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HYDRALERT: AN ARDUINO-BASED FLOOD EARLY WARNING SYSTEM FOR FLOOD-PRONE SCHOOLS IN THE PHILIPPINES

HydrAlert: An Arduino-Based Flood Early Warning System for Flood-Prone Schools in the Philippines

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ABSTRACT

Title: HYDRALERT: AN ARDUINO-BASED FLOOD EARLY WARNING SYSTEM FOR FLOOD-PRONE SCHOOLS IN TAGUM CITY

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This study explores the development of HydrAlert, an Arduino-based flood monitoring and alert system for schools, designed to monitor water level and alert students and school administrators whenever an impending flood is imminent. HydrAlert was programmed to display real-time water level data using the HC-SR04 ultrasonic sensor to accurately measure data. This study's primary objective was to provide a functional, low-cost solution for real-time flood monitoring and an early warning system at the school level. It also aimed to develop and evaluate the usability, practicality, and accessibility of HydrAlert's system. The accuracy measurement for water detection showed an average of 0.40% percentage error across all 12 trials, while the SMS alert response evaluation showed a 100% success rate, with an average of 7.42 elapsed seconds. The system shows consistency in alerting the community in times of flood-related disasters. Its current limitations include the possibility of the system lagging, which delays the SMS response, and the system's occasional lagging. In general, HydrAlert shows potential as a flood monitoring and alert system if further developed, with additional refinements and recommendations to improve its performance, error-handling, and accuracy for a wider applicability in real-time and real-world applications.

CHAPTER 1

INTRODUCTION

Flooding is one of the most destructive natural disasters in the world, which is made worse by climate change. Large-scale flooding incidents in recent years have severely damaged many nations. Severe flash floods in 2021 forced many to relocate and claimed over 200 lives in Germany and Belgium (BBC News, 2021). More than 33 million people were impacted by the record monsoon flooding that hit Pakistan in 2022, which inundated a third of the nation (UN News, 2022). Record-breaking rainfall in China's Henan province in 2021 caused major urban floods and forced hundreds of thousands to relocate (The Guardian, 2021). In order to minimize lives and damage to infrastructure, these worldwide calamities underscore the pressing need for enhanced flood control technologies and early warning systems.

During the occurrence of typhoons, low-pressure areas, and tropical storms, floods are commonly expected, and the Philippines is no exception to that, as this has become a regular phenomenon in the country. Rapid urbanization, blocked drainage, and typhoons have left urban areas in the Philippines helpless during a flood. On February 13, 2023, over 300 incidents of flooding, along with 30 incidents of landslides, were recorded by the National Disaster Risk Reduction and Management Council (NDRRMC), occurring in 8 regions across 22 provinces, with an estimated 90,000 citizens affected by it (Davies, 2023). During Tropical Storm Trami in 2024, the town of Talisay in Luzon was greatly affected, with at least 152 people missing or dead (The Associated Press, 2024). In July 2024, Mindanao was devastatingly hit by floods and landslides due to continuous rainfall in the area, with an estimated 500 families being displaced and over 800,000 people being affected by the disaster (*Daily Flash*, n.d.-b).

Flooding remains unsolved in many barangays of Tagum City. Canals overflow, and drainage systems are clogged. During December 2024, a flash flood in Barangay Magdum forced over 100 families to evacuate, highlighting the crucial need for improved early warning systems (GMA Regional TV News, 2024). Earlier in January 2024, Davao del Norte, including Tagum City, was put under a state of calamity due to widespread flooding that affected 64 barangays and damaged many infrastructure (Davao Today, 2024). Incidents like this emphasize the importance of practical, community-based solutions to enhance disaster preparedness.

This study will focus on developing an Arduino-based flood monitoring system called HydrAlert in some flood-prone schools in Tagum City. To inform the residents, the researchers propose assembling and programming a unit that will automatically activate them via LEDs, a buzzer, water level sensors, and an SMS. This prototype will then be tested by the researchers to measure the reliability and responsiveness of flood simulation scenarios.

