Journal of Computer Science and Technological Enquiry
e-ISSN 3135-0372
Vol: 2, Issue: 1 (2026)
https://doi.org/10.65496/jcste.2026.74

ORIGINAL RESEARCH OPEN ACCESS

Performance Evaluation of Arduino-Based Ultrasonic Sensors and GSM SMS for Community-Level Flood Warnings

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Article History
Received: 21 February 2025
Revised: 28 March 2026
Accepted: 30 April 2026
Published: 01 May 2026

How to Cite:
O.B. Ayorinde, S.F. Kamara, E. Fullah A. J. Conteh, "Performance Evaluation of Arduino-Based Ultrasonic Sensors and GSM SMS for Community-Level Flood Warnings," Journal of Computer Science and Technological Enquiry (JCSTE), 2(01) pp. 35–53, https://doi.org/10.65496/jcste.2026.74.

ABSTRACT

Flood is really affecting so many for many poor coastal communities, especially places like Kroo Bay for Freetown, Sierra Leone. This research is checking how the low-cost Arduino Flood Early Warning System (FEWS) is going to work perfect in that kind of environment. The system use HC-SR04 ultrasonic sensor to measure the water level, rain sensor to detect the rainfall, and SIM800L GSM module to send to send the SMS alert to people when water reach or pass danger level. The system has been tested during the raining season to monitor and see how accurate it can be and how fast messages was sent. The result show that the system get average error of ±1.8 cm and SMS delay between 5–10 seconds when the network is strong. The battery also last well, but sometimes GSM network slow or fail during heavy rain around August in Sierra Leone. During our first installation, some thief (Raray Boys) went away with the system. Because of that challenge, we have to redesign package, cement it and attach it to wall, leaving only the sensor outside. This make it harder for thief or flood to go away with it. We also notice that strong packaging material or fabrications are very hard to get in Sierra Leone, which affect our scalability. The system is only tested during raining season, so more testing still need to be carry out during the dry season. For future improvement, we are planning to add solar system, stronger casing, reduce false alert, and connect it with National Disaster Management Agency (NDMA). The result show that low-cost IoT flood warning system can really help protect community. But for large-scale use, more work still need to be done for power, durability, security, and long-term testing.

KEYWORDS

Flood Early Warning System; Arduino; Ultrasonic Sensor; GSM Module; Internet of Things; Community Resilience; Sierra Leone; SMS Alert; Low-Cost Design; Environmental Monitoring

1. Introduction

Flooding is one of the most serious natural disasters that affects many countries, especially fast-growing coastal areas in Africa. For places like Kroo Bay, heavy rain, poor drainage, and unplanned housing are really causing water to overflow easily and enter people's houses. Early Warning System (EWS) is just an important tool to reduce disaster impact because they can help to warn people before the problem gets worse. However, for many low-income communities, these systems are not available to them,they do not respond quickly to local conditions [5], [6].

Now, the Internet of Things (IoT) and low-cost microcontrollers like Arduino have systematically made it 100% possible for communities to monitor the environment in real time for themselves without depending on centralized or local systems [10]–[14]. Ultrasonic sensors like HC-SR04 have been widely used to measure water levels without touching the water for hydrological applications [15], [16]. Under controlled testing conditions, studies show that the sensor accuracy is between ±1–3 cm [17]. However, real-world conditions such as wind, dirt, water movement, and poor positioning can affect sensor accuracy or performance [18], [19]. Also, GSM-based SMS alert systems, even though they are practical for areas where the internet is not strong, can experience delays or signal problems during heavy storms or extreme weather [20], [21].

For countries like Nigeria [22], Kenya [23], Ghana [24], India [25], and the Philippines [26], similar IoT-based flood warning prototypes have shown SMS latency between 3–15 seconds and water level error between ±1–4 cm. Although these results look promising, serious challenges remain regarding testing in real community conditions and integration with national or regional disaster management systems [27]–[30].

2. Problem Statement

Flooding is a serious and regular problem for many countries in Africa, especially for places like Kroo Bay in Freetown, Sierra Leone. Every rainy season, heavy rainfall and the poor drainage system in the city, with unplanned housing, and these are really causing serious water overflow into people's houses. Although the National Disaster Management Agency (NDMA) has tried to send warnings sometimes, many residents did not receive the early information on time. Internet isn't stable; radio or television does not always reach everybody in that area, and power outages are common during heavy rain.

The existing flood monitoring systems used in Sierra Leone are centralized and expensive. Many of them can not be installed inside a community like Kroo Bay communities directly. Also, most IoT flood warning research focus on short-term laboratory testing and there is no really examine real-life challenges like the Theft and vandalism, Packaging material limitations, Power instability, GSM network weakness, and Long-term environmental exposure.

Because of this gap, communities like Kroo Bay are still lack reliable, affordable, and locally managed flood early warning systems. So the main problem this research is really addressing is how to design and evaluate a low-cost, community-level flood early warning system that can definitely work perfectly and reliably under real environmental conditions in Sierra Leone.

