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Design of a Lora-Based Early Warning System for Watersheed Flood Disaster Using Data Logging

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Abstract

Flood disasters in river basins often occur due to high rainfall, poor river management, and poor land use. To minimize the impact, this study designed a LoRa (Long Range)-based early warning system in watersheds for efficient long-distance data transmission and reception. This system integrates ultrasonic sensors to monitor water level, Arduino Uno microcontrollers and NodeMCU ESP8266 for data processing, LoRa as a communication medium, and a web server for real-time data display, on the web server the water level is divided into 3 statuses, namely Safe (0-20CM), Beware (21-30CM), and Danger (>31CM). An email-based early warning feature is also used to alert the Hazard status when the water level >31 CM. Tests show that this system has a high level of accuracy in water level readings of up to 50 cm and data transmission up to a distance of 1,000 meters in optimal conditions. With the efficiency of communication and real-time analysis, this system can improve community preparedness for flood disasters.

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1. Introduction

Indonesia is a country located on the equator that has two seasons, namely the dry season and the rainy season[1]. Where the dry season occurs from May to October, and the rainy season from November to April[2]. The occurrence of the rainy season more or less affects the surrounding conditions to the point that it often causes disasters, namely floods[3]. In recent years, floods have become a frequent disaster in Indonesia, this is reviewed from the frequency of rain discharge and the length of time since the rain falls. Based on data from the National Disaster Management Agency (BNPB)[4]. The impact of this flood is indeed very extraordinary, houses are damaged due to flooding, household furniture items are washed away and damaged[5]. Flood disasters that have often occurred lately are still one of the focuses of attention. The reason is that the flood disaster caused many casualties, and also caused many losses, both material and psychological losses[6]. On the one hand, floods can actually be said to be an "ordinary" natural phenomenon because almost all countries have experienced and even routinely experienced them, including Indonesia[7]. Floods are seasonal threats that occur when water overflows from existing channels and inundates the surrounding area[8]. In other words, flooding occurs because the water capacity in rivers and waterways increases from their carrying capacity, so that the water in the area around the canal is flooded and causes flooding[9]. In the event of a flood, the water will inundate the entire plain that is usually not flooded before[10]. The causes of floods that often occur are factors from littering and the absence of rainwater absorption which results in the accumulation of garbage in the river which makes the river flow closed and clogged. Another factor is geographical factors where high rain intensity increases the risk of flooding[11]. Another factor is that the narrowing of river flows is caused by sedimentation and accumulation of garbage. Sedimentation comes from the erosion of river banks. In the rainy season, soil erosion occurs due to the soil being unable to withstand the pressure of rainwater[12]. This makes the environmental conditions in Indonesia diverse where this condition causes anxiety in the community when experiencing a sudden flood disaster that the community is not aware of. Therefore, the community needs to be given early warning so that they are better prepared to face the arrival of floods. Today's evolving technology allows us to connect water level monitoring with several devices at once. This technology is often referred to as IoT, which conceptually IoT is connecting surrounding objects using an internet connection. The growing internet infrastructure allows the internet to be connected not only with computers or smartphones but also with various other tangible objects[13].

From the research conducted by previous researchers, there are several studies on the development of flood warning systems that have been carried out, such as using flood detection devices using ultrasonic sensors as a measure of water level distance. With these sensors, the tools used have a high level of accuracy in previous studies[14]. In a similar study conducted by Ghasypam, et al. (2023) which detected the height and discharge of river water based on the Internet of Things which utilizes *waterflow* meter sensors to measure discharge and flow velocity, as well as ultrasonic sensors used to measure water levels[15]. Meanwhile, in other research, there is the use of communication and information technology such as mobile technology[16]. In previous research, LoRa applied to earthquake warning systems was referred to as *Chirp Spread Spectrum* (CSS) modulation technology that allows long-distance data transmission with low power [17]. In other research, it is also stated that LoRa is a network that has a fairly wide range[18]. Meanwhile, the disadvantage of using LoRa itself is that it allows interference because the system works on the IMS band where everyone can use the frequency according to the allowed device[19]. There are also several previous studies that use communication modules as needed, for example Arifin, et al. (2020) who chose to use the 433MHz RF module as data transmission to read water level sensors[20]. However, the module has a short range. So, in this study, the LoRa E220-900T30D module will be used as a communication tool.

