UJEAS

UNIZIK JOURNAL OF ENGINEERING AND APPLIED SCIENCES

UNIZIK Journal of Engineering and Applied Sciences 5(2), June (2025), 2384-2394
Journal homepage: https://journals.unizik.edu.ng/index.php/ujeas
PRINT ISSN: 2992-4383 || ONLINE ISSN: 2992-4391

Design of a comprehensively integrated wireless sensor network web-based expert system architecture.

Chidimma Augustina Ikechukwu[1*], Victor Eze Idigo[2], Scholastica Ukamaka Nnebe[3], ThankGod Izuchukwu Ozue[4], Anwuli Isioma Agwunobi[5], Ifeyinwa Chidum Dimson[6].

[1]PhD Student, Communication and Control Option, Department of Electronics and Computer Engineering, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria.
[2] Department of Electronics and Computer Engineering, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria.
[3]Department of Electronics and Computer Engineering, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria.
[4]PhD Student, Control and Computer Option, Department of Electronics and Computer Engineering, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria.
[5]Lead Contract and Procurement Claims Engineer, Nigerian Liquefied Natural Gas Train 7 Project, Bonny Island Rivers State, Nigeria.
[6]Department of Electronics and Computer Engineering, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria.
[*]Corresponding Author's E-mail: chidelles4u@yahoo.co.uk

Abstract

Flooding is a significant natural disaster that causes widespread damage to infrastructure, the environment, and human lives. It is crucial to implement effective early warning systems that allow for timely responses. This project presents a novel system architecture that collects and analyzes environmental data critical to flood prediction such as rainfall, river water levels, temperature, humidity, and atmospheric pressure. The system integrates WSN technology using the weather station method, a web-based expert system for data analysis and flood prediction, and a robust notification system that delivers flood alerts via SMS, audio alarms, and visual indicators. Three water level thresholds were defined in this project; normal range above 28.59cm, warning range between 28.58cm and 23.50cm critical range below 17.89cm. On the 3rd August 2023 at 14:26pm, a critical range of 17.80cm was observed, immediately this threshold was met, the alarm and visual light notifications were turned on to alert residents of a likely flood event, an SMS was sent to the predefined registered number on the network and this was received by 14:28pm. The findings validate the reliability of the system in providing timely notifications, enabling proactive flood management. This work highlights the importance of deploying adaptive sensor-based technologies in flood-prone regions for enhanced disaster mitigation.

Keywords: Early warning System, Flood monitoring, Real-time alert, Web-based platform and Wireless Sensor Network.

1. Introduction

Flooding represents a pervasive and catastrophic natural hazard with substantial socio-economic impacts globally. This has been a major concern considering the adverse setbacks it presents to its immediate environment towards achieving a sustainable development. Nigeria has not been left out from the dilemma that comes with this disaster.The flooding that escalated precisely on 13th September 2022, with the perennial release of water from the Lagdo Dam in neighbouring Cameroon was believed to have been the worst that Nigeria has experienced in decades (Mahadeo et al 2023). According to "This Day Newspaper" reports, about 603 people died, and more than 1.3 million people were displaced, while over 108,393 hectares of farmlands were destroyed across the country (www.thisdaylive.com). In many flood-prone regions, traditional flood management systems which are often characterized by delayed responses, poor notification network to alert residents and insufficient data for timely decision-making have proven inadequate. This became imperative that a flood prediction and management device be installed and operated in real time in riverine regions such as the Bonny Island whose terrain is basically linked by water bodies from different riverine communities. The combination of robust system architecture gives a good leverage for the prompt and effective predictive management of flooding. This technique which encompasses the use of WSN and other devices would mark a paradigm shift from isolated methodologies to a holistic, interconnected approach. The previous introduction on flooding highlighted the need for robust system architecture by integrating Wireless Sensor Networks (WSN) and IoT devices to monitor and manage flood risks in vulnerable regions like Bonny Island. It underscored the limitations of traditional flood management approaches in providing real-time data and effective response strategies. Comparatively, recent literature adds depth to this understanding;

