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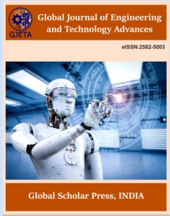

(RESEARCH ARTICLE)

Design of a flood management web-based system to facilitate effective decision making and communication during flood events

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Abstract

This study presents a flood management system designed to bridge the gap associated with timely flood prediction. The system combines real-time data collection, expert systems, and multi-channel alert systems to predict flood event. The project consists basically of the transmitting unit and the receiving unit. The Wireless Sensor Network gathers all the sensor data (such as Pressure, Humidity, Temperature, Rainfall and Waterlevel) then node-mcu (ESP8266) uploads them to the thingspeak webpage and transmits the data to the receiver for processing and decision making. The receiver sends the processed signal on the feedback with respect to some preset conditions for the waterlevel (which are 28.59cm for Normal range, 23.50cm for Warning range, 17.89cm for Critical range) and once the critical range which is the danger range is met, the notifications such as alarm, light and SMS are sent to alert the residents. From the table of values in the designed prototype, the critical range of 17.80cm was detected at time 14:26pm on the 3rd August, immediately this threshold was reached, the buzzer alarm continued to beep steadily, the Light bulb was turned ON, an SMS was sent to the registered mobile number. The message was delivered at 14:28pm as shown in the result analysis. This shows a very prompt response time in the face of a flood event. The bulb and alarm alerts remained ON until the water level returned back to the normal range.

Keywords: Expert System; Flood Monitoring; Multi-channel Alert System; Real-time Data; Wireless Sensor Networks

1. Introduction

Flooding remains one of the most destructive natural disasters which have increased in frequency and severity due to climate change and leading to devastating social, economic, and environmental consequences. The negative impact that flooding brings to the society at large each year is quite alarming considering the level of destruction incurred in the process. Every single reoccurrence of this disaster necessitates more proactive, coordinated, efficient and timely flood management strategies to combat this threat and hazard to humanity. In Nigeria, the menaces and aftermath that the flooding of September 13, 2022 brought to most communities were completely disheartening; some communities were inaccessible and virtually cut off from goods and services, there was no form of physical activities, school children had to quit schools in affected areas, no market for supply of foodstuffs, there was general poverty in the land to the highest

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degree [1]. In Anambra, Rivers and Bayelsa States, people had to rely on boats as major roads had been destroyed [2]. In Rivers State, communities close to the riverine areas "slept with their eyes open" as the direction of the flooding was unpredictable.

Many traditional flood management approaches lack real-time monitoring and effective communication, which hinders proactive decision-making. Harun et al. [3] developed a WSN-based flood monitoring system that provided real-time water level monitoring for early warnings. Wu et al. [4] further enhanced this by incorporating machine learning algorithms to improve the accuracy of flood predictions. Liu et al. [5] explored decision-making frame works using data-driven approaches and expert systems to predict flood scenarios. These systems provide decision-makers with recommendations based on historical data and current environmental conditions. Venita et al. [6] proposed a warning and alert system to monitor flooding. There were 4 types of alert given; green bulb which indicated no danger, orange bulb which indicated low level danger, blue bulb indicated medium danger and red bulb indicated high danger. Each colored bulb was turned ON in each of the alerts. In all these, there still exist some gaps in the area of effective communication via the use appropriate notification systems in the face of a flood event. Thus, it became so imperative that a flood management system is designed to bridge this gap by combining real-time data collection, expert systems, and multi-channel alert systems. The system uses a prototype to facilitate decision-making and communication among emergency services, government agencies, and the public during flood events.

2. Material and methods

Weather Station method was used for collecting and monitoring real time meteorological data and hydrological data using a distributed network of sensors that communicate wirelessly. A prototype was also designed which consists of a transmitter unit and a receiver unit.