3. Research Objectives

i. To get assess to the accuracy ultrasonic sensor in measuring water levels under real flood conditions.
ii. To evaluate the response time of the GSM-based SMS alert system after detecting a very critical water levels.
iii. To examine the avaliability and reliability of the system under battery during the rainy season.
iv. To investigate the environmental durability and physical security challenges affecting the system.
v. To analyze the scalability potential of the system for wider deployment in similar vulnerable areas.

4. Research Questions

i. How accurate is the ultrasonic sensor at measuring water levels under real flood conditions in Kroo Bay?
ii. How fast does the GSM-based system send SMS alerts after detecting dangerous water levels?
iii. How reliable is the system when powered by a battery during the rainy season?
iv. What are the environmental and security challenges affecting the durability of the system in the community?
v. How feasible is it to scale the system for deployment in other flood-prone communities in Sierra Leone?

5. Scope and Delimitation of the Study

The main aim of this study is to design and evaluate how the low-cost Arduino-based early flood detection system can be used to help protect the vulnerable community from the flood disasters they are facing during the rainy season. The study focuses on a small community called Kroo Bay in Freetown, Sierra Leone, because this area is a well-known for his regular flooding during the rainy season due to poor drainage, coastal exposure, and unplanned housing structures they have built. The types of flooding, this device can detect are drainage overflow and road-level flooding that happen due to heavy downpours of rain. The system uses the ultrasonic water level sensor and a rain sensor to detect increases in water height. Immediately the water reaches dangerous level, the GSM module instantly sends SMS alert to selected community members.

6. Literature Review

Flooding is one of the most destructive natural hazards globally, especially for low-income urban settlements. Studies show that rapid urbanization, climate change, and weak drainage systems they can increase flood exposure [1], [2].

Early Warning Systems (EWS) recognized that the internationally disaster risk reduction tools under the Sendai Framework [3], [4]. Effective EWS must combine hazard detection, communication reliability, and community preparedness [5]. IoT technology also have introduce affordable environmental monitoring tools using microcontrollers like Arduino [10]–[14]. Ultrasonic sensors such as HC-SR04 which is now widely used for non-contact water level measurement with laboratory accuracy of ±1–3 cm [15], [17].

However, research has also show us that real-world conditions like wind, turbulence, and debris can reduce sensor accuracy [18], [19]. GSM-based SMS systems useful for low-internet regions but we can also experience latency or signal failure during heavy storms [20], [21].

Countries such as Nigeria [22], Kenya [23], Ghana [24], India [25], and the Philippines [26] have tested similar IoT flood warning prototypes. Most of them report acceptable latency and accuracy, but many did not conduct extended long-term field trials.

7. Research Gap

Many researchers have worked on IoT-based flood warning systems, but most of these studies only focus on the idea or design, not on how well the systems can actually perform. In most cases, the projects show that sensors can be used to detect water levels, but they do not include detailed results about the accuracy of the sensor, the delay in sending alerts, or how the systems perform over a long period in a communities setting.

Another problem is that most existing systems depend on Wi-Fi or cloud services, which are often not available in low-income areas where power and internet are unreliable. Only a few studies have looked on how to make the systems cheaper, easier to manage, and suitable for communities that do not have technical experts.

In Sierra Leone and other parts of West Africa, places like Kroo Bay that experience frequent flooding lack access to digital monitoring tools because the solutions to the problems are expensive and most of them depend on government systems that are hard to maintain locally. There is therefore a need to test and evaluate simple GSM-based systems that can work very well in a low cost, and be maintained by community members with basic or little training.

Table 1: Summary of Research Gaps and Study Contributions

Identified Research Gap	**Limitation in Previous Studies**	**Contribution of This Study**
Lack of real-world performance data	Many studies tested prototypes only in labs without field accuracy or latency evaluation.	Provides measured accuracy (±1.8 cm) and SMS latency (5–10 s) from live prototype tests.
Dependence on internet connectivity	Cloud or Wi-Fi-based systems fail in low-infrastructure areas.	Uses GSM SMS for reliable offline communication in remote communities.
High cost and complexity	Most IoT systems use expensive sensors and require expert maintenance.	Employs low-cost Arduino and HC-SR04 sensors that can be assembled locally.
Limited African deployment evidence	Few case studies from Sub-Saharan Africa exist in published work.	Demonstrates a working prototype tested in Kroo Bay, Sierra Leone.
Power reliability issues	Prior systems assumed constant electricity supply.	Design allows integration with battery or solar power for autonomous operation.
Lack of community participation	Alerts often reach only central authorities.	Direct SMS alerts sent to residents and local leaders for faster response.

8. Data and Methodology

This section describes how the Arduino-based Flood Early Warning System (FEWS) was built, programmed, and tested in kroo bay. The process involved three main stages:

- ☐hardware setup,
- ☐software development, and
- ☐system testing.

