

Design and implementation of an IoT-based real-time water level monitoring system of belik river at yogyakarta city

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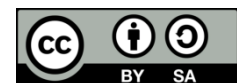
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ABSTRACT

Flooding is a serious threat in the Belik River area, Yogyakarta, especially during high rainfall and blocked water flow, while the existing Early Warning System (EWS) managed by BPBD Yogyakarta is still not functioning optimally. This study aims to design and implement a real-time water level monitoring system that can be used as an early warning system for flooding. The research method uses a Waterfall approach that includes the stages of requirements, design, implementation, testing, and operation and maintenance. The developed system is based on the Internet of Things (IoT) using HC-SR04 ultrasonic sensors and NodeMCU ESP32 microcontrollers connected to Firebase for data storage, visualized through a website, and equipped with automatic notifications via the Telegram application. The system was implemented at two points on the Belik River, Yogyakarta, with water level data recorded every minute for 3 hours over three days. The data obtained was pre-processed by averaging the sensor readings and ignoring abnormal data to improve stability. Evaluations were carried out on sensor accuracy, data transmission stability, real-time display on the website, and Telegram notification speed. The results of the study showed an average measurement error of 1.27%, with a tendency for the error to increase at distances greater than 300 cm. This system has proven capable of providing rapid information to the Regional Disaster Management Agency (BPBD) and the surrounding community to take early anticipatory measures against potential flooding, thereby helping to reduce the impact of losses and speed up emergency response.

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1. INTRODUCTION

Flooding is one of the disasters that frequently hits the city of Yogyakarta, especially in the Belik River area, which crosses densely populated areas [1]. The main factors causing this are high rainfall, a suboptimal drainage system, and the habit of people still dumping garbage into the river [2]. This situation has resulted in floods with water levels exceeding 120 cm, overflowing into residential areas, while the Early Warning System (EWS) owned by the Yogyakarta City Disaster Management Agency (BPBD) is still not functioning optimally [3]. Therefore, a more effective water level monitoring system is needed, one that can be used in real-time, is easily accessible, and is affordable.

In this study, the concept of the Internet of Things (IoT) was used to support water level monitoring, which is used as a device that allows devices to connect and exchange data automatically via the internet [4]. This system also uses an HC-SR04 ultrasonic sensor to measure the distance to the water surface [5]. The HC-SR04 ultrasonic sensor was chosen because of its high accuracy and responsiveness in measuring water levels. Research by Chandra et al. (2023) also proved that the use of HC-SR04 in Arduino Uno-based River water level detection devices was able to provide precise measurement results with voice-based early warnings [6]. Then there is the NodeMCU ESP32 microcontroller to process data and send it to the server via a Wi-Fi connection [7]. ESP32 is widely used in flood monitoring research due to its wireless connectivity support and its ability to integrate various sensors [8]. The data is then stored in Firebase so that it can be updated in real-time [9]. Research by Megantoro et al. (2022) also shows the effectiveness of integrating ESP32 with Firebase in hydroponic monitoring systems, proving that this platform is reliable for IoT applications that require real-time data acquisition and storage [10]. Information from the water level monitoring results is then displayed through a website interface built using JavaScript to make the information easily accessible [11]. In addition, early warning notifications are sent via the Telegram application to increase the speed of response to potential flooding [12].

Various studies have developed Internet of Things (IoT)-based flood monitoring systems using various approaches. Fendi et al. (2023) implemented a flood monitoring system using ESP32 with mechanical sensors, but this system does not provide an interactive website-based interface, so data access is still limited [13]. Rezki et al. (2024) developed an ESP32-based system integrated with Telegram notifications, but it does not include real-time graphical data visualization via a website [14]. Darso et al. (2023) used the Blynk platform for real-time monitoring, but Blynk has limitations in terms of design flexibility and dependence on third-party platforms [15]. The research by Hasibuan et al. (2024) also designed a prototype flood warning system based on ESP32 with ultrasonic sensors, flow sensors, and tipping bucket rain gauges for monitoring water discharge and rainfall intensity. The system can send notifications via smartphones using Wi-Fi and Bluetooth connectivity, but it does not yet provide website-based interface integration or automatic notifications via Telegram as in this study [16]. Another study by IJAERS (2024) analyzed the design of an IoT-based flood detection and warning system using a GSM module to send SMS notifications, but this system has not integrated real-time visualization through a website, so access to information is still limited [17]. In addition, several studies combine advanced methods such as fuzzy logic and artificial intelligence for flood prediction, but this approach is more complex and requires higher computational resources, making it less suitable for simple implementation in flood-prone areas [18], [19].