The purpose of this research is to design a LoRa-based *flood early warning system*. The data obtained from the water level sensor will be transmitted using LoRa communication and will be displayed in real time or continuously and analyzed with certain parameter values for the parameter value of the flood itself. The value of the parameter that has a hazard status will be a reference for the flood early warning system, so that when the water level is in dangerous conditions, an early warning will be sent to the community to increase the response and alertness of the community in facing the upcoming flood.

2. Research Methodology

2.1 System Specification

The flood disaster early warning system is designed with the following specifications:

1. The parameter used for the flood disaster early warning system in river basins is the water level in the river, measured using an ultrasonic sensor.
2. The use of a LoRa Node, which consists of a microcontroller with a LoRa module for wireless communication.
3. Data or information is reported in real time, allowing for more accurate monitoring of variable pattern changes.
4. Data logging is utilized for evaluation to analyze changes in river water level patterns as a flood disaster warning.
5. When the water level rises to a dangerous level, a warning notification is sent to smartphones using the Gmail platform.

2.2 Hardware Design

This hardware design contains block diagrams which aim to describe the flow of the network work process or communication system.

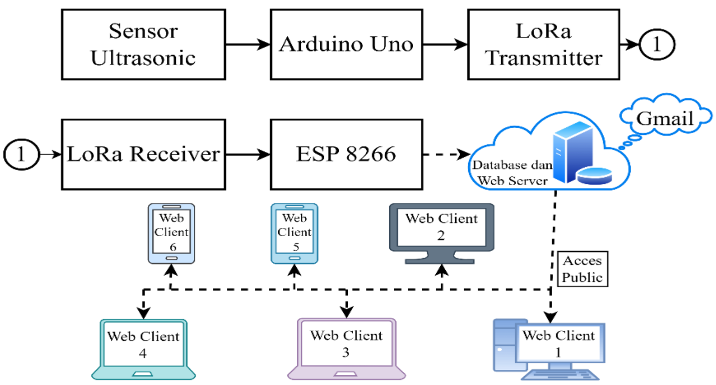

Figure 1. Diagram Block

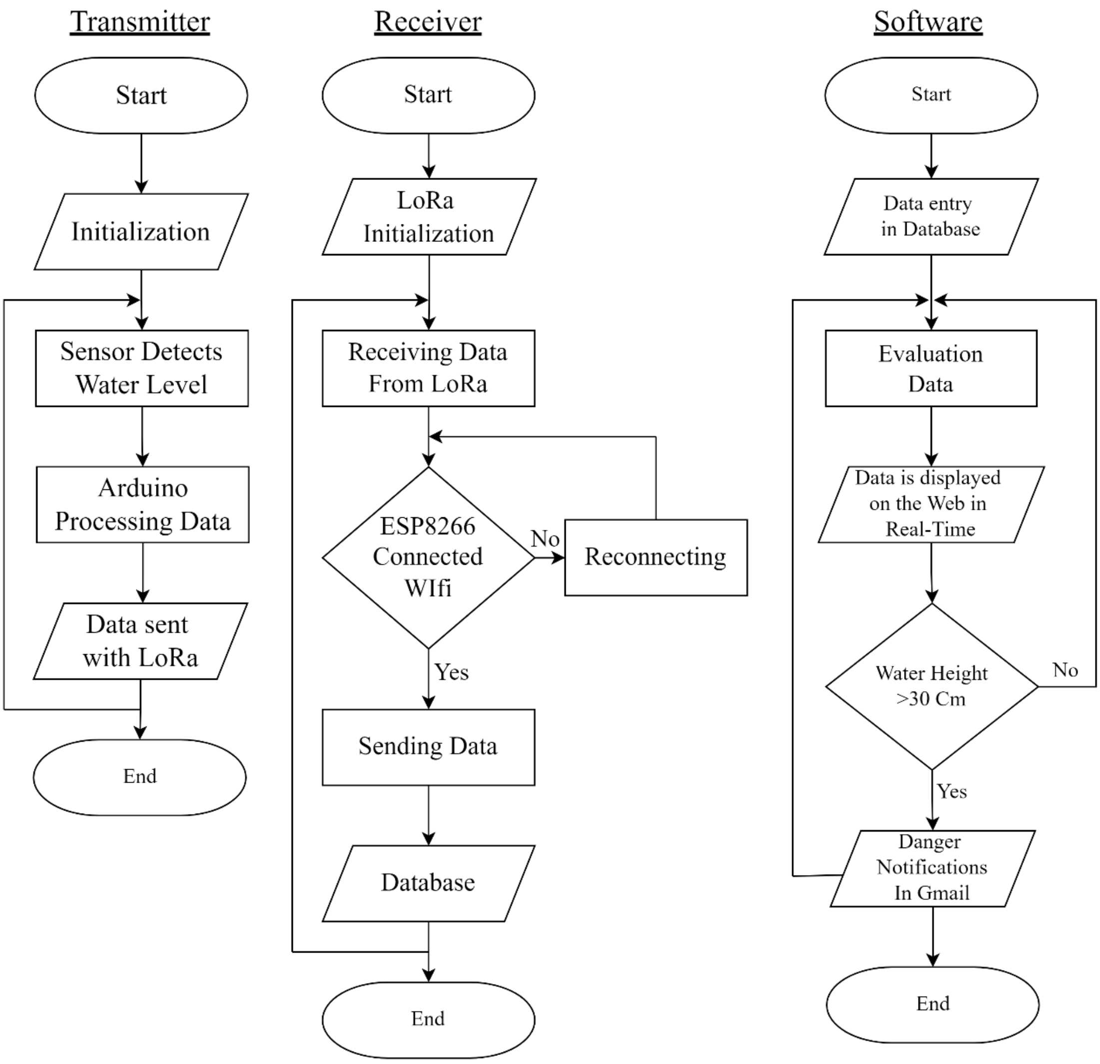

Figure 2. Transmitter, Receiver, and Software Flowchart