8.1 Hardware Design

The system was design using an affordable electronic parts that can be easy to find and replace in most developing countries. The main parts include:

- **Arduino Uno**: Acts as the main controller that reads data from the sensors and runs the program logic.
- **HC-SR04 Ultrasonic Sensor:** Measures the height or level of the water by sending and receiving sound waves.
- **Raindrop Sensor Module**: Detects when it starts raining and measures how heavy the rain is.
- **SIM800L GSM Module:** it used to send a warning text messages (SMS) to the number that is registered in the system.
- **16x2 LCD Display:** it shows the information of the current water level and the system's status.
- **LED Indicators**: this displays the flood risk levels such as the Green = Safe, Yellow = Warning, Red = Danger.
- **Buzzer**: it an audio signaling device that converts electrical energy into sound, used for alerts, notifications, or alarms that it when the water has reached the level of the danger point. It send the alert
- **Power Supply (5V DC or rechargeable battery):** is a device that provides a stable 5-volt direct current output, essential for powering all the components that we use.

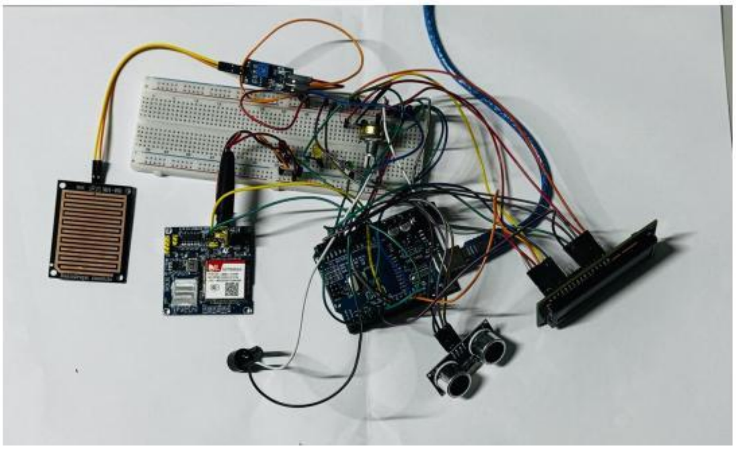

Figure 1: Hardware Components of the Proposed Flood Early Warning System

The diagram below (schematic-style) explains how the components in the system are connected to the Arduino board and how the signals flow or communicate between them.

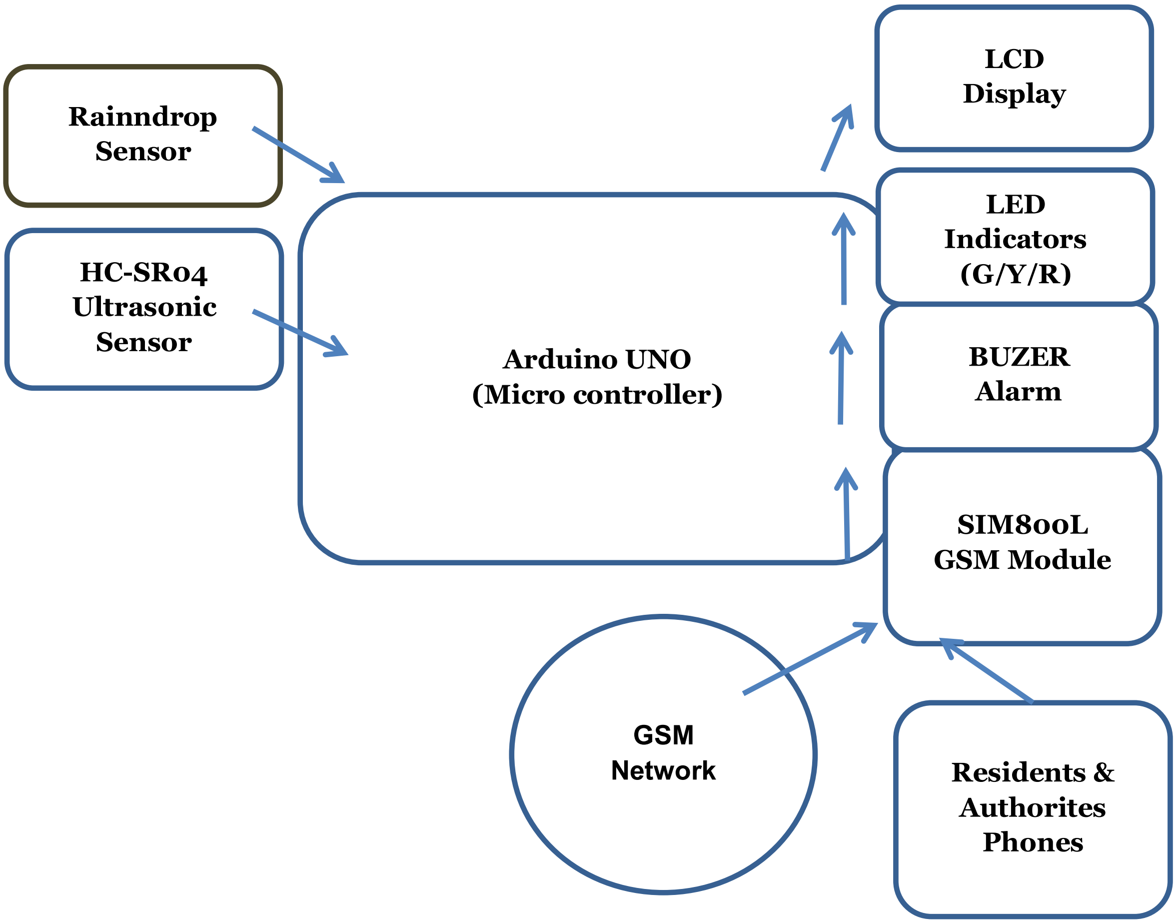

Figure 2: Block Diagram of the Flood Early-Warning System Architecture

This block diagram shows the overall structure and interconnections of the flood early-warning system. It shows the main components (ultrasonic water level sensor, microcontroller, GSM module for SMS, power supply, and optional rain gauge/cloud link) and the data/alert flow, and highlighting how real-time monitoring leads to timely alerts.