2.1. Material

The materials required for the implementation of this research include; temperature and humidity sensor (DHT11), air pressure sensor (BMP180), rain sensor (FC-37), ultrasonic sensor (HC-SR04), waterflow sensor Goso F50-5V, Node MCU Microcontroller (based on the ESP8266 Wi-Fi module), GSM Module (SIM800L), light control NPN transistor (BC547), light alert 10W AKT bulb, buzzer circuit, water pumps and power supply (solar panel). Two DC water pumps were used for the water discharging and refilling of the buckets (B1 and B2), the two were connected to the GPIO Pin of the Esp8266 controller through a pair of Bc547 transistors and resistor. Once the push button on the system was pressed, the first water pump would start to fill up the bucket B2 (from the refilling bucket B1) and immediately the water level in the bucket B2 gets to certain level (critical range according to this prototype) it would automatically stop and the second water pump would start to discharge the water back to the main bucket B1. Then when it goes down to the normal range, the system would automatically stop it. The refilling and discharging of water from the buckets are used to provide a water level scenario at the flood prone areas so as to ascertain the system's response time at the defined thresholds. Figure 1 shows the pictorial view of the prototype as used in the implementation of the research.

Figure 1 Pictorial View of the Research Prototype

2.2. Design of transmitting and receiving units

The transmitter and the receiver units were designed and packaged as shown in Figures 2a, 2b and 3a, 3b respectively.

Figure 2a Internal features of the transmitting unit

Figure 2b Packaging of the transmitting unit

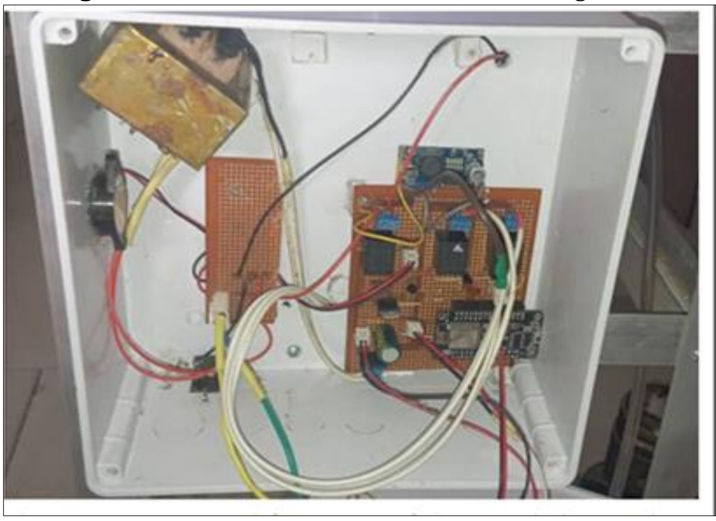


Figure 3a Internal features of the receiving unit

Figure 3b Packaging of the receiving unit

2.3. Mode of Operation

The operation of the system was such that once the system was powered ON, it would take some seconds for the system's initialization and synchronization with the transmitter. Initially in the system's idle state, that is, when the transmitter is not turned ON, the buzzer, the bulb and the discharging water pump would be on "ON Mode" because on default, the value on the receiving memory will be zero (with zero overall effect on the system). Immediately the transmitter was turned on, the transmitter would send the new values of what it read from the sensors, and since the receiver was connected to a PC via the Micro USB Port, the values would be displayed on the system. Once the water gets to the warning range, the buzzer would beep every 2 seconds and it would continue. Immediately it gets to the critical range the buzzer would beep steadily and the Light bulb would be turned ON, an SMS would now be sent to a predefined number on the system (this number is the number of the emergency unit already programmed into the system) and the bulb would remain ON until the water level returns back to the normal range.

2.4. System flowchart

Figure 4 shows the designed system flowchart. After the system's power up and initialization, data are being read from the sensors and checked if any thresholds are met, notification alerts were sent at critical range.