In Figure 1 shows a Block Diagram that starts with an Ultrasonic Sensor to detect water level, the data obtained will be processed by Arduino Uno which will then be sent using the LoRa Transmitter Communication media. After that the data will be received by the LoRa Receiver and the data will be processed in the ESP 8266 Microcontroller which will then be sent to the database and Web Server using the Wifi module on the ESP 8266, the database and web server contain data on water level and the status of the water level to be monitored in real-time, and data that meets the desired status (danger) will be sent to Gmail as an early warning notification.

2.3 Software Design

This software design contains flow diagrams of transmitters, receivers and software which aims to show the workflow process. In Figure 2, the Transmitter flowchart works by starting to initialize the program after that the sensor works by detecting the water level, the data obtained from the sensor will be processed by Arduino Uno where when the water level is more than 0 cm then the data will still be sent with LoRa Transmitter communication. Then the Receiver flowchart is by receiving data with the LoRa Receiver and connecting the ESP 8266 microcontroller after that the microcontroller will be connected to WiFi. Once connected, the data will be sent to the database to be collected. After that there is a flowchart starting with the data will be received by the LoRa Receiver which will then be processed in the ESP 8266, after the data is processed, the data will be sent by the ESP 8266 to the database. After the data arrives in the database, the data will also be displayed on the web server which will be monitored in real-time, and on the web server there are several water level statuses, namely Safe, Alert, and Danger. When the water level is at a danger status, the status will be sent to Gmail as an early warning notification, and when the water level status is not at a danger status, namely Safe and Alert, the status will not be used as an early warning notification and will not be sent to Gmail, and the status will still be displayed on the web server for monitoring.