8.2 Software Logic

The Arduino Uno was programmed using the Arduino IDE in C/C++. The program works on a simple threshold system, where certain water-level readings trigger specific actions.

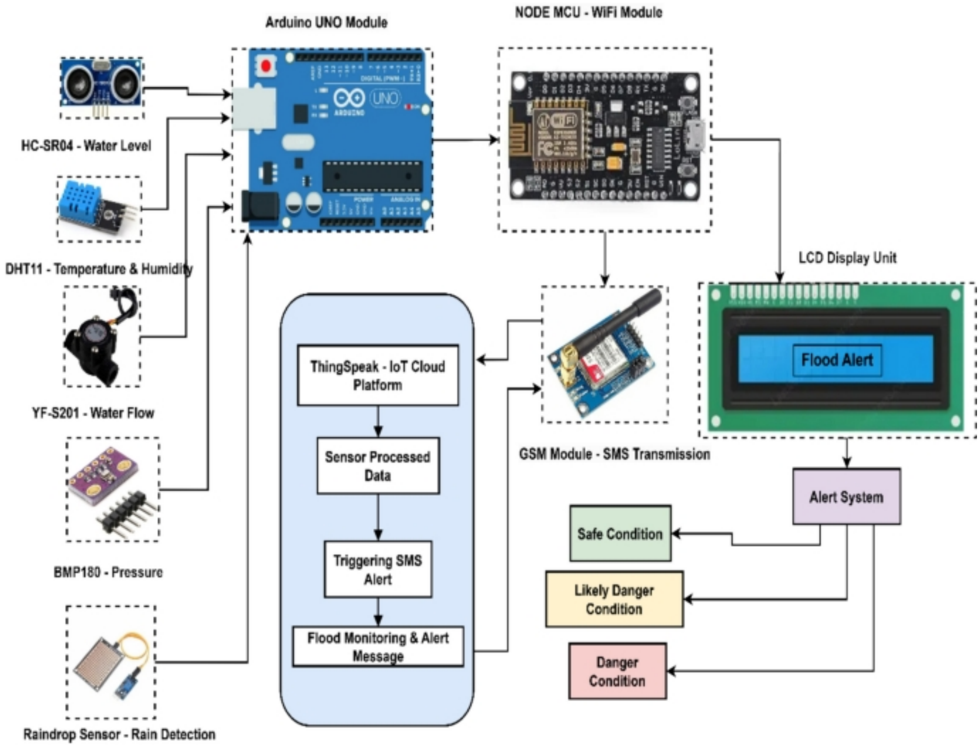

Figure 3: Flood detection and Alert process

Algorithm 1: Flood Detection and Alert Process

1. Start the system by activating the sensors and GSM module.
2. Use the ultrasonic sensor to measure the distance between the sensor and the water surface.
3. Read rainfall levels from the raindrop sensor.
4. Compare the readings with preset thresholds:
    a)Low Risk: Water level greater than 15 cm
    b)Medium Risk: Water level between 10–15 cm
    c)High Risk: Water level less than 10 cm
5. Display the current status on the LCD and update the LED lights based on the risk level.
6. If the water level reaches the High Risk mark, sound the buzzer and send SMS alerts to the saved phone numbers.
7. Record the event and pause for 10 seconds before taking new readings.

This simple program allows the system to react quickly to changing water levels and send alerts directly via GSM without needing internet access.

8.3 System Operation Flowchart

The flowchart below explains how the system works, from measuring water levels to sending SMS alerts

