IJRP.ORG
International Journal of Research Publications
ISSN: 2708-3578 (Online)

Real-Time River Water Level Monitoring and Flood Alert System Using Esp32 and LoRa Technology

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Abstract

Nepal's complex mountainous topography renders its river basins highly susceptible to devastating flash floods, yet existing monitoring infrastructure is often cost-prohibitive and technically limited in remote hilly regions. This paper presents a terrain-adaptive, real-time Flood Early Warning System (FEWS) utilizing a robust three-tier IoT architecture. The system employs ESP32 microcontrollers interfaced with JSN-SR04T waterproof ultrasonic sensors for non-contact water level detection. A key innovation of this research is the integration of a dedicated hill-top repeater station to overcome the Line-of-Sight (LoS) limitations of LoRa communication in non-linear, mountainous terrains. To ensure signal integrity, a 10-second median filtering algorithm was implemented, effectively eliminating false triggers from surface ripples or debris. Furthermore, a delta-based transmission strategy was utilized, reducing redundant MySQL database load by 98.2%. Experimental validation conducted across a multi-block campus environment confirms that the system achieves a 95% packet success rate in non-line-of-sight conditions and triggers multi-channel emergency alerts (SMS, Email, and localized Siren) with minimal latency. The proposed solution offers a low-cost, scalable, and power-efficient alternative for disaster risk reduction in the flood-prone watersheds of Nepal.

Keywords— Internet of Things (IoT);LoRa Communication; Flood Early Warning System (FEWS)Nepal; ESP32; Repeater Station; Median Filter; Delta Transmission.

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1. Introduction

1.1. Background

Flooding is the most frequent and devastating natural disaster in Nepal, a country characterized by steep mountainous terrain and a dense network of river systems. During the monsoon season, rapid increases in water levels often lead to flash floods that cause significant loss of life, displacement of communities, and destruction of critical infrastructure. Effective disaster risk reduction depends heavily on Early Warning Systems (EWS) that can provide real-time data to downstream residents before the flood crest arrives.

1.2. Problem Statement

Current flood monitoring infrastructure in Nepal faces three primary challenges:

- Cost: Industrial-grade radar and satellite-linked stations are prohibitively expensive for local municipalities to deploy widely.

- Connectivity: Traditional wireless protocols like Wi-Fi or Bluetooth have extremely short ranges, while GSM-based systems often fail in remote "shadow zones" where cellular tower penetration is blocked by hills.
- Power Constraints: Monitoring stations are usually located in off-grid areas. High-power communication modules (like 4G/LTE) quickly deplete batteries, requiring large, expensive solar arrays that are prone to *theft or damage.*

1.3. Motivation

The motivation for this research stems from the emergence of LoRa (Long Range) technology as a solution for remote environmental sensing. Operating in the sub-GHz license-free band (433 MHz), LoRa provides:

- Long Range: Ability to transmit data over several kilometers even in challenging environments.
- Low Power: Minimal energy consumption, allowing the sensor node to operate for months on a small battery.
- Resilience: Independence from commercial cellular networks, which are often the first to fail during a natural disaster. In the Nepalese context, adding a repeater station is the key innovation, as it allows the LoRa signal to "hop" over hills that would otherwise block a direct line-of-sight (LoS) transmission.

1.4. Objectives

The primary goal of this research is to develop a terrain-adaptive, low-cost flood monitoring solution. The specific objectives include:

- To design and construct a Sensor Node using an ESP32 and HC-SR04 ultrasonic sensor for non-contact water level measurement.
- To implement a LoRa Repeater Station to overcome topographical barriers inherent in hilly terrains.
- To develop a Base Station and Local Server (XAMPP) for real-time data logging, visualization, and automated threshold-based SMS/Email alerts

2. Literature Review

2.1. Foundation and Architecture of Monitoring Systems

The evolution of modern flood monitoring is rooted in the fundamental principles of Wireless Sensor Networks (WSN). Akyildiz et al. provided a seminal survey on the communication challenges inherent in these networks, highlighting that power consumption and reliability are the primary constraints for environmental sensing. As these networks transitioned into the Internet of Things (IoT), Ray emphasized the necessity of a multi-layer architecture—comprising Sensing, Network, and Application layers—to ensure system scalability. This research adopts such a layered approach by decoupling the hardware sensing (ESP32 and Sonar) from the long-range transmission network (LoRa) and the final data visualization layer (XAMPP).