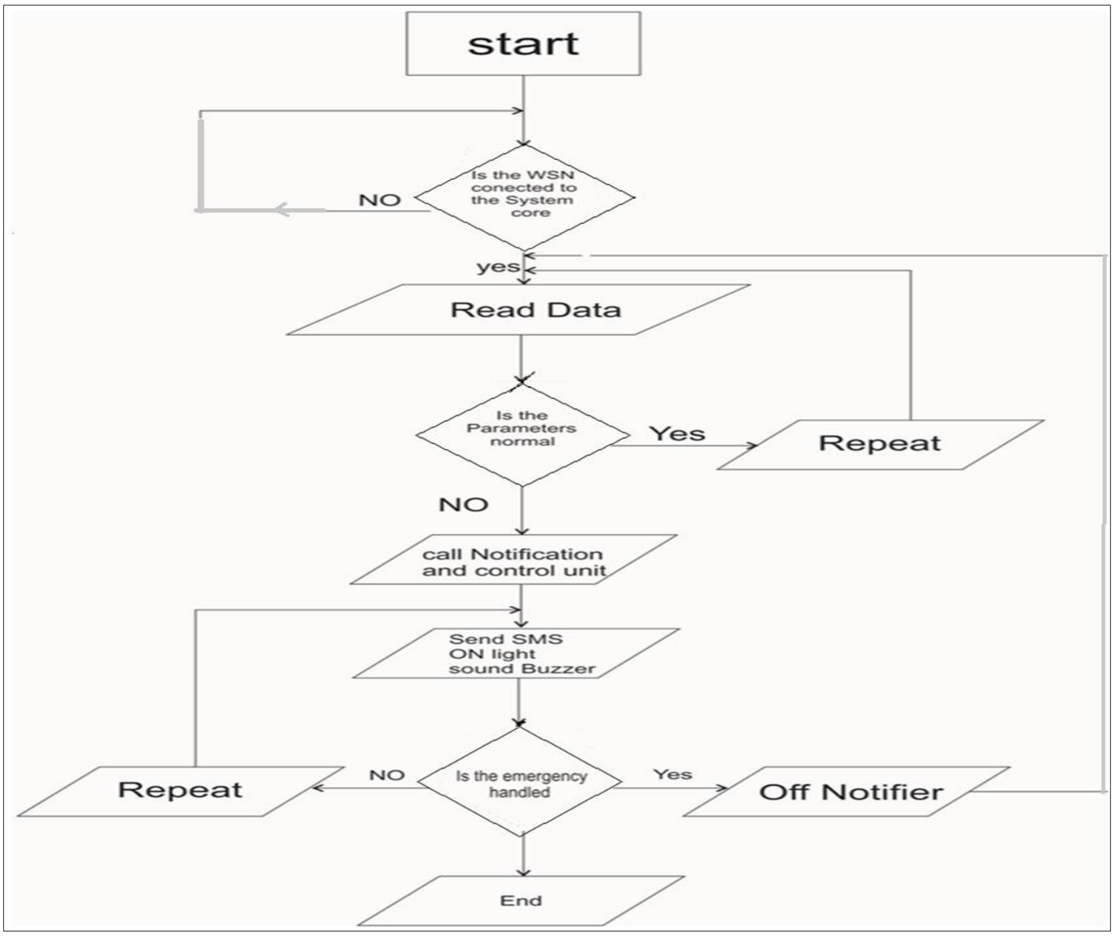


Figure 4 The System's flowchat

3. Result and Discussion

The simulation incorporated various environmental parameters, including rainfall intensity, water level, air pressure, temperature and humidity content. The waterlevel was programmed to provide the thresholds for the multi-channel alerts while the other indicators provided more information to support these thresholds.

The project was carried out using the proposed prototype and the results were simulated and visualized on the thingspeak platform, the table of values obtained has been shown in Table 1.

A histogram was also used to show the variations of each sensor data result (for each of the flood indicators) and the chart in the thingspeak channel showed the instantaneous variations of the uploaded data. These values were uploaded within some seconds while displaying the data values against the dates and time.