Although these studies are effective in conducting monitoring, most are still limited to specific platforms that are less flexible and do not yet combine real-time website-based monitoring with dual notifications. This indicates the need for a monitoring system that is not only real-time, but also has easier data access and can provide early warnings quickly.

Based on these gaps, this study proposes a water level monitoring system integrated with a Firebase-based interactive website and equipped with real-time notifications via Telegram to improve the effectiveness of early flood warnings. This study aims to design and implement a real-time water level monitoring system, provide more effective early warning information, and facilitate data access through an interactive web interface.

2. METHOD

The research method was systematically organized, starting from data collection, design, implementation, to testing. This research was conducted to design and implement an Internet of Things (IoT)-based water level monitoring system. The overall research process is illustrated in Figure 1. Research Flow, which shows the stages carried out in developing the IoT-based water level monitoring system, starting from data collection to system maintenance.

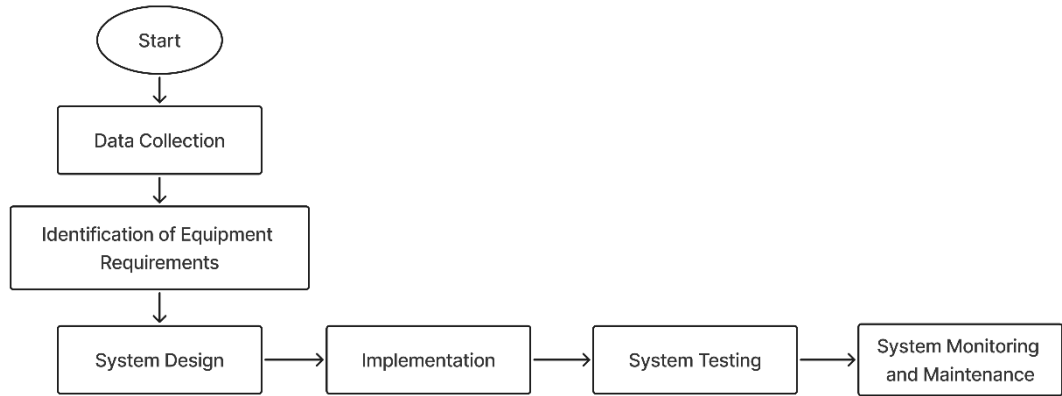


Figure 1. Research flow

Requirements Definition

The research process began with collecting data on the condition of the Belik River, including the normal water level of 20 cm, the direction of flow towards residential areas, and factors that could potentially cause the river to overflow, such as high rainfall, suboptimal drainage, and the habit of residents throwing garbage into the river. This information was obtained through direct interviews with members of the Yogyakarta City Disaster Management Agency (BPBD), neighborhood association (RT) and community association (RW) leaders, and residents living near the Belik River. The data obtained served as the basis for determining the hardware, software, and threshold requirements for the flood early warning system. A similar interview-based approach was also applied in the Community-Based Flood Risk Management study in Meru, Klang, which emphasized the participation of flood-affected communities in obtaining data on local needs and risks faced [20].

Requirements Definition

System Design

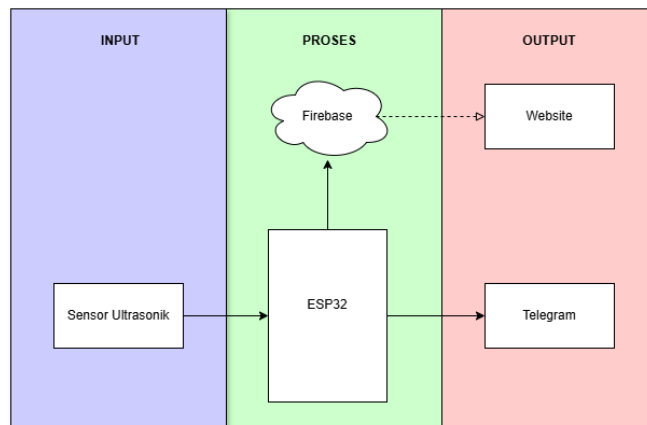


Figure 2. Input and output system diagram

The input-output diagram of the system is shown in Figure 2. Input and Output System Diagram. The system uses NodeMCU as a microcontroller that receives data from HC-SR04 ultrasonic sensors. The data is sent to Firebase for storage and displayed on a website in the form of real-time graphs. Additionally, the system is equipped with a Telegram application to provide automatic notifications when the water level exceeds the alert threshold. A similar approach is also used in research on IoT-based early flood warning systems that

integrate ultrasonic sensors, NodeMCU, and automatic notifications via the Telegram application to ensure measurement accuracy and reliability of information delivery [21], [22].