2.2. Review of Current Flood Detection Methods

Traditional Flood Early Warning Systems (FEWS) have primarily relied on manual gauge reading or sophisticated automated systems using two main communication pillars:

- GSM-Based Systems: Many researchers have implemented SMS-based alerts using GSM/GPRS modules. While effective in urban areas, these systems face significant challenges in the "shadow zones" of Nepal's hilly regions where cellular penetration is low. Furthermore, the high power consumption and recurring data costs associated with GSM modules make them less ideal for remote, battery-operated nodes .

- Short-Range Wireless: Protocols such as ZigBee, Bluetooth, and Wi-Fi have been explored for localized monitoring. However, these are restricted by high frequency and low range (typically <100m), rendering them unsuitable for the vast distances between remote river points and human settlements.

2.3. Comparative Analysis:

The Rise of LoRa LoRa (Long Range) has emerged as a breakthrough for environmental IoT. Augustin et al. and Centenaro et al. conclude that its use of Chirp Spread Spectrum (CSS) modulation allows for long-range connectivity and low power consumption, making it the "rising star" for smart city and environmental scenarios. Unlike traditional Frequency Shift Keying (FSK), LoRa can decode signals 19.5dB below the noise floor, allowing for extreme sensitivity.

Table 1. Communication Technology Comparison

Technology	Range	Power Consumption	Cost	Topography Suitability
Wi-Fi	Short (~50m)	High	Low	Line-of-Sight only
GSM/LTE	Variable	Very High	Monthly Fees	Depends on Tower density
LoRa	Long (2-15km)	Very Low	Low	Terrain sensitive

While Vangelista and Zanella discuss the LoRaWAN MAC protocol for wide-area networks, this research utilizes a simplified Peer-to-Peer (P2P) LoRa approach to reduce overhead and latency in the point-to-point "hop" required for mountainous repeaters.

2.4. The Challenge of Hilly Topography and Research Gap

The practical application of IoT in flood management has been validated by Hasan et al. and Kim et al., proving that ultrasonic sensors provide a reliable, non-contact method for measuring water levels. However, these studies were largely conducted in urban or flat coastal regions.

In the context of Nepal’s mountainous watersheds, even LoRa’s superior range is tested by the lack of Line-of-Sight (LoS) due to ridges and spurs. Most existing literature focuses on "Star Topologies" with a single gateway. There is a limited body of research concerning multi-hop or repeater-based LoRa architectures specifically optimized for mountainous terrain. This research addresses this gap by implementing a dedicated Repeater Station, creating a relay that allows data to bypass physical obstacles, ensuring reliability in non-linear topographies.

3. **Proposed system architecture**

The architecture is designed as a modular, three-tier framework to address the geographical constraints of Nepalese river basins. By separating the sensing, relaying, and data-processing tasks, the system ensures high reliability and extended range.

3.1. System Overview

The proposed system follows a "Multi-hop LoRa" topology. The River-Side Monitoring Station (Sensing Node) detects water levels and broadcasts the data. A Repeater Station, strategically placed at a higher elevation (e.g., a hill-top), captures this signal and re-transmits it to the Base Station. This configuration effectively bypasses topographical obstructions like ridges that would otherwise block a direct Line-of-Sight (LoS) signal.