HydrAlert aims to partner with Tagum City in enhancing flood preparedness at the school community level. In addition, this early flood warning system allows local government units to warn flood-prone schools in a more effective and inexpensive way during major flooding events. The system involves students in issues and their environments and fosters intelligent systems for disaster risk reduction. This project has the potential to serve as a model for other school areas in Mindanao facing similar challenges.

CHAPTER 2

METHODOLOGY

This chapter presents a detailed discussion of the research design, process model, project mechanisms, hardware setup, project testing procedures, and data analysis.

Research Design and Process Model

This study utilizes a quantitative and qualitative-experimental design to evaluate the performance, reliability, and accuracy of the flood monitoring alert system for flood-prone schools in Tagum City. Quantitative data on the system’s water levels, response time, and SMS success rates. On the other hand, qualitative data on the system's behavior, stability, and responsiveness.

Theoretical Framework

The figure below illustrates the theoretical framework of the project. The framework illustrates the scientific and technological concepts that guide the system's accuracy to detect rising water levels, trigger alerts, and send SMS notifications to support flood preparedness in schools around Tagum City.

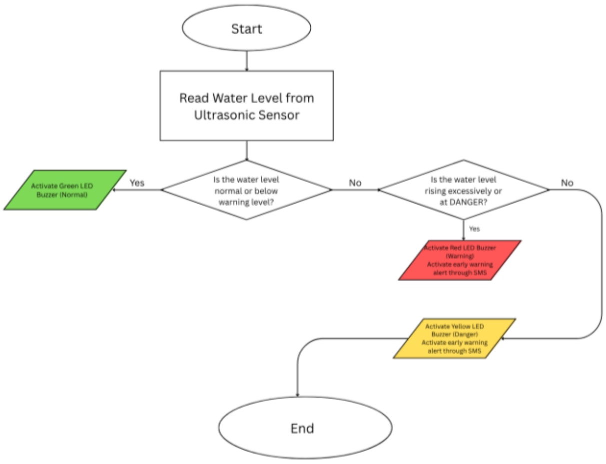


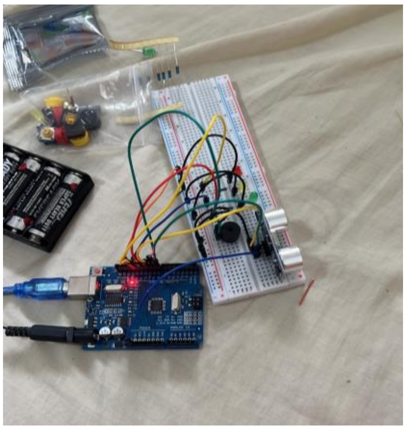
Figure 1. Decision-Making Flowchart of the System

Hardware Systems

The Hardware Systems of HydrAlert consist of actuators and electronic components that interact with the software to enable flood detection, flood monitoring, and alert functions. These systems include the Actuation System, Alert System, Display System, Communication System, and Power Management System.

Preparation and Assembly

The researchers gathered the materials locally, specifically from CreateLabz and local hardware stores. The figure below illustrates the assembly of the system.



Actuation System

The Actuation System of HydrAlert is composed of several subsystems. These include the Visual Alert Subsystem, Audible Alert Subsystem, Communication Subsystem, and Dashboard Display Subsystem. These subsystems enable HydrAlert's primary functions in detecting flood levels, providing early warnings, and communicating alerts to ensure the safety of flood-prone schools.

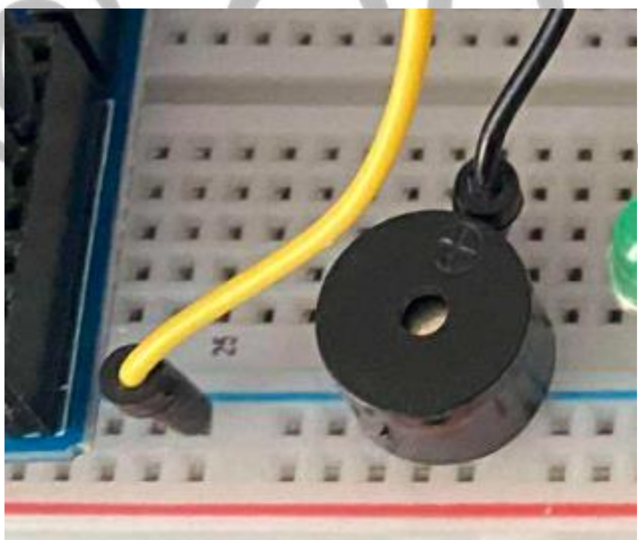
Visual Alert Subsystem.