2.4 Research Flowchart

This research flowchart contains the research steps taken to test the tools and systems that have been created with the aim of finding out whether they are working properly and correctly.

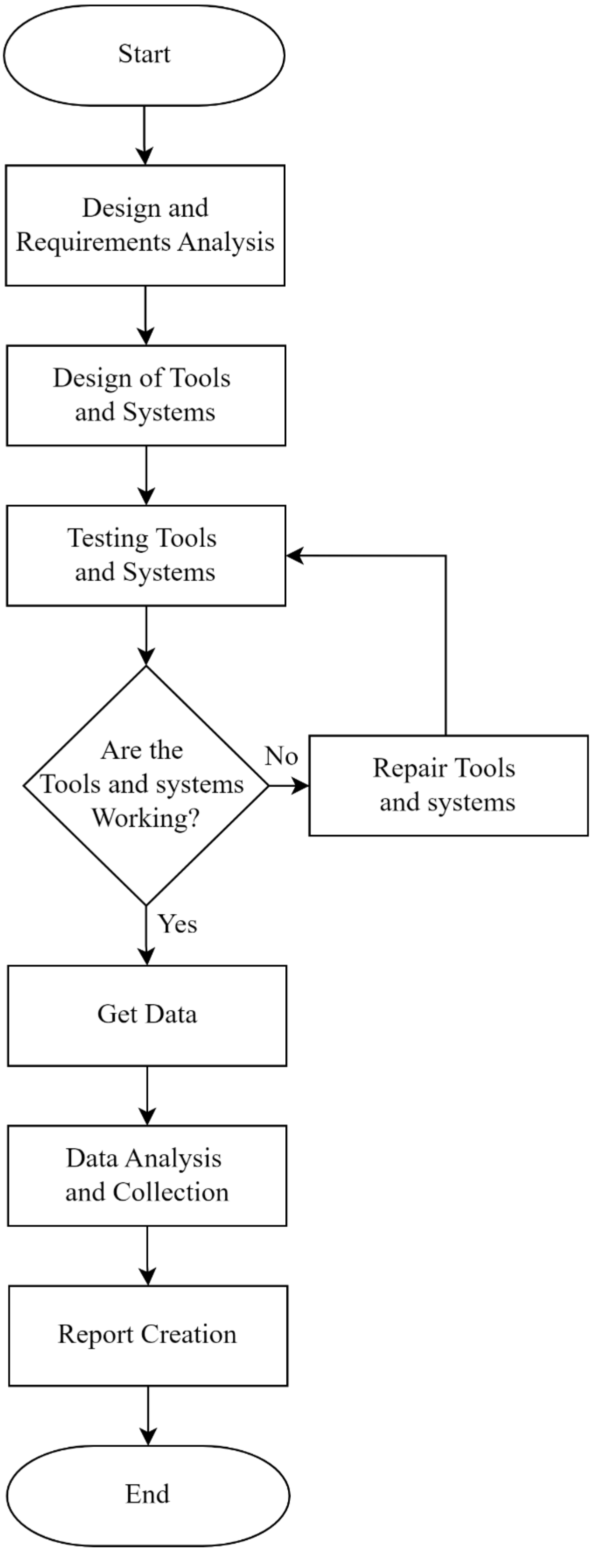

Figure 3. Research Flowchart

Figure 3 The flowchart contains the stages in the research process, namely starting with the design and analysis of needs which is continued with the design of the tools and systems to be created. Then the tools and systems that have been designed are made to be tested. In the testing process, an evaluation of the performance of the tools and systems will also be carried out if they do not function, repairs and retesting will be carried out. However, if the tools and systems function, it will proceed to the data collection stage and data analysis will be carried out which will be continued to make reports from the tools and systems that have been created.