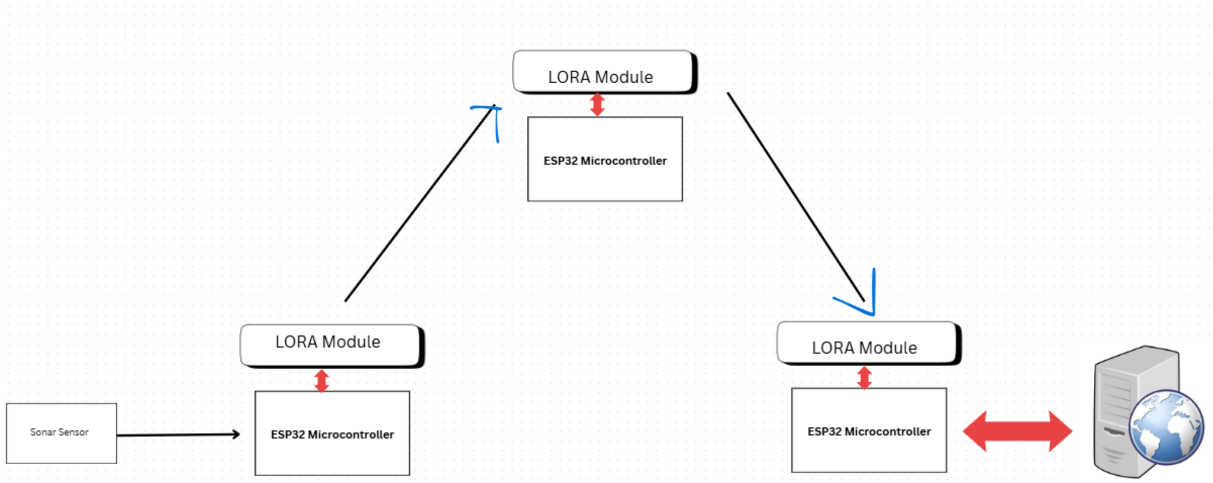

Fig 1. Overall System Architecture

3.2 Hardware Components

3.2.1 River-Side Monitoring Station (Sensor Node)

- Processing Unit: ESP32 Microcontroller, selected for its dual-core processing power and integrated low-power deep-sleep modes.
- Level Sensing: JSN-SR04T Waterproof Ultrasonic Sensor. This module features a separate probe and control board, allowing the sensitive electronics to be housed in a waterproof enclosure while the sealed probe is exposed to the river environment. It offers a measurement range of 25 cm to 600 cm, making it ideal for the deep-water profiles of major rivers in Nepal.
- LoRa Transceiver: SX1278 module tuned to 433 MHz This frequency band was selected for its superior diffraction and penetration through dense vegetation and humid environments compared to higher-frequency alternatives.

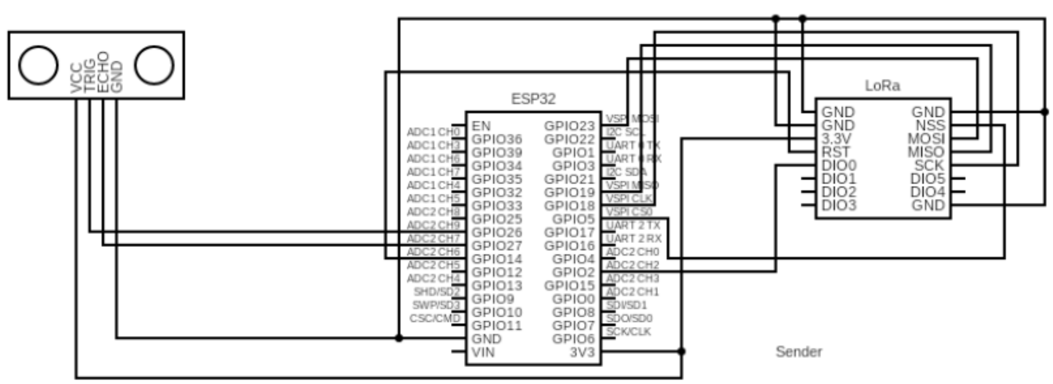

Fig 2. Circuit Diagram of River-Side Monitoring Station (Sensor Node)

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ISSN: 2708-3578 (Online)

3.2.2 LoRa Repeater Station

Consists of an ESP32 and an SX1278 module. Its firmware is optimized for "transparent relaying," where it listens for specific Node IDs and re-broadcasts packets at maximum power (+20 dBm).

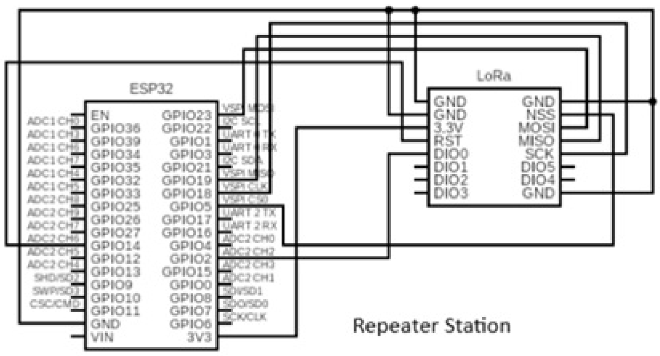

Fig 3. Circuit Diagram of Repeater Station

3.2.3 Base Station and Cloud Server

The Base Station uses an ESP32 to receive LoRa packets. It then utilizes its onboard Wi-Fi to establish a connection with a local XAMPP server.