3.1. Result Simulations from the Thingspeak Platform

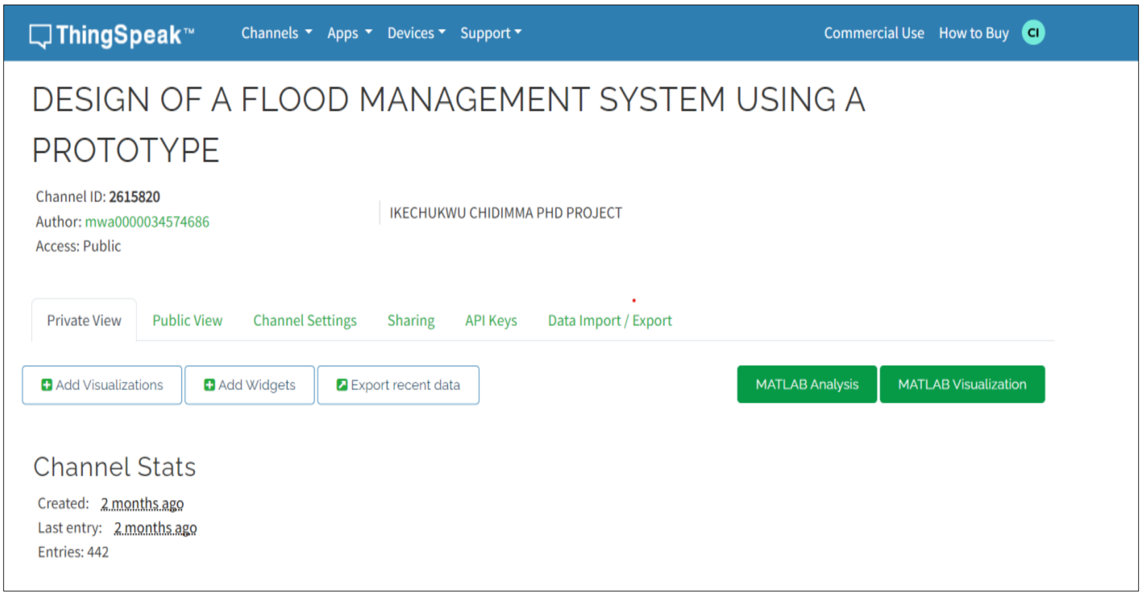
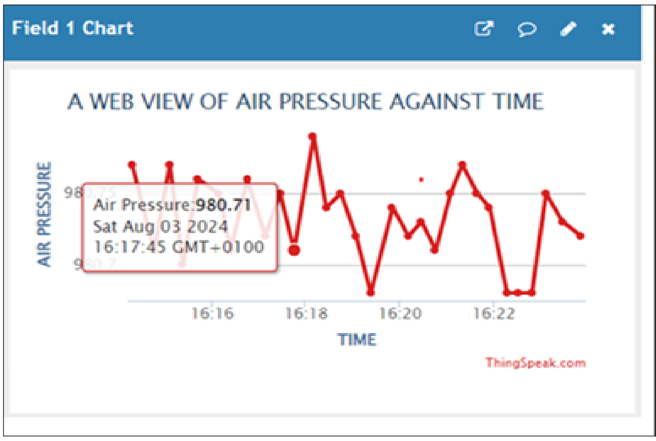