On the breadboard prototype, the system utilizes three LED indicators: Green (*Safe*), Yellow (*Warning*), and Red (*Danger*) that indicate different flood levels. On the other hand, the dashboard display uses four alert indicators: Green (*Safe*), Yellow (*Caution*), Orange (*Warning),* and Red (*Danger*). This allows for a more detailed and precise visualization of the flood status. Each LED is connected to the Arduino through a 220-ohm resistor to regulate current flow. The Arduino IDE automatically switches between LED states based on the sensor's readings, providing clear and immediate visual feedback.

Audible Alert Subsystem.

This subsystem provides sound-based notifications. The Arduino is the main part that activates the buzzer when the system detects a warning or a dangerous water level. During the warning stage, the buzzer beeps short and intermittently, and during the danger stage, it beeps continuously. This ensures that even users who cannot see the LEDs can still recognize the system's alert status. The buzzer is programmed and controlled through the Arduino IDE, which regulates its timing and duration based on real-time sensor input.

Figure 3. Audible Alert System



Communication Subsystem.

This subsystem controls the remote alert transmission from the GSM module (SIM800L). When the water level reaches the danger threshold, the GSM module automatically sends an SMS to registered school employees or emergency contacts. The module communicates with the Arduino through the TX and RX pins, enabling data transfer for message sending. This subsystem increases the effectiveness of the early warning system by ensuring that residents receive flood warnings even if they are not physically present at the monitoring location.

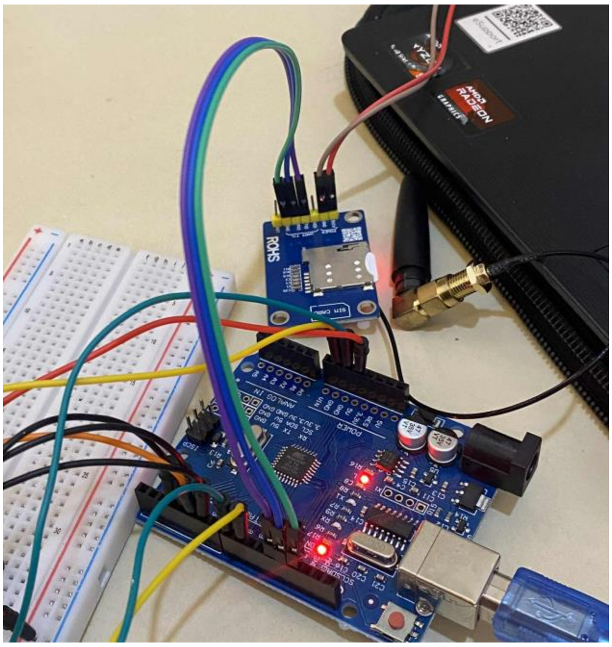


Figure 4. Communication Subsystem

Dashboard Display Subsystem.

This subsystem provides a real-time graphical interface for monitoring water levels and alert statuses. The dashboard shows four alert levels: *Safe*, *Caution*, *Warning*, and *Danger*. Allowing users to observe gradual changes in water levels. It also displays the system's current readings, alert history, and SMS confirmation status, giving users a clear overview of the system's performance during flood simulations. This subsystem enhances the usability and accessibility of HydrAlert, making it easier for users to interpret data and respond quickly in emergencies.