3. Results and Discussions

3.1 Tool Design Results

3.1.1 Transmitter design

In this transmitter there is an Arduino Uno microcontroller, an Ultrasonic Sensor, and a LoRa module which is used to detect the water level and then the data will be sent. Figure 4 shows a tool from the Transmitter system that works using an Arduino Uno which is used to control and control the sensor and LoRa module, then the reading results from the ultrasonic sensor will be sent wirelessly with the LoRa module.

3.1.2 Receiver design

In this Receiver image there is an ESP 8266 microcontroller and a LoRa module which is used to receive data and send data to the database with the ESP 8266.

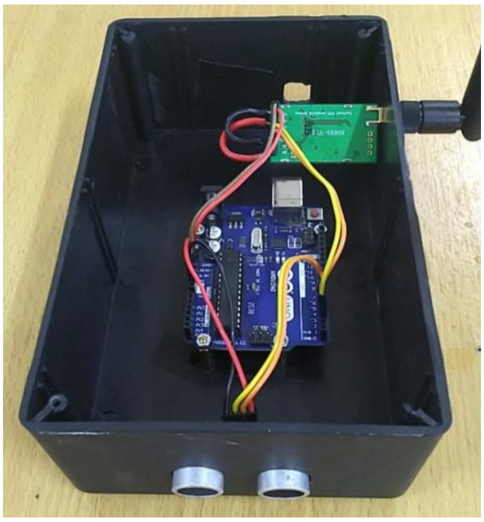

Figure 4. Transmitter display image

Figure 5. Transmitter display image

Figure 5 shows the equipment of the Receiver system using the ESP8266 microcontroller. In the Receiver system this time the LoRa Receiver module will receive data sent by the LoRa Transmitter, then the data will be processed by the ESP 8266 Microcontroller and there is also a WiFi module which functions to send the received data to the database and webserver.

3.2 Results of Tool and Systems Testing

3.2.1 LoRa Communication Test Results

At this point, we discuss the results of LoRa communication between the LoRa Transmitter and LoRa Receiver over several predetermined distances to find out at what distance LoRa communications can be connected and disconnected, and also discuss the packet loss percentage which aims to find out within a certain distance how many data packets are lost in the communication process between LoRa Transmitter and LoRa Receiver.

In Table 1. contains the results of the LoRa distance test where when the LoRa Transmitter and LoRa Receiver communicate, the communication results are stable at a distance of 0-1000 meters, and at that distance the packet loss percentage is relatively small. However, when the distance is >1000 meters, the packet loss percentage is greater, so that the data received takes a long time which results in many data packets being lost, so that communication becomes unstable and not connected. This is due to the many interference factors that occur and the many obstacles such as trees, houses, and buildings that cause data transmission to be disrupted.

$$Packet\ Loss\ Percentage = \left(\frac{Total\ Packet\ Loss}{Total\ Packet\ Sent}\right) X\ 100\% \quad (1)$$

The formula in number 1 is used to calculate the percentage of packet loss which aims to find out how many data packets are lost in LoRa communication. Where the smaller the packet loss percentage obtained, the more stable the communication, but the larger the packet loss percentage obtained, the more unstable the communication and results in communication being disconnected.

3.2.2 Sensor Data Capture Results

At this point we discuss the results of data collection obtained by ultrasonic sensors and also discuss the accuracy of readings from ultrasonic sensors. Where the ultrasonic sensor test this time tests by comparing the distance measured directly with the distance measured using the sensor.

Table 1. LoRa Communication Distance Data with Packet Loss Percentage

No	LoRa Communication Distance	Communication Status	Packet Loss (%)
1	100	Connected	0
2	200	Connected	2,86
3	300	Connected	5,06
4	400	Connected	8,75
5	500	Connected	9,88
6	600	Connected	17,78
7	700	Connected	36,26
8	800	Connected	39,36
9	900	Connected	40,20
10	1000	Connected	42,72
11	1100	Not Connected	74,8
12	1200	Not Connected	79,3
13	1300	Not Connected	81,4
14	1400	Not Connected	87,2
15	1500	Not Connected	92,7