Figure 5 Designed Thingspeak Platform

3.1.1. Air pressure sensor



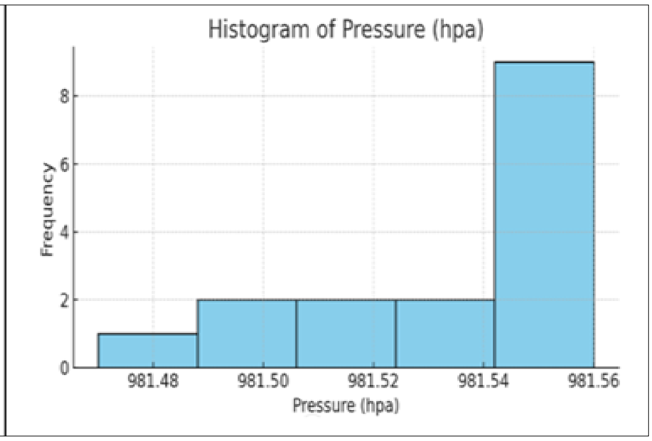


Figure 6a Air pressure sensor Simulation

Figure 6b Air pressure sensor data histogram

3.1.2. Temperature sensor

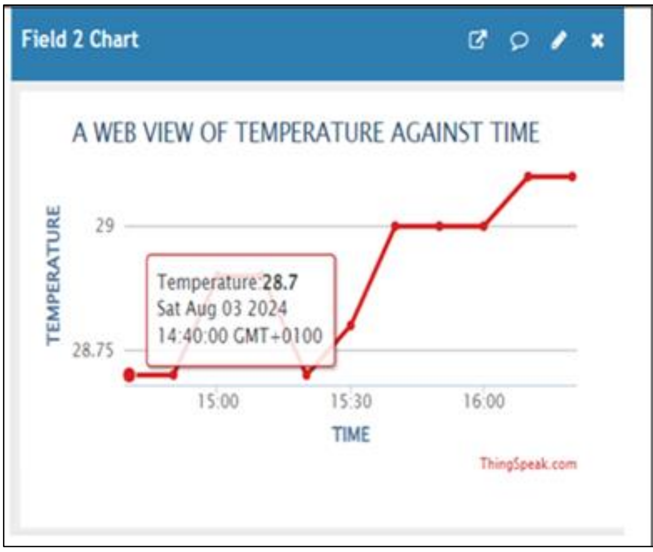


Figure 7a Temperature sensor Simulation

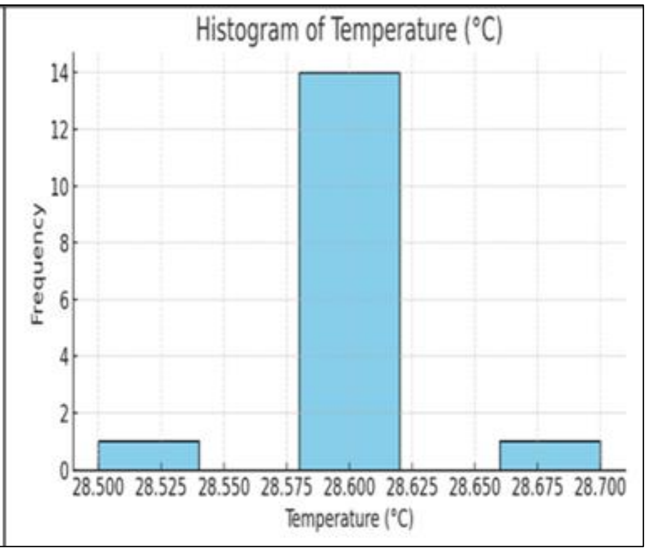


Figure 7b Temperature sensor data histogram

3.1.3. Humidity sensor

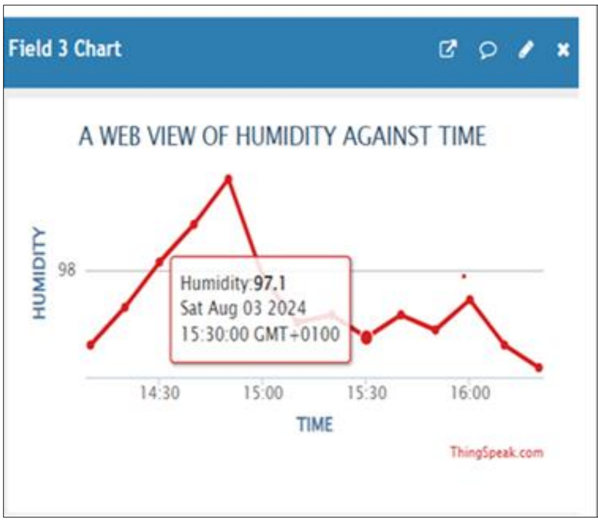


Figure 8a Humidity sensor Simulation

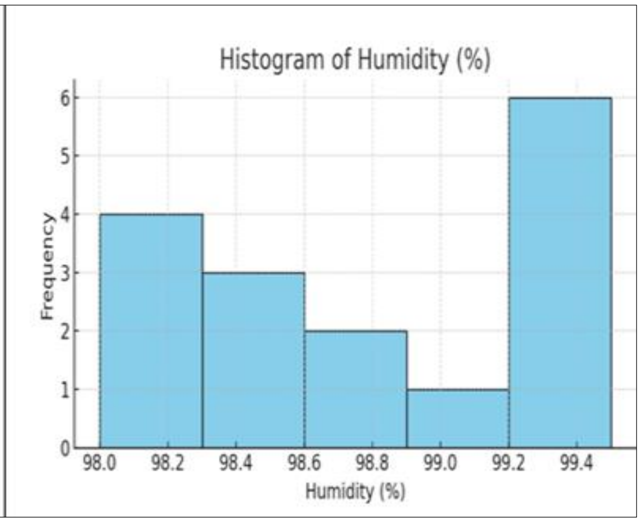
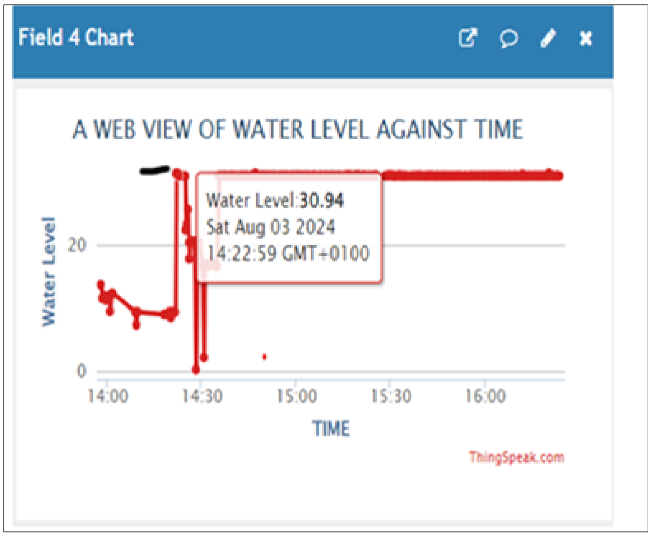