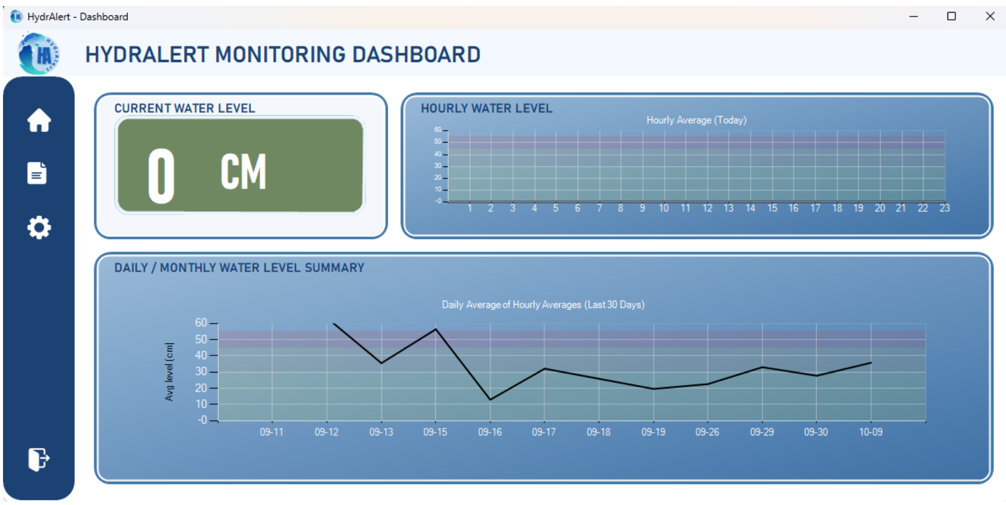


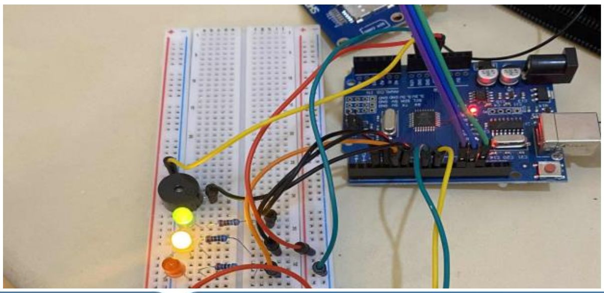
Figure 5. Dashboard Display Subsystem

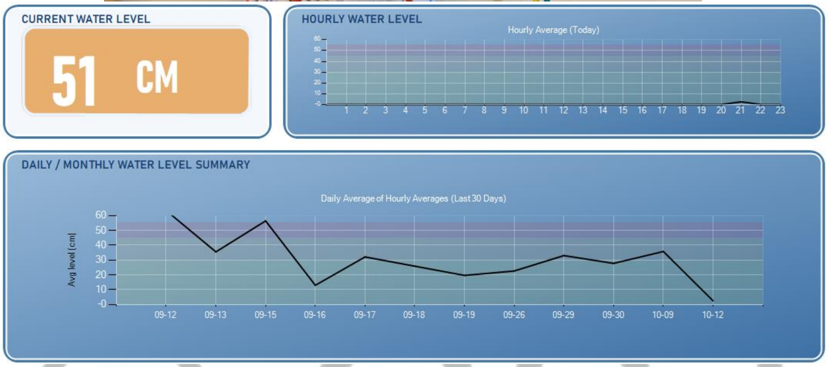
Alert System

The *Alert System* connects all the warnings together. Once the sensor detects that the water has reached a certain height, the Arduino turns on the LED lights and buzzer and sends a message to the GSM module. This allows the system to warn people in different ways—by lights, sounds, and text messages. The main goal of this system is to give early alerts so that the users can act fast during possible flooding.

Figure 6. Alert System

Display System





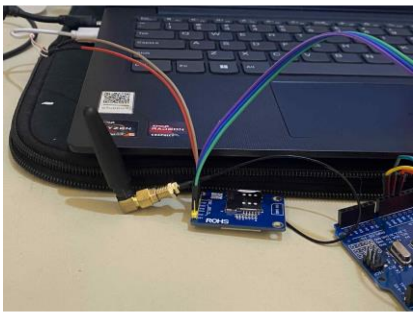
The *Display System* shows real-time data about the flood level through the HydrAlert dashboard. It displays the four alert levels: Safe, Caution, Warning, and Danger, so users can easily see what stage the flood is in. It also shows if the SMS alert has been sent. This helps the school administrators or disaster teams monitor the situation quickly without checking the hardware manually. The display system also shows hourly and daily reports of water by taking the peak water level in that specific hour or day and distributing that data using a line graph to visually present it.