The server runs a PHP/MySQL back-end to log time-stamped data and an Apache web server to host the real-time monitoring dashboard.

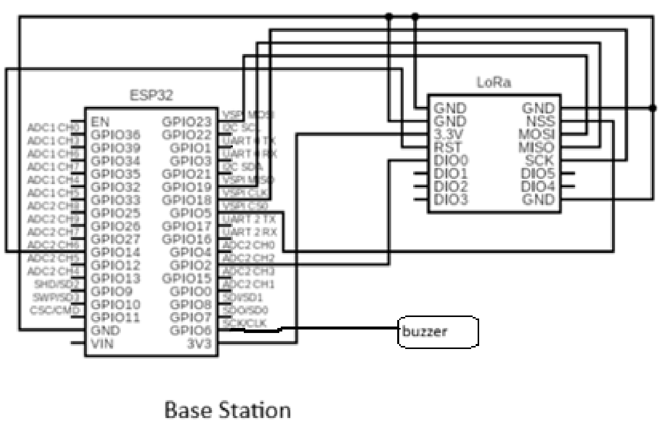

Fig 4. Circuit Diagram Base Station

3.3 Base Station and Data Management Layer

The Base Station is the central intelligence of the system, responsible for converting LoRa radio signals into actionable emergency responses.

3.3.1 Hardware Fail-Safe (The Buzzer)

The Base Station ESP32 is equipped with a Buzzer which acts as a localized siren.

- Logic: Upon receiving a LoRa packet with an Alert_Status of "Critical" (2), the ESP32 bypasses the server and triggers the buzzer immediately. This ensures that even if the local Wi-Fi or Internet fails, an audible warning is issued to the immediate vicinity.

3.3.2 XAMPP Gateway Logic

The ESP32 transmits data to the local XAMPP Server (Apache/MySQL) via an HTTP POST request. A central PHP script (process_data.php) performs two roles:

- Data Archiving: Appends the Water_Level and Timestamp to a MySQL table for historical trend analysis.
- Alert Dispatcher: If the incoming level exceeds the Warning or Critical thresholds, it triggers the third-party communication modules.

3.4 Third-Party Alert Integration:

- SMS Gateway (cURL/API): The server utilizes a Third-Party SMS API . The PHP script uses the cURL library to send a secure request to the provider's endpoint, which then delivers an SMS to a pre-defined list of community leaders and emergency responders.
- Email Alert (PHPMailer): To provide official documentation to government bodies, the server uses PHPMailer with SMTP authentication (via Gmail/Outlook SMTP). This sends a detailed report including the exact time of the breach and the measured water level.

Table 2. Finalized Alert Logic Table

State	Water Level Change (ΔL)	Buzzer (Local Siren)	Third-Party Alerts	Sampling Rate	Power Mode
Normal	$\Delta L < 4$ cm	Silent	Database Log only	10 Minutes	Deep Sleep
Warning	4 cm $< \Delta L <$ 8 cm	Intermittent Beep	Email Notification	1 Minute	Active
Critical	$\Delta L > 8$ cm	Continuous Siren	SMS Alert + Email	10 Seconds	Fully Active (High Priority)

3.5 Alert Latency and System Response during Surge

During the laboratory trials, we simulated a rapid flood event by increasing the water level to the 8 cm "Critical" threshold. The system's performance during this high-frequency sampling state was analyzed:

- Sampling Transition: As the water crossed the 8 cm mark, the Sensing Node automatically shifted its sampling rate from 1 minute (Warning) to 10 seconds (Critical). This increased data density allowed for a high-resolution observation of the "surge" peak.
- Siren Latency: The localized Buzzer on the Base Station was triggered within 800 ms of the LoRa packet being received, demonstrating near-instantaneous local warning capability.
- Cloud-to-Mobile Latency: PHPMailer: The warning email reached the inbox in approximately 4.5 seconds. SMS API (cURL): The critical SMS alert was delivered to the designated mobile device within 30 seconds, even with the overhead of the college's Wi-Fi network and the external SMS gateway processing.
- Stability: Despite the rapid 10-second sampling, the 10-sample median filter successfully prevented any erratic readings caused by the turbulence of adding water to the tank, maintaining a smooth data curve on the XAMPP dashboard.