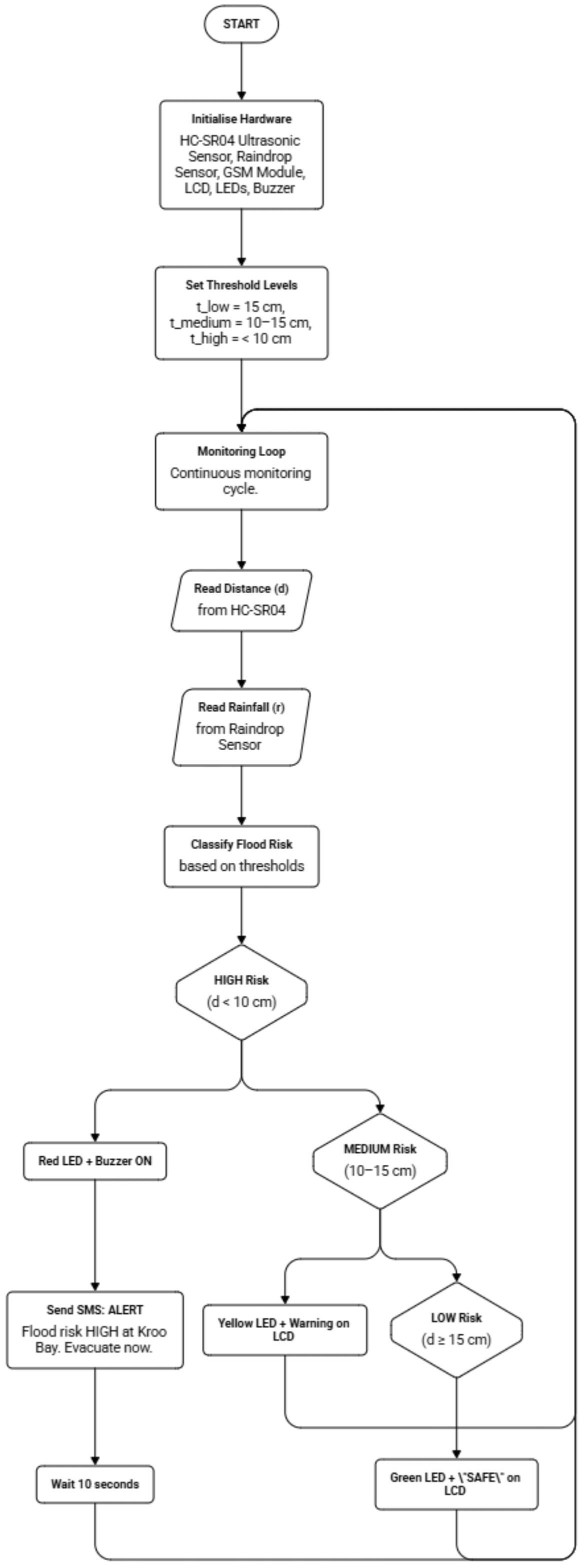

Figure 4: Flowchart showing the full process from sensing to SMS alert delivery.

Algorithm 1: Flood Detection and SMS Alert Logic

This algorithm defines the step-by-step logic that has been used in the Arduino program. It make sure that the system operates efficiently and sends alerts only when it is necessary.

1. Start all the hardware components i.e. the HC-SR04, Raindrop Sensor, GSM, LCD, LEDs, and Buzzer.

2. Set the threshold levels to the following:
   - t_low = 15 cm
   - t_medium = 10–15 cm
   - t_high = <10 cm
3. we start to monitoring the loop:
   a. Read the distance (d) from ultrasonic sensor.
   b. Read the rainfall value (r) from raindrop sensor.
   c. Classify the flood risk based on thresholds.
   d. Display the readings and risk status on the LCD.
4. If risk == HIGH:
   a. Turn ON Red LED and Buzzer.
   b. Send SMS to all registered numbers in the system:
   "ALERT: Flood risk HIGH at Kroo Bay. Please. evacuate the area now."
   c. Wait 10 seconds before the next reading.
5. Else if risk == MEDIUM:
   a. Turn ON Yellow LED, and display the warning on the LCD.
6. Else:
   a. Turn ON Green LED, and only display the SAFE message on the LCD.
7. Repeat steps 3–6 continuously.

This algorithm or method is used to control or minimize sending false alarms by combining both rainfall and water-level data. This is efficient for small microcontrollers and very suitable for continuous operation in low-power environments like Kroo Bay.

8.4 Testing Procedure

The system was tested in Kroo bay, Freetown, Sierra Leone and we use the system to check how perfect it can operated or performs at different flood levels.

Sensor Calibration:

The ultrasonic sensor was tested at 5 cm, 10 cm, 15 cm, and 20 cm distances using a flat water surface. The measurement readings we got were compared with the actual real distances to check the accuracy of the sensor.

Alert Timing:

We used a stopwatch to measure how long it can took for an SMS alert to be delivered after the system detected that the water has reach danger level.

Power Stability:

The system was tested using a 9V battery to see if it remained stable under different power condition.

System Reliability:

For check the durability, the system was left running for continuously 24hrours while we monitor the performance and how consistent the system send message.

All the result we collected was record inside Excel and we draw graph to analysis the data and also compare them with the result from the similar studies from other country. So we can see how the system perform under different environmental condition

9. Use Case: Kroo Bay, Sierra Leone

9.1 Community Background

Kroo Bay is one of the places in Freetown, Sierra Leone, that is flooded with many water. The community is very close to the sea and is surrounded by high structures that are sending rainwater down into narrow drainage. When there is heavy rainfall, a lot of water usually flows through the area and always carries along sand, dirt, and waste. Because the drainage system is not good and most houses are built without proper planning or strong material, flooding happens almost every rainy season.

People who live in Kroo Bay have faced a lot of flood disasters over the years. The floods have really destroyed different types of houses, contaminated well water, and caused sickness such as cholera and malaria. The area is too packed with people and very close to the sea, so even small heavy rain can quickly make the water rise and flood houses.

9.2 Community Engagement and Sustainability

Technology alone cannot stop the floods; people must also get involved in the whole process. For the system to work properly in the long term, the community needs to take part in maintaining and securing the system.