Figure 7. Display System

Communication System

The *Communication System* sends flood alerts through text messages using the GSM module (SIM800L). When the system reaches the danger level, it automatically sends a message to the registered phone numbers of school staff or emergency responders. The GSM module communicates with the Arduino through TX and RX pins, which allow data to move between the two devices. This system makes sure that flood warnings reach people even if they are not inside the school.

Figure 8. Communication System



Power Management System

The *Power Management System supplies electricity to all the parts of the project. T*he system can be powered using a laptop or a USB power bank as its power source, which gives stable energy to the Arduino and connected parts. It also prevents overloading and ensures that HydrAlert continues to work even when power interruptions occur during storms.

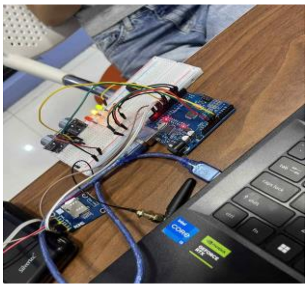


Figure 9. Power Management System

Software System

Detection and Processing System

This system processes the readings from the HC-SR04 ultrasonic sensor to determine the water level. The Arduino continuously measures the distance between the sensor and the water level in centimeters. As the detected distance becomes shorter, it indicates that the water level is rising toward the sensor. The system updates these readings in real time and sends data to the alert and dashboard systems to determine whether warning signals need to be activated.

Alert Programming System

This system controls both the physical and visual indicators of HydrAlert. On the device itself, the green LED represents *safe* conditions, the yellow LED indicates *caution*, and the red LED, together with the buzzer, indicates *danger*. These alerts are triggered automatically based on the distance received by the ultrasonic sensor. Together with the visual indicators, the system sends the corresponding alert level to the dashboard, where it is visually displayed by its corresponding colors: green for safe, yellow for warning, orange for caution, and red for danger, together with its measured distance.

SMS Communication System

This system controls the SIM800L GSM Module. It only activates when the water level reaches the yellow, orange, or red alert levels, ensuring that SMS notifications are sent only during potential or critical flood situations. Once the system is triggered, the Arduino communicates with the GSM Module through the TX and RX pins to send the SMS notifications and alert the users.

Coding System

This system is the brain of HydrAlert. It was developed using Arduino IDE, which uses the C++ programming language to control how sensors detect flood levels, how data is analyzed, and how warnings are issued, which makes the system automated, accurate, and responsive. A user-friendly interface using VB.NET is also used to display real-time water levels and system updates for easier monitoring. Without the coding system, the whole program would not be possible or would fail to operate.

Dashboard Interface System

The dashboard interface system serves as the visual part of HydrAlert. This system displays the real-time data, like the water level and alert status. It also allows users to monitor the flood condition without directly checking the hardware. It is developed using VB.NET for a simple and user-friendly design. The dashboard helps users respond quickly and efficiently when the water level rises.

Project Testing

Flood Simulation and Accuracy Measurement of Water Level Detection

To test the system's capability of monitoring water levels, as well as its ability to respond and alert to changes in water level, the researchers created a flood simulation by placing the ultrasonic distance sensor, which was connected to the main system, above a bucket with a height of 60 centimeters or 0.6 meters. The researchers manipulated the water level by adding a specific amount of water, starting at the base and gradually increasing it up to the top of the bucket. Within a 5-minute interval, the water level continued to increase until it reached the top.

While conducting this setup, the researchers recorded the measured distance displayed in the system's dashboard and the actual distance measured using a steel measuring tape. The data collected was double-checked by using the formula below to get the actual water level. This ensures the validity of the data that was recorded.