Figure 8b Humidity sensor data histogram

The thingspeak homepage for this project is displayed in Figure 5. Figures 6a, 7a, 8a show the instantaneous sensor data for air pressure, temperature and humidity respectively as displayed on the thingspeak platform. These values were collected over a period of time at specific days. Figures 6b, 7b and 8b are the histograms for air pressure, temperature and humidity respectively.

3.1.4. Ultrasonic sensor



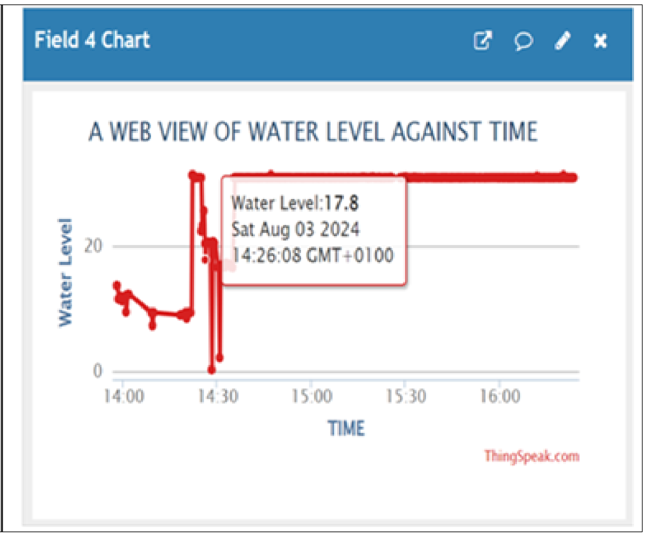


Figure 9a Ultrasonic Simulation for Normal range

Figure 9b Ultrasonic Simulation for Critical range

The thingspeak chart of Figure 9a shows the simulation for a normal range or danger-free state while the Figure 9b indicates a concerning situation where the water level has reached its critical range (during refilling mode) and would stabilize back to its normal range during discharging mode. This critical threshold scenario is a red flag in flood management, requiring immediate and decisive actions to mitigate the negative aftermath of flood and ensure the safety of both infrastructure and populations in the potentially affected areas. The Ultrasonic distance is measured thus:

$$Distance = \frac{Speed\ of\ Sound\ X\ Time}{2} \quad \dots\dots\dots\dots\dots (1)$$

From Figures 9a and 9b, during initialization, these values hovered at some critical ranges which were not of significant impact. With the water supply connected to the modelled prototype, the water level in the bucket which was initially low (that is distance of the level of water in the bucket to the sensor on the top was high) started from its normal range around 14:22pm at 30.92cm (as shown in Figure 9a and Table 1 in green ink). As the water level increased with the bucket in the refilling mode, the distance between the sensor and the surface of the water narrowed and approached the warning range.

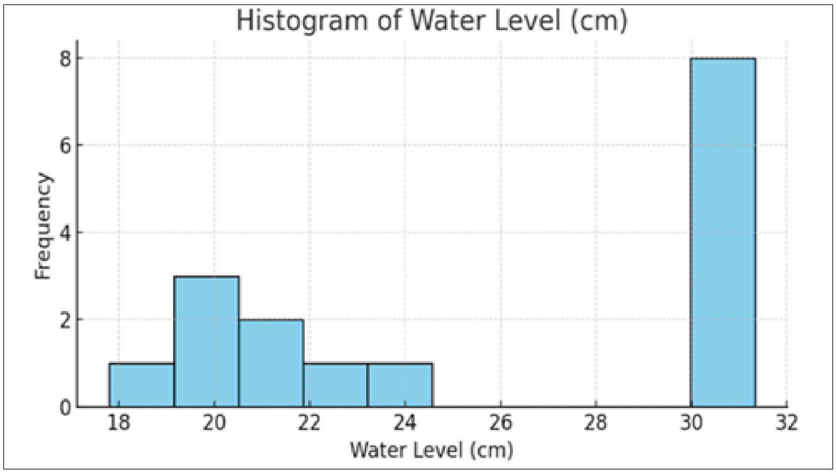
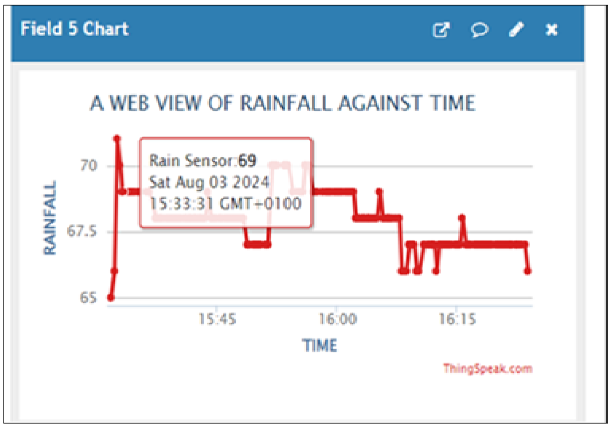