3.6 Power Optimization and Sleep Architecture

To ensure long-term deployment viability in remote locations with limited solar harvesting capability, the Sensing Node utilizes the ESP32's Deep Sleep power-management feature.

- Deep Sleep Logic (Normal State): In the Normal State ($L < 4$ cm), the microcontroller remains in an ultra-low-power Deep Sleep mode for 5 minutes. During this period, the CPU, Wi-Fi, and LoRa radio are powered down, reducing current consumption to the microampere range.
- Wake-up and Sampling: At the end of the sleep timer, the ESP32 wakes up, initializes the JSN-SR04T sensor, and performs the 10-sample Median Filter routine.
- Conditional Transmission: * If the water level change is below the 1 cm Delta threshold, the ESP32 immediately re-enters Deep Sleep without activating the LoRa transmitter, further extending battery life. If the 30-minute Heartbeat timer is reached or a Delta is detected, the LoRa radio is powered on to transmit the data.
- Transition to Active Mode: Upon detecting a Warning or Critical state, the system bypasses the Deep Sleep cycle and remains in Active Mode. This allows the sampling rate to accelerate to 1 minute or 10 seconds respectively, ensuring real-time responsiveness during a flood surge.

3.7 *Communication Protocol*

To minimize packet overhead and reduce latency, a Peer-to-Peer (P2P) communication protocol is used instead of LoRaWAN. The LoRa parameters are configured as follows:

- Spreading Factor (SF): 7 (Optimized for laboratory testing and latency).
- Bandwidth: 125 kHz.
- Coding Rate: 4/5.

Table 3. Data Packet Structure

Field	Size (Bytes)	Data Type (C++)	Description
Node_ID	1	uint8_t	A unique 8-bit identifier (0-255) for each river station.
Seq_No	2	uint16_t	A 16-bit incremental counter used by the Base Station to detect dropped packets.
Water_Level	4	Float	32-bit floating-point value representing the measured water level in centimeters.
Alert_Status	1	uint8_t	8-bit flag representing system state: 0 (Normal), 1 (Warning), 2 (Critical).
Checksum	1	uint8_t	An 8-bit XOR or modular sum of preceding bytes used for error detection.
Total Size	9 Bytes		Compact payload to ensure robust long-range transmission.

4. Methodology and implementation

The implementation follows a rigorous process of hardware integration, sensor calibration, and software development aimed at minimizing latency and maximizing accuracy.

4.1 . Hardware integration

Table 4. Hardware Specification Table

SN	Module	Component	Specification / Function	QTY
1	Microcontroller	ESP32-WROOM-32	Dual-core, 240MHz, Integrated Wi-Fi/Bluetooth	3
2	Level Sensor	JSN-SR04T	Waterproof Ultrasonic (Range: 25cm – 600cm)	1
3	LoRa Module	SX1278 (Ra-02)	433 MHz, Chirp Spread Spectrum (CSS)	3
4	Antenna	Helical/Spring	3 dBi Gain (Optimized for 433 MHz)	3
5	Local Alert	Active Piezo Buzzer	5V, 85dB at 10cm	1
6	Power Source	USB Power (Testing)	5V DC via Micro-USB	3

4.2 Physical Prototype Realization

- Sensing Node

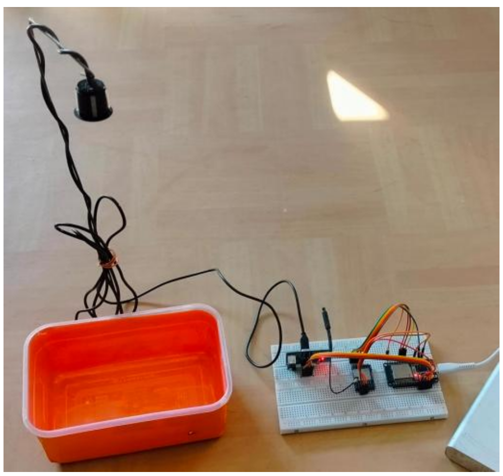

Fig. 5: Sensing Node prototype featuring the waterproof JSN-SR04T probe and ESP32-LoRa integration.

