conditions, particularly regarding water levels and pH status. Notifications provide timely alerts when the reservoir is full or when pH values fall outside the safe range, thereby supporting faster response and more effective water management. Testing results using the black box method confirm that both the hardware prototype and the developed mobile application perform as intended. In terms of contribution, this research offers two main impacts. Practically, it provides PDAM Fakfak with a digital solution that enhances water distribution management in remote regions, reducing delays caused by manual monitoring and improving operational efficiency. Academically, it contributes to the body of knowledge on IoT applications in water management by presenting an integration model that combines multi-parameter sensing, cloud synchronization, and mobile geospatial visualization in a single system. However, this study has several limitations. The prototype only monitored two parameters (water level and pH), and testing was conducted at a limited scale within the Fakfak area. For broader applicability, future research should expand monitoring variables to include additional water quality indicators such as temperature, turbidity, and total dissolved solids (TDS). Furthermore, large-scale trials across multiple reservoirs and diverse geographical contexts are recommended to validate scalability and long-term reliability.

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