Figure 10 Ultrasonic Sensor histogram

With the bucket still on refilling mode and the water level increasing, the threshold gradually approached the warning range, the alarm automatically starts to beep every two seconds. The Critical range defines the flooding scenario where the beeping alarm became continuous at 17.80cm by 14:26pm (as seen in Figure 9b and Table 1 in red ink). At this point, the light bulb comes up and SMS messages were sent to predefined numbers on the system. The sharp rise in the volume of water (from Figures 9a and 9b) followed by stabilization suggests the sensor was accurately detecting changes in water level.

3.1.5. Rain sensor



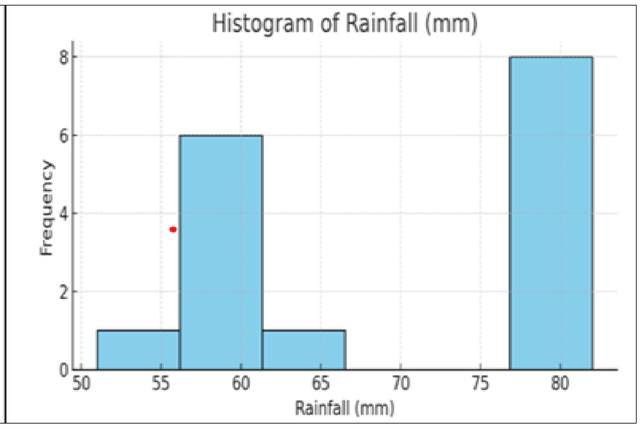


Figure 11a Rainfall sensor Simulation

Figure 11b Rainfall sensor data histogram

Figure 11a shows the thingspeak simulation from the rain sensor and Figure 11b shows the rainfall histogram.

3.1.6. Result Analysis

Table 1 Table of Simulated values for all the Sensors

S/N	DATE/ TIME	PRESSURE (hpa)	TEMPERATURE (°C)	HUMIDITY(%)	WATER LEVEL (cm)	RAINFALL (mm)
1	2024-08-03/14:22:22	981.52	28.70	98.00	31.33	82.00
2	2024-08-03/14:22:40	981.51	28.60	98.00	30.90	81.00
3	2024-08-03/14:22:59	981.47	28.60	98.20	30.92	80.00
4	2024-08-03/14:23:16	981.55	28.60	98.20	30.92	79.00
5	2024-08-03/14:23:36	981.5	28.60	98.40	30.94	79.00
6	2024-08-03/14:23:51	981.47	28.60	98.50	30.94	79.00
7	2024-08-03/14:24:34	981.49	28.60	98.50	30.94	78.00
8	2024-08-03/14:24:50	981.53	28.50	98.60	30.92	78.00
9	2024-08-03/14:25:08	981.56	28.50	98.90	23.41	64.00
10	2024-08-03/14:25:28	98156	28.50	99.10	22.31	57.00
11	2024-08-03/14:25:43	981.58	28.60	99.20	20.11	51.00
12	2024-08-03/14:26:28	981.56	28.60	99.50	17.80	58.00
13	2024-08-03/14:26:26	981.55	28.60	99.50	20.40	58.00
14	2024-08-03/14:26:46	981.55	28.60	99.30	20.40	58.00
15	2024-08-03/14:27:08	981.57	28.60	99.40	20.64	61.00
16	2024-08-03/14:27:26	981.52	28.60	99.50	20.62	59.00
17	2024-08-03/14:27:43	981.54	28.50	99.50	20.40	59.00
18	2024-08-03/14:28:15	981.50	28.60	99.50	20.29	85.00