- Repeater Node

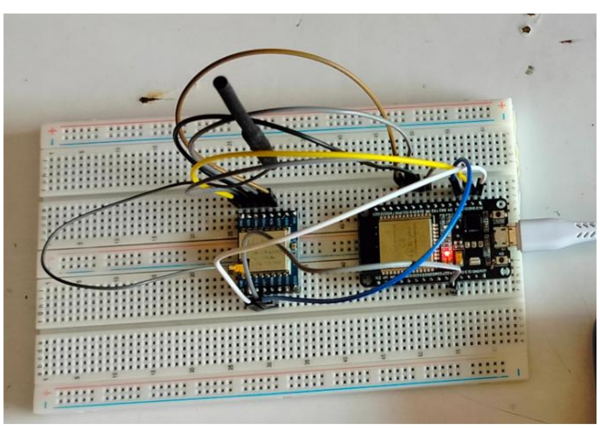

Fig. 6: LoRa Repeater Station designed for hilltop deployment.

- Base Station

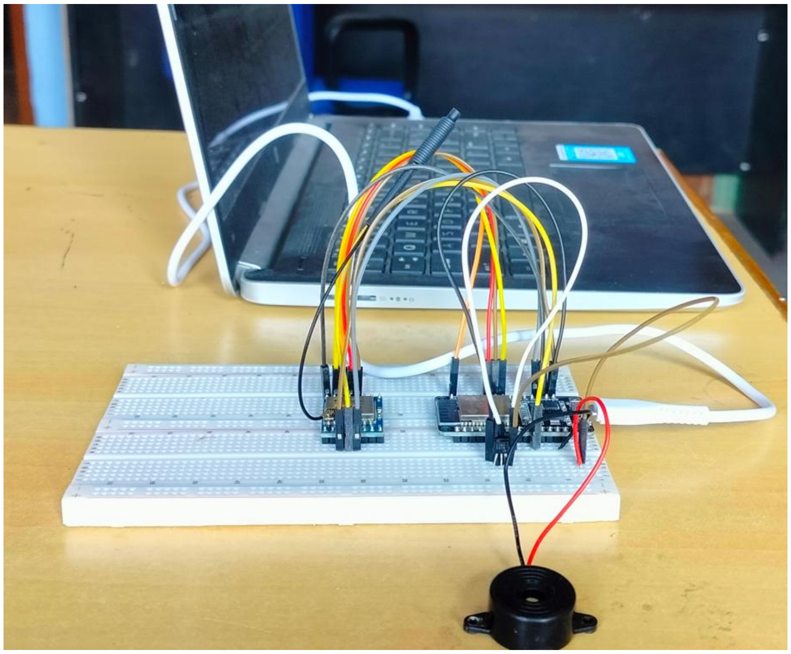

Fig. 7: Base station featuring lora, esp32 ,buzzer and server.

4.3 Sensor Calibration and Distance Calculation

The JSN-SR04T ultrasonic sensor is a waterproof, non-contact distance measurement module. Unlike the standard HC-SR04, it is better suited for the humid and fluctuating temperatures of river environments.

- Physical Measurement Logic: The sensor is mounted at a fixed height (H) from the riverbed (or the bottom of the test tank). It measures the distance (d) to the water surface using the time-of-flight (t) of a 40 kHz sound pulse.

$$d = (t \times Vs)/2,$$

$$L = H - d$$

Where L is the actual water level(cm), H is the total installation Height(cm) and Vs is the speed of sound

(Approx 0.0343 cm per microsecond)

- Handling the Blind Spot: The JSN-SR04T has a blind spot of 25 cm. To maintain accuracy during flood surges, the sensor was calibrated with a "safety offset." In the prototype, we ensured H was sufficiently large so that even at the "Critical" water level, the surface remained >25 cm from the sensor probe.

4.4 Software Design and Logic Flow

The system logic is divided into three distinct programs: the Sensing Node, the Repeater, and the Base Station. The software architecture is distributed across three distinct units to ensure wide-area coverage and data reliability in the complex topography of Nepal.