a) Circuit Diagram

The device series is shown in Figure 3. Circuit Diagram, which consists of a NodeMCU ESP32 with an integrated WiFi module, an HC-SR04 ultrasonic sensor, a solar panel, an 18650 lithium-ion battery, and a TP5100 module for charging. The NodeMCU ESP32 was chosen because it has low power consumption and built-in WiFi connectivity, making it easy to send data to Firebase without the need for additional devices. The HC-SR04 ultrasonic sensor was used because it is affordable, easy to install, and accurate in measuring distances in the range of 2–400 cm, which is suitable for monitoring river water levels. The solar panel was used as the main power source because it can provide independent energy in the field, while the 18650 lithium-ion battery serves as backup energy storage [23]. The TP5100 module was chosen for its battery charging efficiency, and the MP1584 DC-DC Buck Converter was used to adjust the voltage to suit the needs of the components. All components were assembled in a waterproof box to protect the device from external environmental conditions before being installed at the research site.

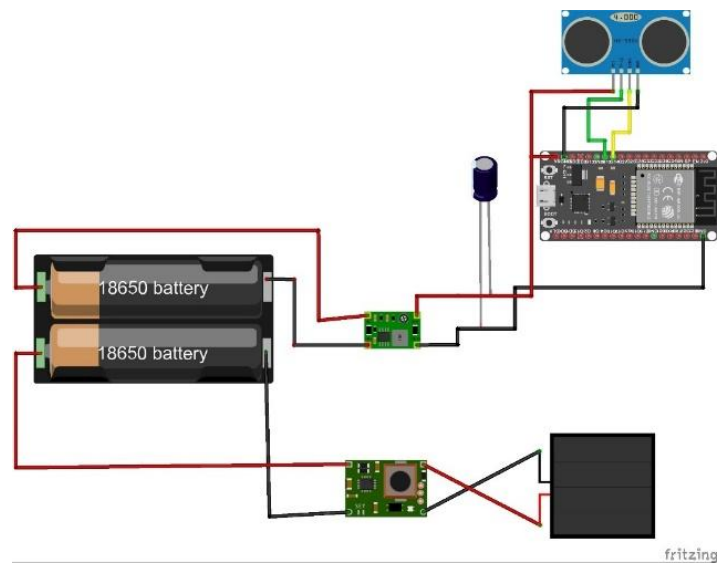


Figure 3. Circuit diagram

Implementation and Unit Testing

The implemented system was tested to ensure sensor accuracy, data transmission stability, and notification and alarm reliability. This testing was conducted over three days from July 20 to 22, 2025, at two points on the Belik River, namely Sagan Village and Iromejan Village. The system will record water levels every minute for three hours each day of observation. The measurement results are automatically sent to Firebase to be visualized and displayed on the website in the form of real-time graphs. The results of this study show consistency with previous studies that utilized ultrasonic sensors in real-time flood monitoring [24].

This location was chosen because the Belik River flows through a densely populated area that is also prone to flooding with a history of high-water levels, as shown in the Spatial Analysis of Urban Physical Vulnerability in Yogyakarta City, which identified areas with high building density as highly vulnerable to disasters, including flooding [25]. Therefore, a water level monitoring system is essential. The placement of the sensors is shown in Figure 4. Placement of Sensor 1 in Sagan Village and Figure 5. Placement of Sensor 2 in Iromejan Village.



Figure 4. Placement of sensor 1 in sagan village



Figure 5. Placement of sensor 2 in romejan village

Integration and System testing

At this stage, integration between the HC-SR04 sensor, NodeMCU ESP32, Firebase, website, and Telegram application is carried out. System testing includes sensor calibration, comparing sensor readings with manual measurements and calculating the error percentage, data transmission, ensuring that water level data is sent to Firebase every minute, website visualization, displaying data in the form of real-time graphs and Telegram notifications, and testing the delivery of warning messages when the water level exceeds the 100 cm threshold.

In addition, data pre-processing is carried out by averaging the results recorded at one-minute intervals to reduce fluctuations caused by surface ripples, as well as ignoring abnormal data such as zero values or readings that deviate significantly from normal points. This stage ensures that the stored data is more stable and accurate when visualized in the form of real-time graphs on the website [26].