Table 2. Comparison results of real data and sensor simulations

No	Real Distance (CM)	Sensor Distance (CM)	Error (%)	Status
1	5	4	20	Safe
2	10	9	10	Safe
3	15	13	13,33	Safe
4	20	18	10	Safe
5	25	26	4	Beware
6	30	30	0	Beware
7	35	36	2,86	Danger
8	40	41	2,5	Danger
9	45	44	2,22	Danger
10	50	49	2	Danger
	Average Error		6,7	

In Table 2. are the results of the comparison of water level readings with real distance simulations and water level readings using ultrasonic sensors. This aims to determine the percentage of error in sensor readings with real distances. And also to determine the status or condition of the water level in accordance with the specified parameters, namely 0-20 with the status "Safe", 21-30 with the status "Alert", and 31-50 with the status "Danger". Then the formula for calculating the error is:

$$Error\ Percentage = \frac{|Real\ Distance - Sensor\ Distance|}{Real\ Distance} \text{ X } 100\% \quad (2)$$

The formula in number 2 is used to calculate the percentage of relative error in distance measurements made by a sensor compared to the actual distance (real distance). This formula is used to evaluate the accuracy of the sensor in measuring distance. A small relative error value indicates that the sensor has a high level of accuracy, while a large value indicates that the sensor is less accurate or needs to be recalibrated.

In Table 3. is a table containing water level data every 1 hour, where this is to find out the water level at that hour using the actual distance and the distance read by the ultrasonic sensor. then there is a percentage of error and also the status of the water level condition at that hour where at that time it was in a safe condition.

$$Average = \frac{Total\ data\ amount}{Amount\ of\ Data} \quad (3)$$

Table 3. Results of data collection in the river

No.	Time	Real Distance (CM)	Sensor Distance (CM)	Error %	Status
1	06.00	13	12	7,7	Safe
2	07.00	14	13	7,14	Safe
3	08.00	9	9	0	Safe
4	09.00	11	10	9,09	Safe
5	10.00	11	11	0	Safe
6	11.00	12	12	0	Safe
7	12.00	11	12	9,09	Safe
8	13.00	11	12	9,09	Safe
9	14.00	12	12	0	Safe
10	15.00	12	12	0	Safe
11	16.00	13	12	7,69	Safe
12	17.00	13	12	7,69	Safe
13	18.00	11	11	0	Safe
14	19.00	9	10	11	Safe
15	20.00	11	10	9,09	Safe
16	21.00	10	10	0	Safe
Average		11,43	11,25	4,84	

The formula in number 3 is a formula to calculate the average of the real distance, sensor distance, and average percentage error. In Table 3. the average real distance obtained is 11.43 and the sensor distance is 11.25 with an average percentage error of 4.84%.

3.2.3 Dashboard View on WEB SERVER

The dashboard this time contains the dashboard and water level data and also on the dashboard page contains a donut chart and bar chart which shows the status of water level conditions and also the frequency of the amount of data from that status.

Figure 6 contains a dashboard display where the dashboard display contains the frequency of the amount of data obtained from the water level status, namely Safe, Alert, Danger, and Not Detected. and the safe status is the most data obtained.

3.2.4 Display Water Level Data on WEB SERVER

At this point, the web page used for monitoring water levels displays which contains water level, status and time. Figure 7 shows the data that was successfully sent by the ESP 8266 microcontroller to a database connected to a web server that can be monitored in real time. On the web, there is a display of the total data received, then there is water level data, then water level status, along with the date and time the data was taken.