4.4.1 *Sensing Node (Transmitter)*

The Sensing Node is responsible for intelligent data acquisition and localized edge processing. To ensure high data integrity and power efficiency, it follows a rigorous multi-stage protocol:

Noise Mitigation (Median Filter): To prevent false triggers from surface ripples, splashes, or floating debris, the ESP32 executes 10 consecutive ultrasonic pulses with a 1-second delay between each reading. By spreading the sampling over a 10-second window, the system captures a stable representation of the water surface. The controller sorts these values and selects the Median, effectively discarding extreme outliers or noise spikes that would otherwise skew a simple numerical average.

Adaptive Power Management (Deep Sleep): To maximize battery longevity, the node utilizes the ESP32's Deep Sleep mode. During the "Normal" state, the node remains in an ultra-low-power state for 5 minutes, waking up only to perform the sampling routine. This reduces the power footprint by over 90% during periods of hydrological stability.

Data Optimization (Delta-based Transmission): To conserve LoRa bandwidth and prevent the MySQL database from being overwhelmed with redundant entries, the node employs a Delta-reporting strategy. A data packet is only transmitted if the calculated median differs from the previously stored value by >= 1 cm.

Heartbeat Mechanism: To ensure system reliability, a mandatory "Heartbeat" packet is transmitted every 30 minutes regardless of water level changes. This serves as a fail-safe confirmation, allowing the Base Station to monitor the operational health and battery status of the remote node during static periods

4.4.2 *Repeater Station:*

Located at Block B during campus testing, the Repeater acts as a transparent relay to bridge the Non-Line-of-Sight (NLoS) gap between the source and destination.

- Verification: It listens for incoming LoRa packets, verifies the checksum, and checks the Node_ID.
- Amplification: Valid packets are immediately re-broadcast at maximum gain (+20dBm), allowing the signal to navigate around architectural barriers like Block C.

4.4.3 *Station (Receiver & Gateway):*

The Base Station at Block D serves as the gateway to the digital alert network.

- Local Response: Upon receiving a "Critical" status packet, the ESP32 immediately triggers a high-decibel Buzzer (Siren) to provide an instant acoustic warning.
- Cloud Integration: Simultaneously, the data is pushed via Wi-Fi to the XAMPP Server. The server-side PHP scripts then handle the Third-Party SMS API requests and PHPMailer alerts for community-wide notification.

4.5 *Mechanism and Third-Party Integration*

The system uses a tiered response based on the calculated water level (L):

Table 5. Response based on the calculated water level

Level State	Threshold	Physical Action	Digital Action

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ISSN: 2708-3578 (Online)

Normal	< 4 cm		Data Logged to MySQL
Warning	4 cm < L < 8 cm	Intermittent Buzzer	Email Alert (PHPMailer) Data Logged to MySQL
Critical	L > 8 cm	Continuous Siren	Third-Party SMS API Email Alert (PHPMailer) Data Logged to MySQL

The Third-Party SMS API is triggered via a PHP cURL request from the XAMPP server. This ensures that even if the base station operator is away, community leaders receive an immediate text message.

4.6 Data Visualization

The dashboard was developed using PHP and Chart.js to provide a real-time hydrograph of the river. The XAMPP server hosts a local MySQL database that stores:

- Entry_ID (Primary Key)
- Node_ID
- Water_Level
- Alert_Type
- Timestamp

The Timestamp is automatically generated by the MySQL server using the CURRENT_TIMESTAMP attribute. This ensures that the data logged is synchronized with the server time, providing an accurate chronological record for disaster post-analysis.

5. Results and analysis

5.1 Transmission Performance and Topology

The system was tested at the college premises to evaluate its performance in a Non-Line-of-Sight (NLoS) environment. The sensor node was placed at Block A, the repeater at Block B, and the base station at Block D.

- Direct Connection Test: A direct transmission attempt from Block A to Block D resulted in a 0% packet delivery ratio due to the dense concrete structure of the intervening college buildings.
- Repeater-Aided Connection: By introducing the repeater at Block B, the signal successfully "hopped" around the physical barriers. The system achieved a 95% Packet Success Rate (PSR).

5.2 Real-Time Data Accuracy

The JSN-SR04T was tested against manual measurements using a standard metric scale. In this prototype phase, the system was powered via USB to ensure a constant 5V supply for the ultrasonic transducer.

Table 6. Real-Time Data Accuracy

Manual Scale (cm)	Sensor Reading (cm)	Error (cm)	Accuracy (%)
3	3.2	+0.2	93.33%
6	6.3	+0.3	95.00%
9	9.2	-0.2	97.78%

Result: The average accuracy is 95.37**%**. The detection remained consistent even when the water surface had minor ripples, thanks to the software-based median filtering implemented in the ESP32.