Shamsuddin et al. (2018) highlighted the role of expert systems in providing real-time insights and recommendations for flood risk management, which is crucial in making quick and informed decisions during high-stress situations. Uyioghosa et al. (2018) further proposed a system that detects and monitors flooding in real time through measurement of water levels both during and after rainfall which are continually detected by sensor nodes. The system however lacked a robust notification system for real-life emergency scenarios since it was carried out using a drum. Wan Alamsyah et al. (2019) designed the Early Flood Detection (EFDe) system using IoT, accessible via browsers and Android smartphones. The system was equipped with an alarm system that triggered within 10-15 seconds when flood potential was detected. However, the system had limited scope for handling complex flood triggers or environmental factors. Shidrokh et al. (2021) implemented a fault-tolerant multi-level system that integrates WSNs with Unmanned Aerial Vehicles (UAVs) to address network connectivity challenges during flood episodes. UAVs act as routers to relay data when sensor nodes fail to transmit, ensuring continuous monitoring of water levels. This system however limited focus on latency reduction and computational efficiency. Namal et al. (2021) further categorized flood management into three key stages: detection, alerting, and refugee relocation. They integrated IoT, cloud platforms, and Android-based applications to manage flood data and alerts. However, there's restricted access to Google Maps data for top personnel only, limiting the system's usability for external stakeholders. A key challenge however, with all these existing literatures is the integration of these technologies into a single comprehensive system that can provides accurate, realtime flood predictions and management strategies. Thus, this system effectively provides a technological solution whose architecture integrates real-time data from WSNs with expert system analytics, robust notification system and multi-channel communication, which aligns with the existing literatures advocating for robust, technology-driven flood management solutions.

2.0 Materials and Methods

2.1 Materials

The materials used to achieve this work are explained within each block of the system's architecture in which their collective individual impacts give the overall system result required.

2.1.1 System's Architecture

The system's architecture is composed of four basic components, these include: Web based user, Wireless Sensor Network (WSN), Expert core system and Notification system.

Figure 1 illustrates the System's architecture for this project. The data flow is such that; The Wireless Sensor Network (WSN) collects raw data from the environment and sends it to the Expert System Core for analysis. The Expert System Core processes the data and communicates the information to the Web-Based User Interface for monitoring and control. Simultaneously, it triggers alerts or updates via the Notification System when specific conditions (of critical range) are met.

A. Web-based User Interface

The thingspeak technology was used as the front-end which users interact with to provide a platform that enables the visualization of the sensor data from the transmitting and receiving units. It was chosen as the front-end interface because of its user-friendly capabilities which allows for easy visualization without the need for complex programming or technical knowledge. In order to create a web-based user interface with thingspeak, the platform consists of some built-in tools and features to design and customize the interfaces. The thingspeak for this work was programmed using embedded C++ programming language. Also, the thingspeak channels were created to represent different aspects of the flood prediction and management system. Each channel would be associated with specific sensor data or system outputs. Thingspeak's visualization tools were employed to create graphs, charts, and gauges that represent real-time and historical sensor data. These were arranged in such a way to provide a clear and concise representation of the system's status.

B. Expert System Core

The ESP8266 Expert System Core is the main controller used in this project. It is basically is a platform whose primary purpose is to ensure intelligent decision-making and problem-solving by analyzing and integrating data from both the transmitting and receiving units and applying predefined rules or algorithms. It was programmed using the Arduino IDE. Communication was done over Wi-Fi using ESP-NOW Protocols (ESP-NOW is a communication protocol). Using the ESP8266 as the Expert System Core for a flood prediction system involves leveraging its capabilities as a microcontroller with Wi-Fi connectivity and its integration as the core component in an expert system requires careful consideration of its strengths and limitations.