19	2024-08-03/14:28:41	981.49	28.70	99.50	20.72	60.00
20	2024-08-03/14:29:04	981.44	28.70	99.20	20.49	59.00

Table 1 is the table of simulated values for all the sensors. The row indicated with green ink shows the normal or safe range of the ultrasonic sensor (that is, rows 1 to 8 are also within the normal range) and the red ink shows the critical or danger range of the ultrasonic sensor. From Table 1, at the point when the reading approached the warning range, the alarm continued to beep every two seconds, it continued this two seconds beep within the warning range. Immediately the value reached the critical range, the alarm remained continuous, the light bulb was turned ON, and the SMS shown in the Figure 12 was sent to the listed number in the embedded C++ coded instruction. The notification alerts of alarm and light continued to remain in the ON mode until the normal range was restored. The transmitter and receiver were in continuous communication of every data that goes to the expert core system and the most appropriate command was issued promptly. From the SMS generated on Saturday 3rd as shown in Figure 12, it was seen that immediately the critical range was attained at 14:26pm on 03-08-2024, an SMS was received by one of the predefined numbers two minutes after the critical range was attained as shown in the expanded text in Figure 13, showing a very practical response time. The alarm at this critical range continued to sound on and the light ON until the normal range which is the safe zone was restored.

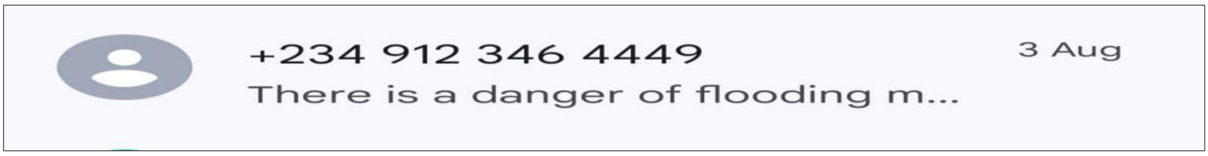


Figure 12 SMS message displaying the date

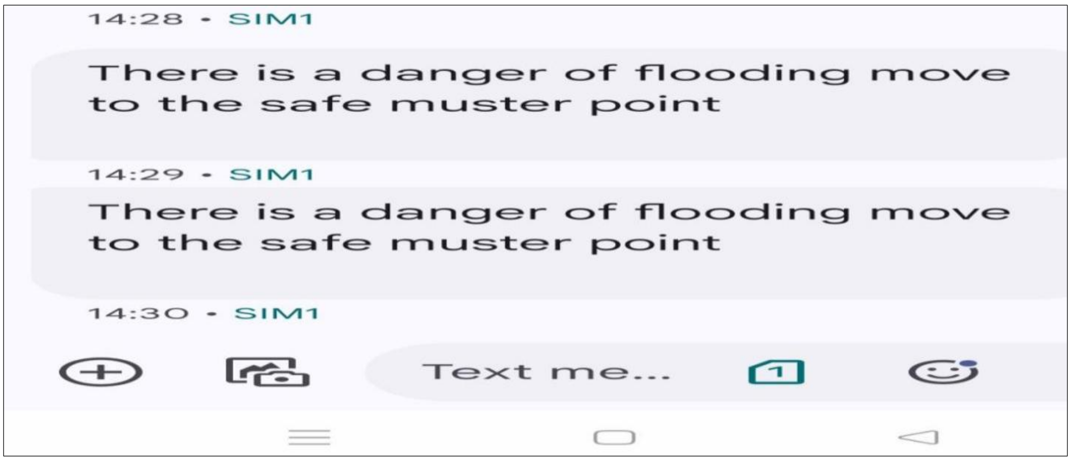


Figure 13 SMS message at time 14:28pm

4. Conclusion

The flood management process system prototype developed in this study proves to be an effective tool for flood prediction and emergency response. The developed system collected real-time environmental data, processed it using predictive algorithms, and provided stakeholders with actionable insights and automated alerts. The prototype was developed to simulate flood scenarios and validate the system's performance. Considering the fast response time when the critical range was attained showed that this prototype would provide the desired flood management system to facilitate effective decision making and communication during flood events.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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