Actual Water Level (cm) = Tank Height (cm) - Sensor Distance (cm)

SMS Alert Response Evaluation

The system sends a text message that serves as a notification alert whenever the water level rises to a specific alert level. The system is programmed to send the message when it reaches the yellow, orange, and red levels, each level representing the rising danger of a potential flood. As the flood simulation test was conducted, the researchers also recorded the elapsed time before an SMS alert was sent to their respective phones. The timer started as soon as the specific water level was reached, and the timer stopped as soon as a text notification was received. This setup was repeated three times for each level, specifically, green, yellow, orange, and red.

After recording the data, a system response note was written. The system response note pertains to the qualitative observation of the speed at how fast the SMS alert was sent. These notes will be written and evaluated based on a predetermined set of response notes for each specific range of time.

CHAPTER 3

RESULTS

After conducting many trials for the flood simulation and the recording of data, HydrAlert has proven to be a successful tool for monitoring floods and alerting school administration to disasters. The system displayed its capability to accurately detect changes in water levels, immediately send alerts when critical levels were reached, and efficiently respond to simulated flood conditions. The results confirm that HydrAlert can serve as an effective early warning system, providing timely notifications that could help lessen the damage, enhance preparedness, and ensure public safety during real flood events. Each trial for the project testing consistently shows the improving performance of HydrAlert, as well as its reliability in times of disasters like floods.

Overall, the results demonstrate that HydrAlert functions accurately and consistently. It detects water level changes effectively and provides timely alerts through the buzzer, ultrasonic sensor, and LEDs. These results confirm the system's reliability and readiness for application in flood-prone schools in Tagum City.

Accuracy Measurement of Water Level Detection

Table 1. Accuracy Measurement of Water Level Detection

Alert Level	Measured Distance (cm)	Actual Distance (cm)	Percentage Error
Green	0	0	0.00%
Green	6	6	0.00%
Green	17	17	0.00%
Yellow	31	31	0.00%
Yellow	36	37	2.70%
Yellow	40	40	0.00%
Orange	45	45	0.00%
Orange	48	47	2.13%
Orange	50	50	0.00%
Red	55	55	0.00%
Red	57	57	0.00%
Red	58	58	0.00%
		Average Percentage Error	0.40%

Results. Accuracy Measurement of Water Level Detection

The experimental outcomes of the system show accuracy in determining the rising water levels and its efficiency in sending SMS flood alerts. Based on Table 1, the device achieved high accuracy in water level detection, with percentage errors ranging from 0.00% to 2.70%, with an overall average of only 0.40%, indicating that the ultrasonic sensor was able to produce precise and consistent readings throughout the testing period. This shows that the ultrasonic sensor provided consistent distance measurements with only minimal issues, which are likely caused by slight changes in sensor angle or water surface reflection during testing.

SMS Alert Response Evaluation

Table 2. SMS Alert Response Evaluation of Alert Level Green

Trial	Elapsed Time (s)	SMS Status (Sent/Not sent)	System Response Note

1	0s	Not sent	Normal reading, no alert
2	0s	Not sent	Normal reading, no alert
3	0s	Not sent	Normal reading, no alert

Table 3. SMS Alert Response Evaluation of Alert Level Yellow

Trial	Elapsed Time (s)	SMS Status (Sent/Unsent)	System Response Note
1	10s	Sent	Alert triggered, minor delay
2	6s	Sent	Alert triggered, minor delay
3	6s	Sent	Alert triggered, minor delay

Table 4. SMS Alert Response Evaluation of Alert Level Orange

Trial	Elapsed Time (s)	SMS Status (Sent/Unsent)	System Response Note
1	12s	Sent	Slight delay in SMS transmission
2	15s	Sent	Slight delay in SMS transmission
3	12s	Sent	Slight delay in SMS transmission

Table 5. SMS Alert Response Evaluation of Alert Level Red

Trial	Elapsed Time (s)	SMS Status (Sent/Unsent)	System Response Note
1	10s	Sent	Critical alert, SMS received
2	11s	Sent	Critical alert, slight delay
3	7s	Sent	Critical alert, SMS received

Results. SMS Alert Response Evaluation

For the *SMS Response Evaluation* (*Tables 2-5*), the system managed to successfully transmit all the messages from all alert levels: *Green, Yellow, Orange,* and *Red,* achieving a 100% SMS success rate across 12 total trials. The mean elapsed time for message transmission was 7.42 seconds. Although slight delays were observed, all messages were received without failure.