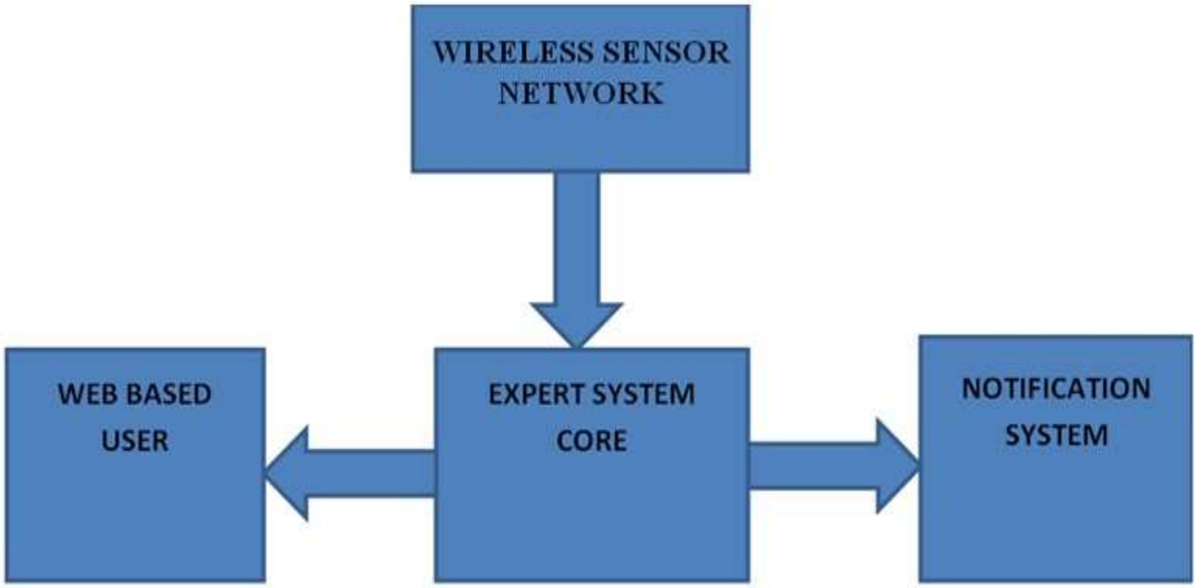

Figure 1: Block Diagram Showing the Components of the System Architecture

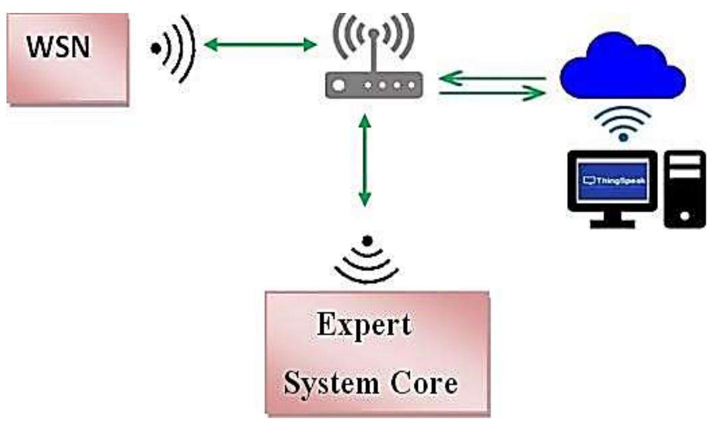

Figure 2: Expert System Core

Figure 2 illustrates the integration of a Wireless Sensor Network (WSN), an Expert System Core, and cloud-based services. The WSN collects environmental data, which is transmitted to a central router or gateway for processing and forwarding to both the Expert System Core and cloud platforms (Thingspeak). The cloud platform facilitates remote monitoring and data visualization, while the Expert System Core analyzes the data locally to make decisions or generate actionable insights.

C. Wireless Sensor Networks (WSN)

The Wireless Sensor Network for this research includes the: Temperature Sensors & Humidity Sensors (DHT11), Pressure Sensors (BMP180), Ultrasonic Sensor (HC-SR04), Rain Gauges (FC-37), the NodeMCU and Power supply. From Figure 3, The DHT11 sensor provides temperature and humidity data. The BMP180 sensor provides atmospheric pressure and temperature data. Ultrasonic sensor was used to measure water level or distance. The Rain sensor provides information about the rainfall condition. The NodeMCU firmware is pre-flashed on the ESP8266 module, providing a Lua-based interpreter environment. The collected sensor data are processed by the ESP8266. The entire system was powered with a solar supply to maintain a steady power supply to the WSN so that it would be able to continually collect the weather data and transmit them for further processing and decision making. The block diagram in Figure 3 shows the basic components of the WSN.

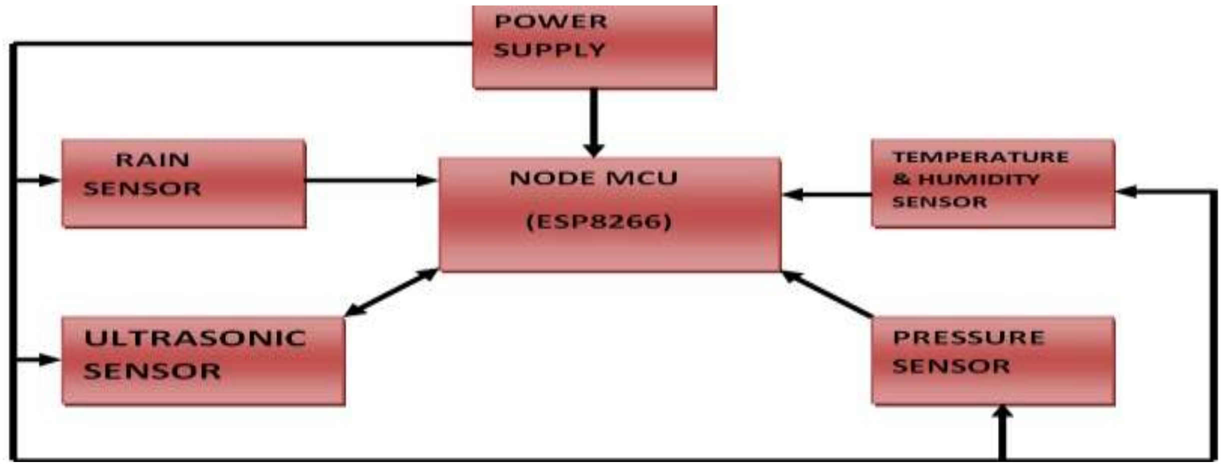

Figure 3: Components of the Wireless Sensor Network.