Operation and Maintenance

The evaluation was conducted by testing the stability of data transmission to Firebase and real-time display on the website, as well as testing the speed of Telegram notifications when the water level exceeded the 100 cm alert threshold. In addition to the evaluation, the operation and maintenance phase was also carried out periodically to ensure that the system could function continuously in the field. Maintenance is carried out by cleaning the sensors of dirt or river debris that can interfere with measurement accuracy, checking the condition of the cables and NodeMCU connections to ensure they remain stable, and ensuring that the solar panels are not covered with dust or moss so that the battery charging process runs optimally. These maintenance steps are important to ensure that the device remains reliable in providing real-time water level information to BPBD and the surrounding community.

3. RESULTS AND DISCUSSIONS

The IoT-based water level monitoring system that has been developed has undergone a series of tests, including component testing, connectivity testing, and field implementation testing. The purpose of these tests is to ensure that the hardware and software perform as designed.

Working Principle of the System

This system works by utilizing the HC-SR04 ultrasonic sensor to measure the distance between the sensor and the river water surface in real time. The measurement data is processed by the NodeMCU ESP32 microcontroller, then sent to the Firebase database to be displayed via a monitoring website. The system is also equipped with automatic notifications via Telegram that will send early warnings if the water level exceeds 100 cm from the riverbed [27].

Results of Sensor Testing

The test was conducted by comparing the ultrasonic sensor readings with manual measurements using a tape measure at distances of 100 cm, 200 cm, and 300 cm. The test results are shown in Table 1. Ultrasonic Sensor Calibration.

Tabel 1. Ultrasonic sensor calibration

No	Manual Distance (cm)	Sensor Distance (cm)	Difference (cm)	Error (%)
1	100	100,02	0,02	0,02 %
2	200	200,52	0,52	0,26 %
3	300	310,60	10,60	3,54 %

The test results show an average error of 1.27%. This value is relatively small, so the sensor can be considered accurate enough to detect water levels. However, there is an increase in error at greater distances, especially above 300 cm. This may occur because the angle of reflection of the ultrasonic waves does not always return precisely to the sensor, and the condition of the water surface affects the stability of the reading. These findings are in line with the research by Djalilov et al. (2023), who also reported that the accuracy of ultrasonic sensors decreases at distances greater than three meters [28].

Website Implementation

Website monitoring testing was conducted to ensure that the display, connectivity, and data storage functions worked as designed. The test results show that the website is responsive and accessible via both desktop and mobile devices, as shown in Figure 6. Desktop Website and Figure 7. Mobile Website. These findings are in line with the study Design and Implementation of a Firebase-Integrated IoT-Based Flood Detection and Early Warning System [29], which shows that Firebase integration enables a responsive web display and real-time data delivery on mobile devices.

