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Innovative Flood Monitoring System: Enhancing Disaster Response and Community Safety

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Abstract: The study evaluated the Flood Monitoring and Warning System of the Disaster Risk Reduction and Management Office (DRRMO) in Kabankalan City, Negros Occidental, Philippines. It focused on the system's reliability in recording flood levels, calling for emergency response promptly, and distributing warning messages accurately to the community. The research included 53 DRRMO personnel and 169 residents of Barangay 8, a flood-prone area. Initial assessments by DRRMO personnel indicated very good ratings for recording flood levels and emergency calls, and an excellent rating for sending warning messages. Residents rated the flood monitoring application interface as excellent and communication with DRRMO as very good. Interviews with DRRMO personnel emphasized the need to upgrade the system's recording features, resident alerts, and real-time updates. The new flood monitoring system was developed using a microcontroller and ultrasonic sensors to measure water levels and alert authorities to potential flood risks. The system was well-received, with high effectiveness ratings for monitoring applications, warning message distribution, and emergency response calls. The study demonstrated that the microcontroller-based system accurately measures water levels, effectively sends alerts, and is highly acceptable to end-users. The findings suggest that the innovative flood control system significantly enhances flood management in Kabankalan by providing precise, timely information to emergency responders and the community, thus improving the overall efficiency of flood management effort.

Keywords: *Flood Monitoring System, Microcontroller, Ultrasonic Sensors, Early Warning Systems, Global System for Mobile Communication.*

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I. INTRODUCTION

Typhoons are the most common natural disaster in the Philippines. The Philippines is susceptible to tropical cyclones due to its geographical location, which often bring torrential rains, floods over large areas, and powerful winds, resulting in considerable human casualties and agricultural and property loss.

Typhoon Rai, also known as Typhoon Odette in the Philippines, was a powerful tropical cyclone that devastated the country in December 2021 (5). It made landfall in the Mindanao provinces of Surigao del Norte and Dinagat Islands, five provinces in the Visayas, including Kabankalan City, and the island of Palawan in Luzon before leaving the Philippine area of responsibility on December 17th. Typhoon Rai was reported to have impacted thirteen million people in the Philippines, damaging a number of government and private institutions. Damages were estimated to reach PHP 5 billion (USD 88 million) in the aforementioned region, PHP 20 billion (USD 352 million) in Siargao, and PHP 5.9 billion PhP (USD 104 million) in Negros Occidental, including Kabankalan City.

To address the challenges posed by the lack of flood monitoring technology, the researchers propose to create a system which will use a technology to accurately and consistently monitor flood levels in vulnerable areas. The system will also provide real-time data to local authorities and communities and notify residents via Short Messaging System (SMS) when the water level reaches a critical threshold, ensuring that everyone is promptly informed and can take necessary precautions by providing accurate and timely information (1).

According to (8) the use of technology in early warning systems is a critical aspect of disaster preparedness because these systems can help save lives and protect not only individuals but also critical infrastructure and facilities (7,8). The importance of early warning cannot be overstated because it allows people to take the necessary precautions and evacuate the affected areas in a timely manner (2, 3, 4, 6, 9).

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II. MATERIALS AND METHODS

This study adopts a mixed research approach employing assessment and enhancing the existing system used by the DRRMO office for addressing concerns during flood emergencies and the development of proposed prototype to address the concerns identified during pre-evaluation.

➢ *Participants*

Participants of this study were drawn using random sampling technique and the sample size was calculated using Slovin's formula.

Table 1 Distribution of Participants

Variables	Population	Sample Size
DRRMO Office staffs	60	53
Community	300	169
Total	330	198

This study employed a self-made questionnaire to gather data from respondents. The questionnaire was validated by a three-member jury, yielding a mean assessment rating of 4.00, indicating validity. The instrument's reliability was tested using Cronbach's alpha coefficient, resulting in a high reliability score of 0.85. The questionnaire used a 5-point Likert scale, ranging from 1 (Poor) to 5 (Excellent), to assess the effectiveness of the proposed flood alert system.