D. Notification System

The notification system for this project was designed to alert people through a multi-channel network, these are; the visual light indication using a light control NPN transistor (BC547) and a light alert 10W AKT bulb, an alarm system using buzzer circuit which is the IRF44n MOSFET transistor and a SMS alert using a GSM Module (SIM800L). The SIM800L has a slot for a SIM card, which is necessary for accessing the GSM network. The SIM800L communicates with a microcontroller or other devices using port. In Figure 4, the Expert System Core continuously collects data from sensors, and updates the platform with real-time weather information. A specific threshold was set for normal range, warning range and critical range for the ultrasonic sensor and other weather parameters, when the water level gets to the critical range, the system would trigger a notification of light and alarm to come up, and send an SMS to the predefined phone number that is registered on the system. Figure 4 shows the block diagram of the notification system and its interface with the expert system core.

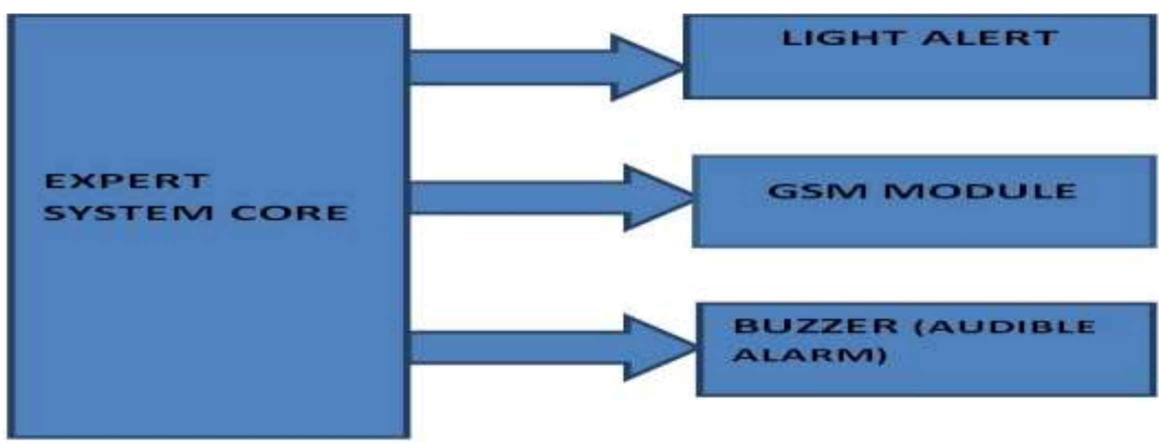

Figure 4: The block diagram of the notification system.

2.2 Research Test Bed

The study area chosen for the purpose of this research is the Bonny Island which as its name implies is conspicuously surrounded by a body of water.

Bonny Island is located approximately 40 km south of Port Harcourt in Rivers State, Nigeria, and is positioned on the leeward side of the Cameroon Mountain. It serves as the administrative headquarters of Bonny Local Government Area with major communities such as Grand Bonny, Finima, Opusunju, Kala Sunju, Green Iwoama, and Kalaibiama. Geographically, it lies at latitude 4°27'N and longitude 7°10'E, with an estimated population of 309,200 as projected by the National Population Commission (NPC) as of February 21, 2022. The Island has a relatively flat topography on an elevation of 3.05 atmospheric mean sea levels with a total land area of 343.9m^2. Figure 5 shows the geographic view of test bed area.