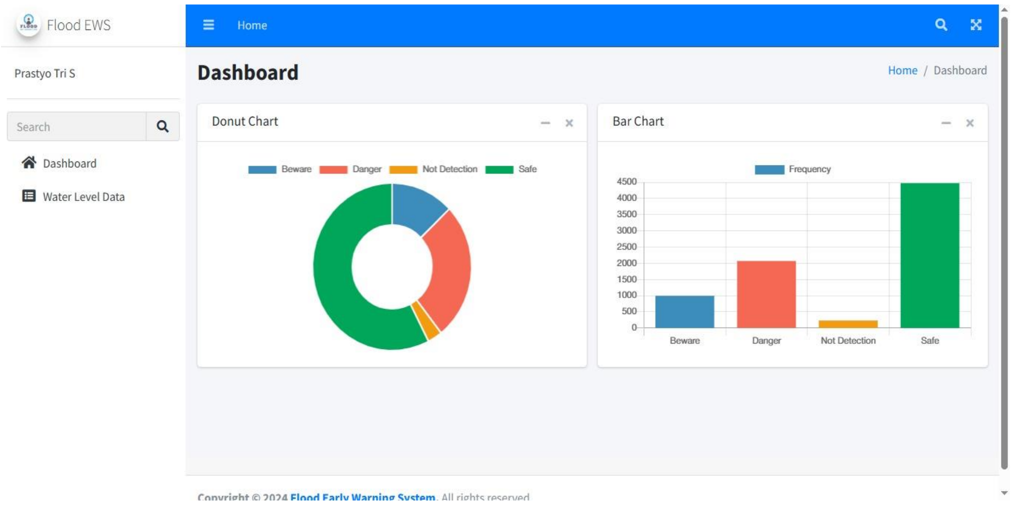

Figure 6. Dashboard

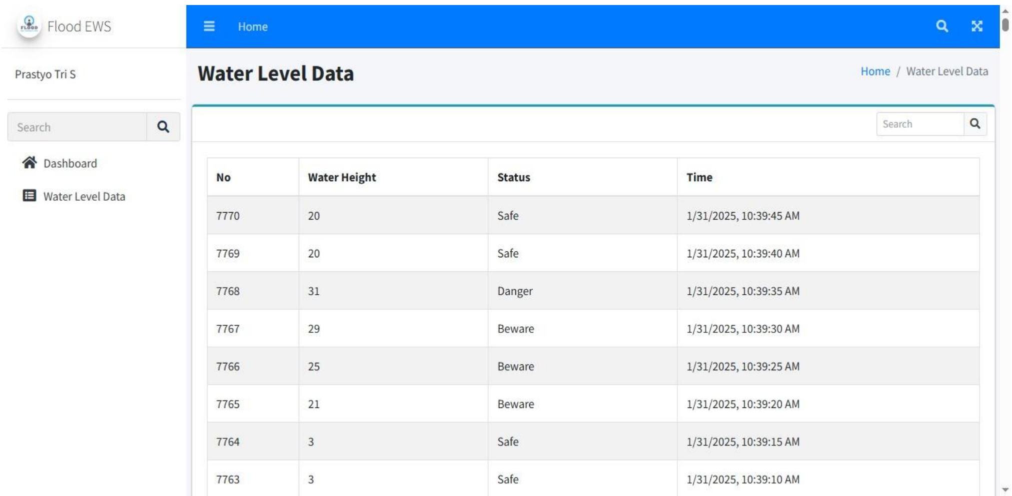

Figure 7. Web Monitoring Water Level

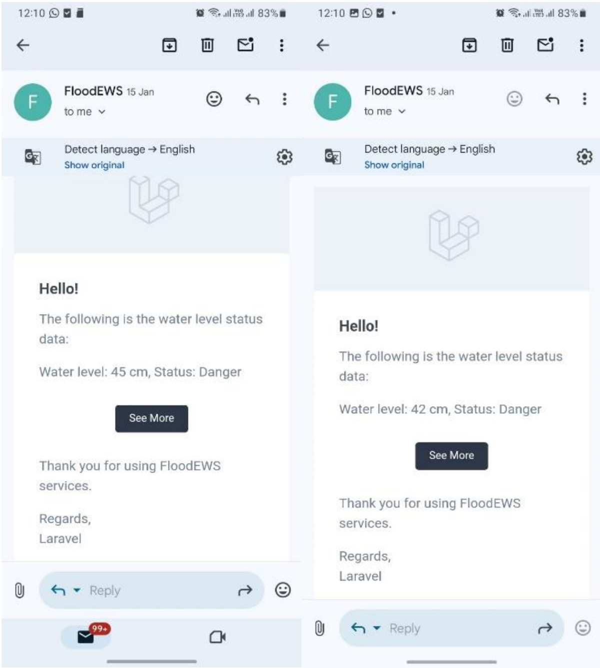

Figure 8. Notification View in Gmail

3.2.5 Notification Delivery Results

At this point, it shows the results of the display on Gmail which contains an early warning message, where when it is in danger status, an early warning message appears, but when the status is in a safe and alert condition, no early warning system message will appear.

Figure 8 shows the display of notifications in Gmail received by users. It is important to emphasize that the system only sends notifications via Gmail when the water level status reaches a danger condition as part of the early warning system. However, the complete history of water level status changes, including safe, beware, and danger conditions, can still be accessed through the monitoring page. Thus, while Gmail notifications are only sent for dangerous conditions, users can still view the overall status of water levels through the monitoring system.

3.3 Discussions

Based on test results, the system that uses an ultrasonic sensor to detect water level has an average error percentage of 4.84%. Meanwhile, other research[15] reported a lower average error percentage, namely 1.84% – 2.01%. This shows that the accuracy of the ultrasonic sensor in this research is still lower than previous research. These differences can be caused by several factors, such as the test environment conditions, the quality of the sensor used, or the calibration method applied. Therefore, further optimization is needed, such as improving data filtering methods or using sensors with higher specifications, to reduce error rates. Then the communication system used is the LoRa E220 900T30D Module, where this type of LoRa has a fairly long communication range and has a fairly strong communication signal, whereas in other research[3] a different type of LoRa is used so that the LoRa communication range is relatively lower and not far away.

Then in this research the platform used for monitoring water levels is used, namely using a website which makes it easy to monitor water levels directly and can be accessed by everyone, whereas in the same research[15] the platform used for monitoring water levels also uses the website but in a different display aspect where in this research it shows a more specific display of information so that the information read is easier for the public to understand.