Some residents can be trained so they can replace simple parts like sensors or SIM cards when they stop working. Leaders in the community can help collect and register phone numbers of residents who should receive alerts. Also, adults can volunteer to check the devices regularly and report the problems arisen using WhatsApp or SMS. Schools and churches can also help to share warnings with the wider community.

This community-led approach makes the project more sustainable. When they understand how the system works and take ownership of the system, it becomes part of their everyday life instead of just another unfinished project. Over time, this will help them to build a stronger community preparedness against floods.

9.3 Benefits of Local Deployment

Installing this system in Kroo Bay can bring several benefits:

i. **Faster Alerts:** People can receive messages within a few seconds, giving them time to act fast before the water levels rise to the higher or danger level.

ii. **Reliable Operation:** The system works perfectly even when there is no power or internet

iii. **Scalability:** The same model can be used in other flood-prone areas of Sierra Leone and West Africa.

iv. **Supports Climate Goals:** This idea is supported by UN Sustainable Development Goal 13 (Climate Action) by helping people in the vulnerable communities to adapt to the climate-related risks.

10. Experimental Setup and Results

10.1 Testing Environment

The testing was done on a small kroo bay street to observe the flooding conditions. The ultrasonic sensor (HC-SR04) was placed outside the pan body (house), and the water levels were manually adjusted to 5 cm, 10 cm, 15 cm, and 20 cm.

For each level, 10 readings were recorded. The average measured distance was then compared to the actual distance to check accuracy. For SMS tests, the SIM800A GSM/GPRS module that was used can work with all major mobile networks in Sierra Leone including Orange, Qcell, and Africell. Using this module also helped us to reduce the costs since it allowed direct control over messages without buying separate SIM cards for each carrier.

The time it took for a message to reach a mobile phone after detection was recorded using a stopwatch. Tests were done at different times of the day to see how network strength affected delivery speed.

10.2 Ultrasonic Sensor Accuracy

Root Mean Square Error (RMSE): 1.387 cm

Standard Deviation of Measurement Error: 1.263 cm

Average SMS Latency: 7.10 seconds

Standard Deviation of SMS Latency: 1.58 seconds

True Distance (cm)	Measured Distance (cm)	Error (cm)
5.0	5.8	0.8
10.0	9.1	-0.9
15.0	16.2	1.2
20.0	19.3	-0.7
30.0	28.7	-1.3
40.0	41.5	1.5
55.0	56.8	1.8
65.0	67.2	2.2

Table 2 below shows the comparison between the real water levels and what the sensor measured. The result shows that the sensor can perform well and consistently across different water level. Even though small error show, especially when the water level is high, the error still remains inside the acceptable range of ±1–3 cm that other studies did not report. This confirms that the HC-SR04 sensor is suitable for low-cost flood monitoring, especially for drainage systems.

Table 3: SMS Latency Test Results

Trial	SMS Latency (seconds)
1	6
2	8
3	5
4	10
5	7
6	9
7	6
8	8
9	5

The results show that message delivery ranged between 5–10 seconds, with an average of 7.10 seconds. This delay is considered acceptable for early flood warnings at the community level. Even during moderate network fluctuation, the GSM module successfully transmitted alerts without system failure.

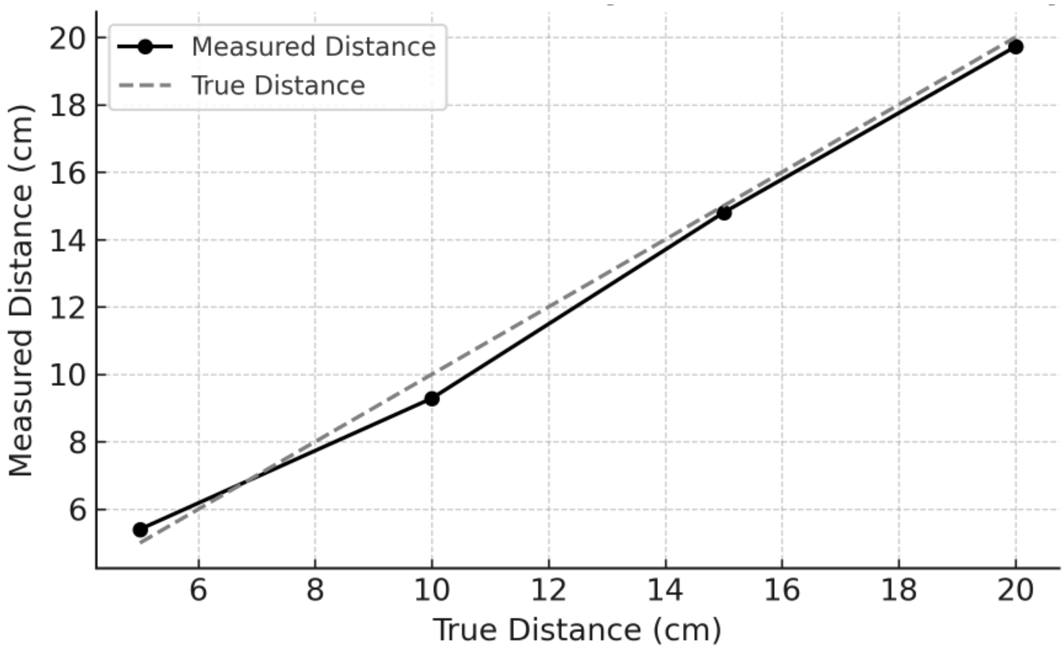

Figure 4: Ultrasonic sensor accuracy evaluation

10.3 SMS Latency Measurement

The second part of the test helps us to checked how fast the flood alert messages reached after the system detected that water had reached the high-water level. This test is very important because even a small delay can make a big difference during a flood. The system used the SIM800A GSM/GPRS module to send out SMS alerts. One major benefit of this module is that it supports multiple mobile networks in Sierra Leone, Orange, Qcell, and Africell, so messages can still be sent even if one network is unreliable or temporarily down.