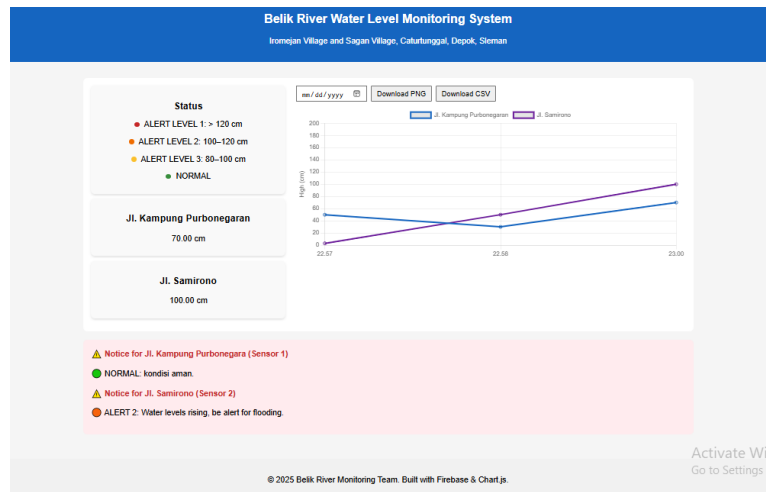


Figure 6. Desktop website

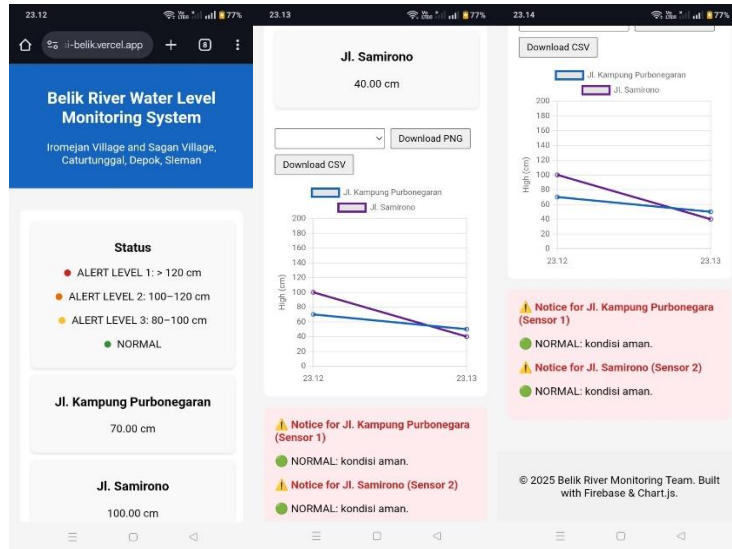


Figure 7. Mobile website

In addition, the website's connectivity with Firebase is stable, allowing sensor measurement data to be displayed in real time. This proves that the website can provide consistent water level information that is easy for users to understand.

Results of Telegram Notification Testing

The system is also equipped with automatic notifications via the Telegram app, which are sent when the water level exceeds 100 cm. An example of a notification is shown in Figure 8. Telegram Notification.



Figure 8. Telegram notification

Test results show that notifications are sent properly according to the programmed logic. Thus, this feature can support early flood warnings and provide information quickly to the public and the Yogyakarta City Disaster Management Agency (BPBD).

On-Site Implementation

The devices were installed at two locations, namely Jl. Kampung Purbonegaran. and Jl. Samirono, Belik River, Yogyakarta. Testing was conducted over three days with data transmission intervals of one minute. The average water level measurements from both sensors are shown in Table 2. Average Height of Sensor 1 and Sensor 2.

Tabel 2. Average height of sensor 1 and sensor 2

No	Date	Weather	Average Height of Sensor 1	Average Height of Sensor 2
1	20-07-2025	Bright	27,360	24,680
2	21-07-2025	Cloudy	30,390	27,420
3	22-07-2025	Bright	27,420	25,730

Test results show that both sensors are capable of detecting water levels stably. The average difference in water levels between the two sensors is influenced by the physical conditions of the river. Sensor 1 is in a wider area, so it holds a larger volume of water, and its height tends to be higher than Sensor 2. If the water level in Sensor 1 exceeds 120 cm, the Sensor 2 area has the potential to flood more quickly because the river is narrower and easily overflows. These findings are in line with research conducted by Hashemi-Beni et al (2024), which shows that physical differences in rivers have an impact on water level detection results [30]. The data sent to Firebase also corresponds to the actual conditions in the field. This shows that the system is stable enough to be used as an early warning tool for flooding.

System Analysis and Limitations

Overall, the system proved capable of monitoring water levels in real time, sending rapid notifications, and displaying data through an interactive website. However, there are several limitations that need to be considered. First, the system is still highly dependent on a stable internet connection for data transmission. Second, the error rate tends to increase when the measurement distance exceeds 300 cm. Third, the device must be installed in an open position without obstructions for optimal sensor readings. These limitations are like those reported in the study by Ratmini et al. (2025), which also noted dependence on stable internet connection [31]. However, this study has the advantage of interactive website-based data visualization and dual notifications via Telegram.

4. CONCLUSION

This research resulted in a water level monitoring system based on ultrasonic sensors and NodeMCU ESP32 that can detect water levels in real time. Based on testing, the average measurement error was 1.27%, with a higher error rate at greater distances due to the angle of reflection of the ultrasonic waves. The measurement data is sent to the Firebase server and displayed in real-time on a website with a responsive display on desktop and mobile devices in the form of numbers and graphs, making it easy for users to monitor. This website also provides early warnings when the water level exceeds 120 cm from the riverbed and automatically sends notifications via the Telegram application when the water level exceeds the threshold of 100 cm. Field tests at two points on the Belik River over three days showed that the system can operate stably and detect water levels according to actual conditions.

However, this study has several limitations, including that it was only conducted on the Belik River in Yogyakarta City and focused on measuring water levels without considering other factors such as flow velocity, rainfall, or drainage conditions. In addition, the system still relies on a stable internet connection to send data to the server. Therefore, for further research, the system can be developed by adding environmental parameters such as flow velocity and rainfall intensity, expanding the monitoring area, and integrating machine learning-based prediction models to improve the accuracy and speed of early flood warnings.

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