DISCUSSION

The accuracy measurement for water level detection, as well as the SMS alert response evaluation, indicates a high level of accuracy and reliability in monitoring flood conditions. For the measurement of water level detection, the results presented an average of 0.40% error, demonstrating the system's precision and consistency with the use of the ultrasonic distance sensor. The minimal percentage error suggests that the system's calibration and sensor positioning were effectively optimized to ensure accurate detection. Minor discrepancies, such as the 2.70% error observed in one of the trials, may be attributed to environmental factors—specifically, slight tilts in the sensor's alignment, ripples or movement on the water surface, and the natural delay in signal reflection. These variations, however, remain within an acceptable range for real-world applications, signifying that the device maintains its precision even under minor experimental inconsistencies.

The system's SMS alert system significantly showed successful results with its consistent readings and alert transmission. HydrAlert's alert system achieved a 100% success rate across all 3 trials per alert level, with an average of 7.42 seconds of elapsed message transmission time, showing that the GSM module responded quickly under different flood-simulated conditions. These results showed the efficiency of the SIM800L GSM module in sending real-time notifications. Although there were slight delays in the elapsed time that were recorded, ranging from 6 to 15 seconds, these results may be attributed to other variables that may have affected it, such as signal strength and network congestion.

Additionally, the hardware system's integration of visual, audible, and communication alerts enhances the system's performance in monitoring floods and alerting citizens in real-life applications. The dashboard interface also consistently provides real-time monitoring data during the project testing phase, and when applied in real life, it specifically provides hourly, daily, and monthly data to ensure organized records and easy accessibility to info for many users. This organized data recording system supports both local authorities and residents in making data-driven decisions for disaster preparedness and risk assessment.

The findings of this research demonstrate HydrAlert's capability and potential as a technological tool for flood resilience and monitoring. These indicate HydrAlert's potential to be improved, particularly by developing it into an accurate, responsive, and sustainable tool that can significantly strengthen flood preparedness and disaster resilience in local communities. HydrAlert ensures accessibility, transparency, and efficient data management, making it an effective tool for enhancing disaster preparedness among citizens.

CHAPTER 4

CONCLUSION AND LIMITATIONS

This study successfully developed HydrAlert, an Arduino-based flood early warning system created to help flood-prone schools in Tagum City improve disaster preparedness. The device uses an ultrasonic sensor to detect water levels and a GSM module, LED, and buzzer to provide real-time alerts. Through testing conducted at home using a customized 60 cm bucket, HydrAlert proved its capability of accurately detecting water level changes and triggering immediate notifications, showing its potential as a low-cost warning device.

The results show that the system gets triggered when the water level hits the set point. The GSM module performed its function flawlessly by delivering SMS notifications to the mobile numbers, and the buzzer and LED lights were also activated according to the plan. These results indicate that HydrAlert can be a great help for users by notifying them about the flooding, and therefore, it will be easier for the community and schools to make prior arrangements, and also they will be able to respond faster to the water level increase.

However, the study also faced several limitations during testing. The trial was performed only in a controlled environment at home, which does not fully represent real flood conditions where outer factors like debris, heavy rainfall, or unstable network signals may affect performance. Another major limitation was the device's vulnerability to a laptop's power. Since it must remain connected to the laptop to operate, the system could stop working during power interruptions or when the laptop battery drains. This also made testing hard because the device and laptop should not be wet.

Therefore, HydrAlert showed its capability as a simple yet helpful flood early warning system using affordable devices. To improve its reliability and performance, future studies should focus on field testing the device in actual flood-prone areas, developing a bold power source such as a rechargeable battery or solar supply, and designing a waterproof casing to protect the device. Addressing these improvements will make HydrAlert more durable, efficient, and suitable for real-world disaster response.

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