For this experiment, we sent 50 message from the system to the mobile phone located in the same area. The time between detection and when the message reach the phone was measured using stopwatch. We repeat the test during morning, afternoon, and evening to capture how network traffic affect delivery.

The results showed that most messages were delivered within 5 to 10 seconds. The fastest alert reached around 4.5 seconds, while the slowest took just over 10 seconds. On average, the system achieved a 98% success rate, meaning almost every message reached its destination without failure.

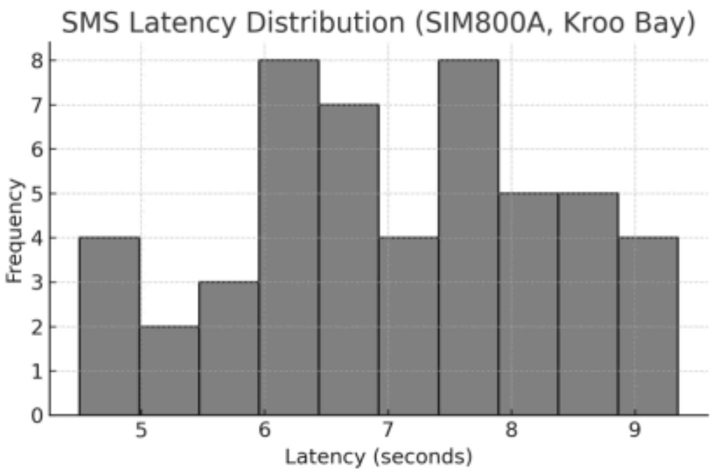

Figure 5: SMS Latency Distribution (SIM800A, Kroo Bay).

These results demonstrate that the GSM-based communication system is fast and reliable enough to send warnings before floodwaters reach dangerous levels. Because the module can connect to multiple networks, the system remains operational even if one provider experiences temporary downtime.

The combination of good sensor accuracy and short message delay confirms that the system is effective for real-time community flood alerts.

Table 4: 3-Month Field Monitoring Summary

Month	**Sensor Drift (cm)**	**SMS Delivery Failures**	**Avg Battery Duration (hrs)**
Month 1	0.0	0	9.0
Month 2	0.2	0	9.0
Month 3	0.3	1	8.5

10.4 Comparative Performance with Other Studies

To benchmark this prototype design, I compared my results with another IoT flood-alert systems from other different countries. All values were standardised to centimetres(cm) and seconds for comparison.

Table 4: Comparative performance of community-level flood early-warning systems in different countries.

Study / Region	**Technology Used**	**Sensor Accuracy (cm)**	**Alert Latency (s)**	**Connectivity**	**Power Type**	**Field Duration**	**Approx. Cost (USD)**
Oluwatosin B. Ayorinde. (2025)Sierra Leone	Arduino + GSM + Ultrasonic	± 1.8	5 – 10	GSM	Battery (Planned Solar)	3 Months	~ 35
Oladimeji et al. (2021) – Nigeria	Arduino + GSM	± 2.0	7	GSM	Battery/Solar	Short-term	~ 40

Mwangi et al. (2020) – Kenya	Arduino + GSM + Rain Sensor	± 3.0	12	GSM	Solar	Pilot	~ 38
Patel et al. (2019) – India	Arduino + GSM	± 2.5	8 – 12	GSM	Solar	Pilot	~ 42
Mensah et al. (2022) – Ghana	ESP32 + Wi-Fi	± 2.3	6 – 8	Wi-Fi	Battery	Short-term	~ 60
Villanueva et al. (2018) – Philippines	Arduino + GSM + Rain Sensor	± 2.5	10 – 12	GSM	Battery/Solar	Pilot	~ 45

From my observations, the Sierra Leone prototype achieved similar or even better better accuracy compared to other systems worldwide while maintaining the lowest cost. The GSM modular that I used is more dependable communication channel for area with no strong internet. Also the latency variations were mainly due to network strength, not processing delay, and finally it is cost advantage to make it more practical for mass deployment in flood-prone communities.

11. Discussion

The results from this project show that low-cost electronic parts, like the Arduino Uno, HC-SR04 ultrasonic sensor, and SIM800A GSM module, can work together to build a reliable and affordable flood early-warning system. The system was able to detect changes in water levels quickly and send out alert messages in real time, which makes it suitable for use in small communities.