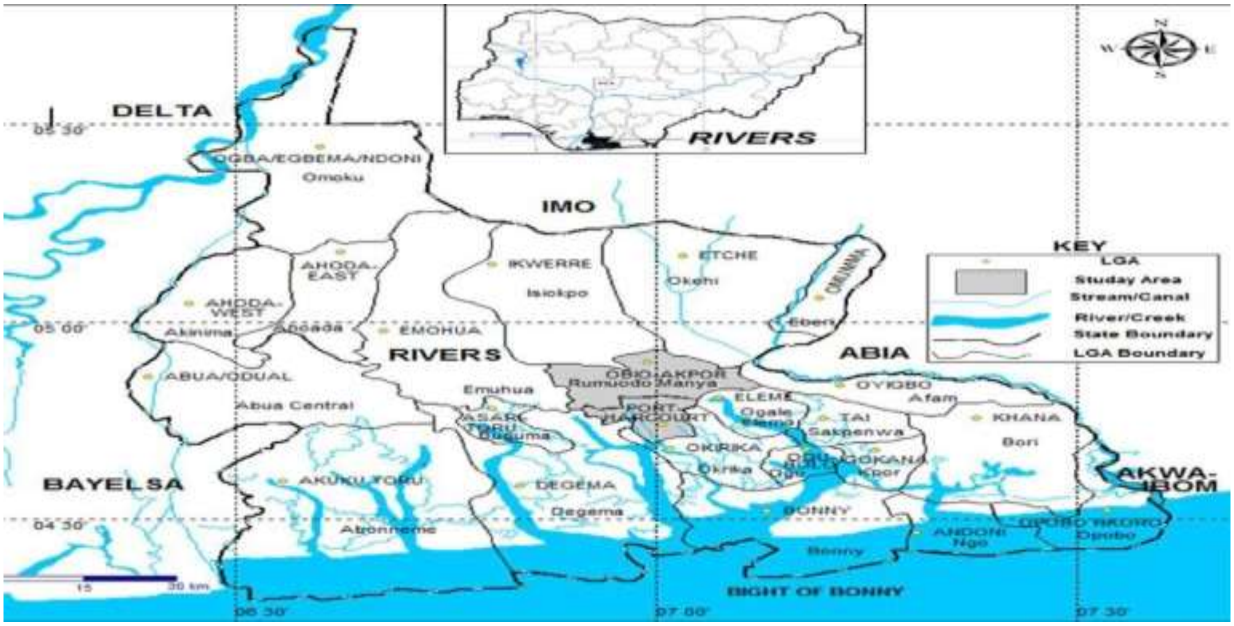

Figure 5: Geographic View of Test Bed Area. (Akuro et al,2014).

2.3 Methods

The Weather Station Method was employed in this project with the use of Wireless Sensor Networks (WSNs). This method is a modern approach for collecting and monitoring of real-time meteorological data (such as atmospheric pressure and humidity, temperature, windspeed) and hydrological data (such as rainfall, water flow and water-level) using a distributed network of sensors that communicate wirelessly. The Weather station method of this research was implemented by mounting poles (about 1.5m from the ground level) to securely hold the packaged unit containing the sensor nodes in order to produce a more comprehensive and localized data.

2.3.1 Implementing the Test Bed Measurement.

The poles were calibrated to reflect the predefined water-levels to give an indication of the normal, warning and critical ranges which are 28.58cm, 23.17cm and 17.89cm respectively. These measurements were indicated by the stripes on the pole (as shown in Figures 8b, 8c and 8d respectively) and the distances were taken with respect to the surface of the water and the ultrasonic sensor. Once the system is powered on, the transmitter and receiver registers to the network and thus synchronizes with the network to turn ON the green light on the casing of the unit. The transmitter reads the sensor data from the sensor network (these sensor data are water level, temperature, rainfall, pressure and humidity), uploads them to the webpage (thingspeak) and sends them to the receiver through Wifi network. The receiver then checks to see if any of the thresholds are reached, sends the feedback to the transmitter and alerts the notification when the critical range is exceeded.