As well as the use of email-based early warning messages when the status is dangerous, it makes it easier for people to receive these messages and message reception is quite fast when the internet connection is smooth, however in other research[21] there are SMS gateway-based early warning messages with a message reception delay of an average of 2 minutes or 120 seconds.

5. Conclusion

Based on the objectives and results of several tests that have been carried out, it is concluded that the remote flood early warning system can use Lora communication which is able to detect water levels in real time and send data to the database and web server and notifications via email. The system designed this time shows accurate results in sensor readings from 0-50 CM with an average error percentage of 6.7%, and obtained by the 1st day data collection experiment, an average error percentage of 4.84% was obtained. Then communication on the LoRa Transmitter and LoRa Receiver with a distance of 0-1000 meters has the ability to communicate with a smaller percentage of packet loss, while at a distance of> 1000 meters communication becomes unstable with a larger percentage of packet loss. data transmission up to a distance of 1000 meters. Then the sending of data from the ESP 8266 to the database depends on the Wifi connection used, where when the connection is slow, the data reaching the database will be slow, and when the connection is fast, the data will arrive at the database faster. With this capability, the system can be a fairly effective tool to reduce the impact of flooding through fast and reliable early warning. The use of technologies such as LoRa, ultrasonic sensors, and web-based platforms, enables continuous monitoring and data analysis that supports better decision making. In the future, developments can be made by increasing the number of sensors for wider coverage and more complex data management.

The suggestion in this title is for further development to increase the number of sensors that aim to improve the accuracy of data collection and more accurate information about water levels. And optimization is needed on the LoRa module communication media so that there is no delay in incoming data, so that the data obtained can be more accurate and early warning notifications can be sent and received faster to the community. And other developments can be towards creating applications on smartphones that allow people to monitor directly from their smartphones and get notifications more easily, so that flood preparedness can be improved.

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