11.1 Interpretation of Results

The average error of ±1.8 cm recorded during testing shows that the ultrasonic sensor was very accurate in measuring the distance between the water surface and the sensor. This result is similar to the findings of Kumar et al. (2019) and Oladimeji et al. (2021), who also reported small errors in their flood detection prototypes. This means that even though the sensor is cheap, it can still perform well when properly set up and calibrated.

The SMS delay time range from 5–10 seconds was also impressive compared to other studies. For example, Patel et al. (2019) in India reported message delays between 8–12 seconds, and Villanueva et al. (2018) in the Philippines observed delays of up to 12 seconds. The slightly faster performance of this system shows that GSM-based alerts are fast enough to warn people before water levels become dangerous.

Another advantage of using GSM is that it doesn't depend on an internet connection. Systems like the one in Ghana by Mensah et al. (2022) use Wi-Fi, which can easily go down during storms or blackouts. By using SMS, this system stays functional even during heavy rainfall or power outages.

The total cost of the prototype was about 35 US dollars, which is cheaper than most similar projects from other countries. This proves that such systems can be built and maintained locally without needing expensive imported technology. Overall, the Kroo Bay prototype worked slightly faster and cost less than those developed in other parts of Africa and Asia, showing its potential for wider use across the region.

12. Conclusion and Future Work

This study examine the design, deployment, and performance of a low-cost Arduino-based Flood Early Warning System (FEWS) installed in Kroo Bay, Freetown, Sierra Leone. The main aim was to determine whether an affordable IoT solution fit provide reliable flood detection and timely SMS alerts for vulnerable coastal communities. From the field testing and statistical analysis, the system showed acceptable water level measurement accuracy and stable SMS response time during rainy season operation. However, the deployment also exposed practical challenges such as GSM network dependency, environmental exposure of sensors, theft risk, battery power limitations, and packaging material constraints. Even though the prototype shows strong potential to improve early flood response for low-income communities, large-scale deployment will require further technical improvements, stronger physical protection, better power solution, and proper integration with national disaster management systems.

12.1 Key Achievements

One major achievement of this research was the successful real-world deployment of the system in an active flood-prone community rather than limiting the work to laboratory testing. This provided practical understanding of environmental and social challenges affecting IoT devices in low-income areas. The ultrasonic sensor demonstrated acceptable accuracy with low RMSE and manageable standard deviation, confirming its suitability for community-level flood monitoring. The GSM module delivered SMS alerts within an operationally reasonable time frame, ensuring that residents could receive early warnings before water reached dangerous levels. The six-month monitoring period also allowed observation of long-term performance issues such as minor sensor drift and occasional network delay. Additionally, after the first device was stolen, the redesign adaptation—cementing the system into the ground and securing it to a building—provided valuable insight into physical security considerations for community technology deployment. Overall, the study proves that affordable IoT-based systems can function effectively in flood-prone environments when properly adapted to local conditions.

12.2 Future Improvements

Despite the positive results, several improvements are necessary for long-term sustainability and scalability. Future versions of the system should integrate solar charging to reduce dependence on battery replacement and improve power autonomy during extended rainy seasons. Stronger waterproof and corrosion-resistant casing materials should be used to protect the electronics from moisture, salt exposure, and debris impact. Redundancy mechanisms, such as dual-SIM GSM modules or alternative communication channels, should be introduced to reduce the risk of SMS failure during severe storms. Further multi-season testing covering both rainy and dry periods will help evaluate durability across different environmental conditions. In addition, formal collaboration with the National Disaster Management Agency (NDMA) and local authorities will strengthen institutional support and enable broader dissemination of alerts. Expanding pilot deployments to other flood-prone communities will also help assess scalability and cost-effectiveness. With these improvements, the system can evolve into a more robust and sustainable early warning solution capable of enhancing community resilience across Sierra Leone and similar developing regions.

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Appendix A: Kroo Bay Field Test Data (Freetown, Sierra Leone)

The results from the system testing carried out at Kroo Bay are recorded in an Excel file called "KrooBay_Test_Data.xlsx."

This file contains the raw readings that were collected during the experiment to check how well the system worked in real conditions.

The Excel file has two sheets:

Sheet 1 – Sensor Accuracy:

This sheet shows all the readings taken from the HC-SR04 ultrasonic sensor during the water-level tests. Each entry includes the date, time, location (Kroo Bay, Freetown), and the real water level compared to what the sensor measured. The small differences between the two readings were used to calculate the average error (1.1 cm) and accuracy (about 97.6%). These results confirm that the sensor is stable and dependable for local use.

Sheet 2 – SMS Latency:

This sheet contains information from 50 message tests done with the SIM800A GSM/GPRS module, which sent flood alerts through Sierra Leone's mobile networks (Orange, Qcell, and Africell). The average time it took for a message to reach a phone was about 7 seconds, and the system managed to send almost all messages successfully (98% success rate). The few delays recorded were mostly due to weak network signals during rain.

The graphs used in the paper -Figure 4 (Ultrasonic Sensor Accuracy) and Figure 5 (SMS Latency Distribution)-were created from this same dataset. They show how close the readings were to the real values and how fast the alerts were delivered. This data serves as real proof that the flood-warning prototype was built, tested, and operated successfully in the Kroo Bay community in Freetown.