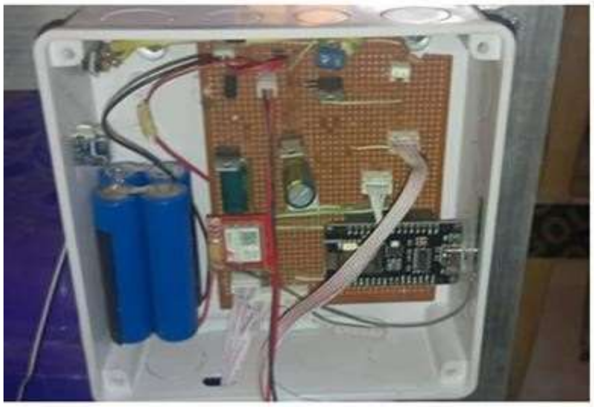

Figure 6a : Internal features of the transmitting unit

Figure 6b: Packaging of the transmitting unit

Figure 7a: Internal features of the receiving unit

Figure 7b: Packaging of the receiving unit

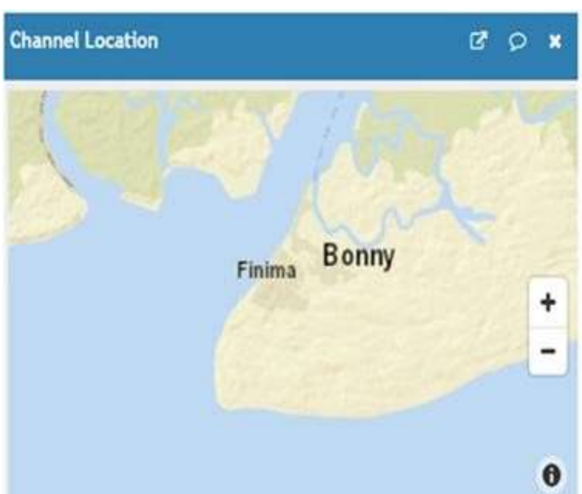

Figure 8a: Thingspeak location of Testbed area

Figure 8b: Normal range measurement

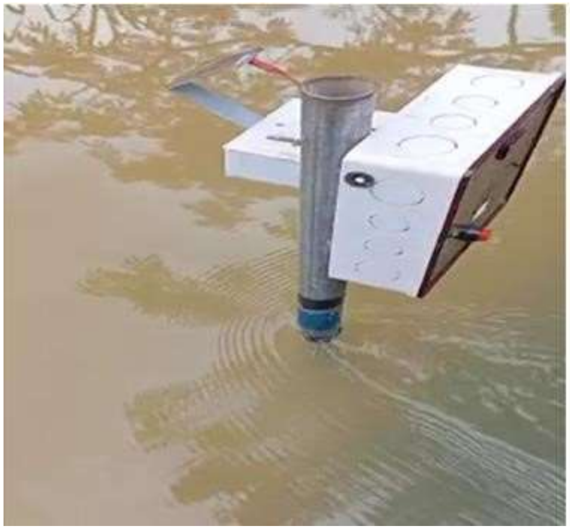

Figure 8c: Warning range measurement **Figure 8d: Critical range measurement**

Figures 6a and 7a shows the internal features of the transmitting and receiving units respectively while Figures 6b and 7b shows their external packaging. Figure 8a shows the channel location of the Test bed area as shown on the thingspeak platform. Figure 8b shows the initiation of the normal range/safest range at the test bed area. Figure 8c shows the initiation of the warning range. As the water level increases beyond the normal range to the warning range, the buzzer starts to beep every 2 seconds. Immediately the water level increases further to a critical range (as shown on Figure 8d), the buzzer alarm on the receiver units beeps continuously and steadily, the light is turned ON and an SMS is sent to the registered network. The other meteorological indicators are also monitored at each of these ranges and any spike or sudden increase is monitored and checked as an indication of a likely flood event.

3.0 Results and Discussion

The results obtained from the test bed are shown and visualized in the Integrated Development Environment (IDE) using the thingspeak platform as the Web-Based interface. This Platform has programs that display both the Matlab visualization and Matlab Analysis. The project was carried out at the test bed on different occasions. These values were uploaded within some seconds while displaying the data values against the dates and time with some level of precision.

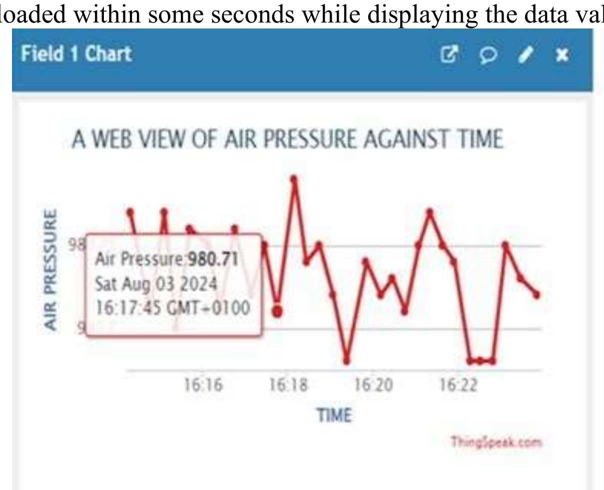

Figure 9: Air Pressure sensor simulations **Figure 10: Temperature sensor simulations**