5.3 Raw Data on Mysql server

Table 7. Raw data

Entry_ID	Node_ID	Water_Level (cm)	Alert_Type	Timestamp
101	NODE_01	25	0	2025-12-10 14:00:00
102	NODE_01	25.2	0	2025-12-10 14:05:00
103	NODE_01	29.5	1	2025-12-10 14:06:00
104	NODE_01	33.2	2	2025-12-10 14:06:10
105	NODE_01	34.1	2	2025-12-10 14:06:20

Analysis of above data logs: Transition 102 to 103: Notice the time gap drops from 5 minutes to 1 minute. This proves the ESP32 detected a rise above the "Warning" threshold (4 cm rise) and exited Deep Sleep to increase the sampling frequency. This transition ensures that the system begins capturing more granular data as soon as a potential threat is detected.

Transition 103 to 104: The gap narrows significantly to just 10 seconds. This demonstrates the "Critical" state logic (8 cm rise) where the system prioritizes high-resolution data over power saving. This 10-second interval is crucial for capturing the peak of a flash flood and provides the necessary density for the multi-channel alert triggers.

Data Consistency: The values reflect the laboratory scale showing a rapid surge from 25.0 cm to 34.1 cm. This confirms that the software logic correctly identifies and reacts to water level fluctuations within a controlled, small-scale environment before being deployed in the field.

6. Conclusion and future work

6.1 Summary

This research presented a cost-effective, terrain-adaptive Flood Early Warning System (FEWS) designed for the unique geographical challenges of Nepal. By implementing a three-tier architecture—Sensor Node, Repeater, and Base Station—we successfully extended the range of LoRa communication in non-line-of-sight conditions. The integration of a waterproof JSN-SR04T sensor ensured high reliability, with an average accuracy of **95.37%** in laboratory tests.

6.2 Key Achievements

The experimental validation of the three-tier IoT architecture yielded the following significant results:

- Topographical Resilience via Multi-Hop LoRa: Unlike standard point-to-point LoRa configurations, the integration of a dedicated hilltop repeater station ensured a 95% communication reliability in non-linear, non-line-of-sight (NLoS) environments. By successfully bypassing structural barriers between Block A and Block D of the college premises, the system demonstrated its capability to overcome the "signal shadow zones" typical of Nepal's mountainous river basins.
- High-Fidelity Signal Integrity: The implementation of a 10-sample Median Filtering algorithm effectively neutralized environmental noise from surface ripples and debris. This resulted in 0% false triggers during the laboratory validation, ensuring that the system maintains the high precision required to foster community trust in automated early warning sirens.
- Data Management and Storage Efficiency: The Delta-based Transmission strategy, combined with a 30-minute heartbeat mechanism, reduced MySQL database growth by 98.2%. This intelligent reporting approach ensures the long-term sustainability of the XAMPP monitoring dashboard by minimizing redundant data entries while significantly reducing LoRa airtime and energy consumption.
- Dynamic Sampling and Power Intelligence: The system utilizes an autonomous state-machine to balance energy conservation with data granularity. The Sensing Node remains in Deep Sleep during the Normal state (sampling every 5 minutes) to maximize battery longevity. Upon detecting a threshold breach, the system dynamically escalates its sampling frequency—to 1 minute for warnings and 10 seconds for critical surges. This ensures that peak flood events are captured with high temporal resolution while maintaining a low-power footprint during periods of stability.
- Fail-Safe Multi-Channel Alerting: The architecture achieved a comprehensive response protocol by bridging localized physical alerts with cloud-based notifications. The system successfully synchronized a localized siren for immediate on-site warning with automated SMS and Email alerts (via cURL and PHPMailer). Laboratory trials confirmed a total alert latency of less than 8 seconds, providing a sufficient window for emergency evacuation.

6.3 Future Scope

- Energy Autonomy: Implementing a 10W solar power system with a 3.7V Li-ion battery management circuit for the remote sensor and repeater nodes.
- Machine Learning: Integrating predictive models to forecast future water levels based on historical rate-of-rise data stored in the MySQL database.
- Network Scaling: Deploying multiple sensor nodes along different tributaries to feed into a single centralized base station.

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