Figure 11: Humidity sensor simulations

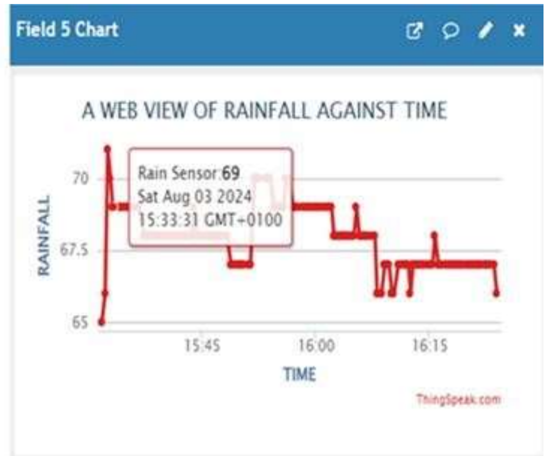

Figure 12: Rain sensor simulations

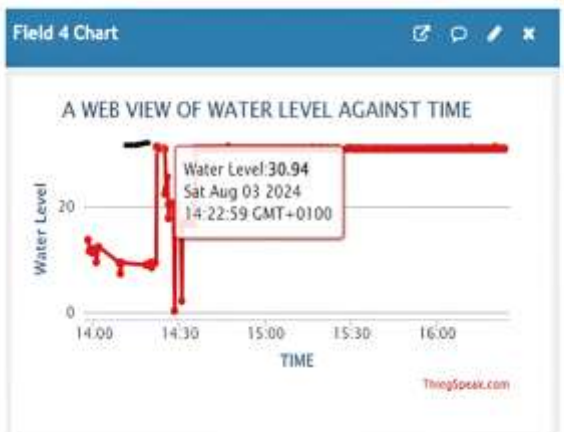

Figure 13: Ultrasonic Normal range simulations

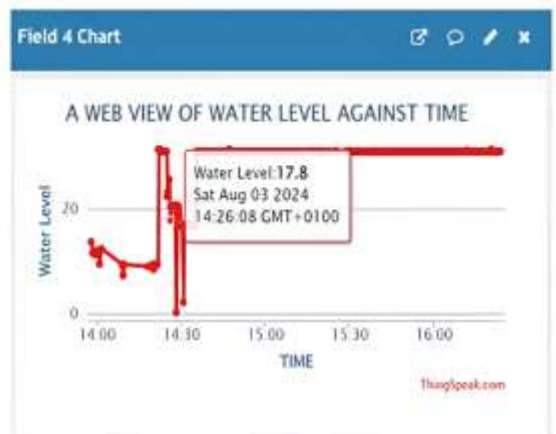

Figure 14: Ultrasonic Critical range simulations

Figures 9, 10, 11 and 12 show the thingspeak simulations from the Air pressure sensor, Temperature sensor, Humidity sensor and Rain sensor respectively. In Figure 13, it was observed that after initialization and synchronization of the transmitter and receiver, the value of the water level during the refilling mode attained a peak of 30.94cm, this showed that the water level was low to cause a likely flood scenario considering the distance between the surface of the water and the ultrasonic sensor. The values before synchronisation are insignificant, the instant the transmitter synchronised with the receiver, a normal range reading was taken. From Figure 13, the water level continued to increase and the ultrasonic measurement gradually attained the warning range, this was followed by a beeping alarm at every two seconds. In Figure 14, at time

14:26pm, a value of 17.80cm (critical/danger range) was measured and at this point, the alarm became more aggressive, the visual light bulb turned on immediately and an SMS was sent to the number registered on the network. Table 1 shows the table of simulated values screenshot from the thingspeak platform. The table consists of the time and date when the results were obtained for each of the sensor data. Figure 15 shows the generated SMS that was sent to the numbers registered on the micro-controller. The critical range of 17.80cm from the ultrasonic sensor (see Table 1) was attained at the 14:26pm on the 3rd August, 2024. This was received at 14:28pm on the same date as shown in Figure 15. This response time was prompt enough to alert residents and other emergency responders for effective decision making. Note that aside using water level as a flood indicator, a combination of the flood indicators in the table above would give a precise information of an impending flood event. Figure 15 shows a screenshot message generated from the registered number when the critical range was attained.

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	28.7	98	31.33	82
2	2024-08-03	14:22:40	981.51	28.6	98	30.36	81
3	2024-08-03	14:22:59	981.47	28.6	98.2	30.92	80
4	2024-08-03	14:23:16	981.55	28.6	98.2	30.92	79
5	2024-08-03	14:23:36	981.53	28.6	98.4	30.94	79
6	2024-08-03	14:23:51	981.47	28.6	98.5	30.94	79
7	2024-08-03	14:24:08	981.49	28.6	98.5	30.94	78
8	2024-08-03	14:24:34	981.53	28.5	98.6	30.94	78
9	2024-08-03	14:24:50	981.56	28.5	98.9	22.41	64
10	2024-08-03	14:25:28	981.56	28.5	99.1	23.31	57
11	2024-08-03	14:25:43	981.58	28.6	99.2	20.61	51
12	2024-08-03	14:26:05	981.56	28.6	99.5	20.4	58
13	2024-08-03	14:26:26	981.55	28.6	99.5	20.4	58
14	2024-08-03	14:26:48	981.55	28.6	99.3	20.4	58
15	2024-08-03	14:27:05	981.57	28.6	99.4	20.61	61
16	2024-08-03	14:27:26	981.52	28.6	99.5	20.65	59

Figure 15: Generated SMS message

4.0 Conclusion

This project developed a robust system architecture that integrates the WSN with the web-based expert system, facilitating real-time monitoring of both the meteorological and hydrological parameters. The system's architecture allowed for efficient data collection, processing, and transmission, ensuring the effective operation of routing protocols necessary for data dissemination across the network. During testing, the system exhibited reliable performance in identifying water level changes and issuing alerts based on critical thresholds. When the water level reached the warning range, the system activated periodic alarms. At critical levels, more aggressive notifications, including continuous alarms, light indicators, and SMS alerts were triggered. The results of the system's implementation demonstrated its capability to respond with minimal delay to reduce flooding impacts.

5.0 Recommendation

Based on the findings and the successful implementation of the system, several recommendations can be made for future roadmap for enhancing this project's broader adoption, these includes: **e**xpanding the system to cover other types of disasters**,** collaboration with government and emergency services**,** public awareness and training programs, enhancement of system security and data integrity by implementing a block chain technology within the WSN for data integrity and tamper-proof logging, **i**mproving the scalability of the system for larger geographic areas**, i**mplementation of multilingual notification systems and finally government funding and support for large-scale deployment.

Acknowledgements

My profound gratitude goes to my supervisors Professor Victor Idigo and Professor Scholastica Nnebe for their selfless supports and encouragements to enable reach this milestone, also, many heartily appreciation goes to my professional colleague, Engr. Mrs Anwuli Agwunobi who made sure this work was implemented to this stage, I say many thanks to you.

List of Abbreviations

WSN – Wireless Sensor Network
IoT - Internet of Things
WL – Water Level
KM – Kilometres
M – Metres
CM – Centimetres
W – Watts
UAV – Unmanned Aerial Vehicles
EFDe - Early Flood Detection
GSM – Global System for Mobile Communication
GND – Ground
IC – Integrated Circuit
MCU – Micro controller Unit
USB - Universal Serial Bus
IDE – Integrated Development Environment
NPN – Negative Positive Negative
SMS – Short Message
SIM – Subscriber Identity Module
UART – Universal Asynchronous Receiver Transmitter
MOSFET – Metal Oxide Semi Conductor Field Effect Transistor
NPC – National Population Commission
NLNG – Nigerian Liquified National Gas
MATLAB – Matrix Laboratory
C++ - C Plus Plus Programming Language
WiFi – Wireless Fidelity
ESP- Extra Sensory Perception

References

Akuro, E.G. & Amangabara, G.T., 2014. Public perception of tidal flooding hazards on Bonny Island, Rivers State; Nigeria. Institute of Geosciences and Space Technology (IGST), Rivers State University of Science and Technology, Port Harcourt, Nigeria.

Hingmire, M. & Bhaladhar, P.R., 2023. A review on urban flood management techniques for the smart city and future research. Springer Nature Switzerland AG, School of Engineering, Sandip University, Nashik, India.

Iyekekpolo, U.B., Idachaba, F.E. & Popoola, S.I., 2018. Early flood detection and monitoring system based on wireless sensor. Department of Electrical and Information Engineering, Covenant University, Ota, Nigeria. Email: benedictuyioghosa@gmail.com.

National Population Commission (NPC), 2022. Population projection for Bonny Island. Federal Government of Nigeria, 21 February.

Namal, S.B.W., Pallewatte, C.D. & Sandareka, P., 2021. Integrated solution system for flood disaster management (using IoT and GIS). General Sir John Kotelawala Defence University. Email: wijekoon997@gmail.com.

Shamsuddin, S.N., Isa, N.K. & Yusof, M., 2018. An expert system for real-time decision-making in flood management. Environmental Modelling & Software, 110, pp.195–207.

Shidrokh, G., Soleymani, S.A., Anisi, M.H. & others, 2021. Real-time and intelligent flood forecasting using UAV-assisted wireless sensor network. Centre for Artificial Intelligence (CAIT), Universiti Kebangsaan Malaysia, Bangi. Email: shidrokh@ukm.edu.my.

This Day Live, 2022. 2022 flood a tragedy foretold. [online] Available at: https://www.thisdaylive.com/index.php/2022/10/27/2022-flood-a-tragedy-foretold [Accessed 21 Apr. 2025].

Wan Alamsyah, W., Mutia, E., Ismida, Y., Suria, A. & Putra, R.A., 2019. Design of early flood detection (EFDe) system based on IoT for flood vocational areas. Department of Civil Engineering, Engineering Faculty, Universitas Samudra, Jl. Meurandeh, Langsa Lama – Langsa.