Data gathering procedures involved distributing the questionnaire to DRRMO staff and residents of Barangay 8. Unstructured interviews were also conducted to gather additional insights. The collected data was tabulated, analyzed, and interpreted using weighted mean and statistical tools.

The study ensured ethical standards by obtaining informed consent from participants, safeguarding their dignity and well-being, and maintaining confidentiality of research data.

The Kabankalan City Flood Alert Management System was developed using ultrasonic water level sensors to detect flood levels and provide real-time data to residents and DRRMO staff. The system's effectiveness was evaluated through acceptability testing, using the same survey questionnaire.

➢ *System Design*

The system consists of two modules: a Flood Alert Application for residents and a Management Information System for DRRMO personnel. Key features include real-time flood status updates, direct communication between residents and DRRMO, automated SMS alerts based on warning levels, and comprehensive report generation capabilities including flood vulnerability assessments per barangay and rescue statistics.

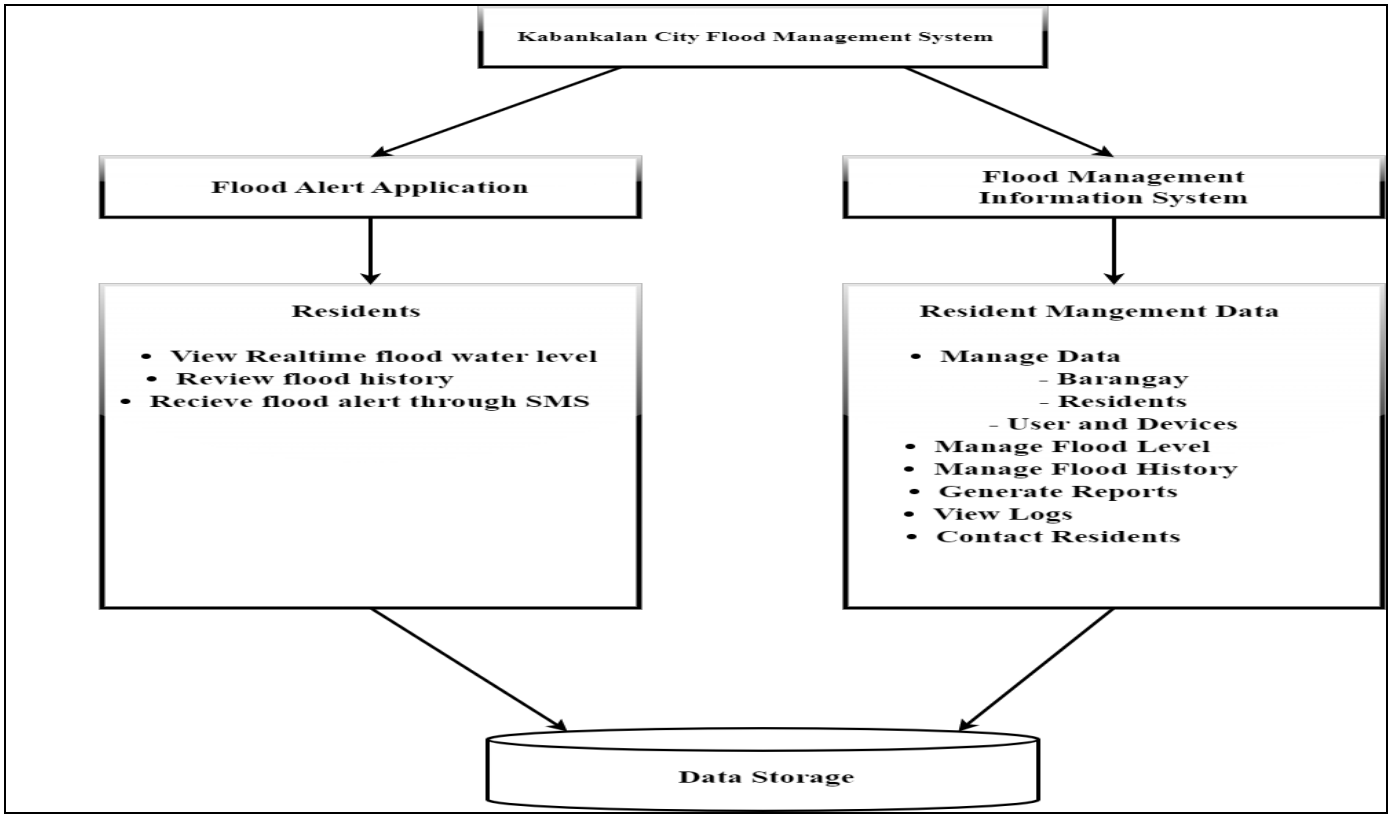

Fig 1 Proposed Conceptual Framework of Kabankalan City Flood Alert Management System

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The system could be segmented in the following development phase.

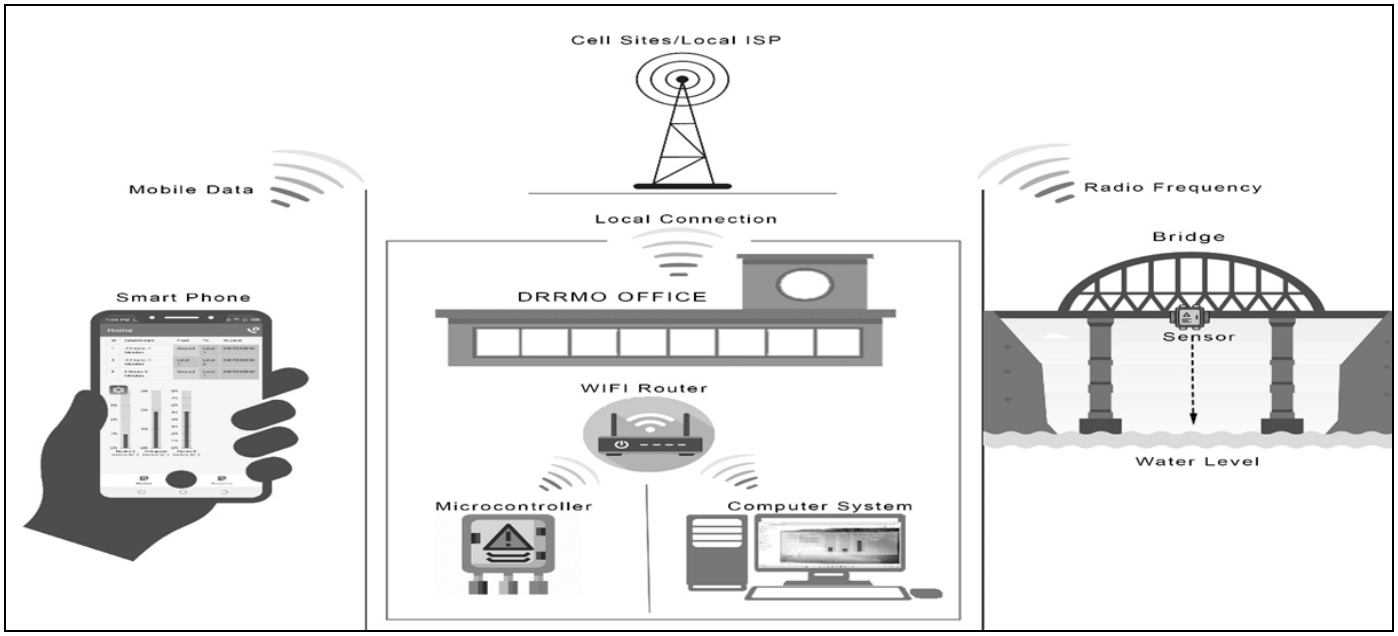

Fig 2 presents the different phases in the developing of the proposed system. It is segmented into the major four development process.

Initially the system for flood detection was first developed it is done by interfacing the microcontroller and the other components such as GSM module, and the Ultrasonic Sensors. The sensor evaluates the water level by sending ultrasound that travels through the air, and bounce if there is an object or obstacle on its path. The sensors measure the time interval between transmitted and received echoes so that the distance to the target is known. When the sensor receives the reflected wave, the distance can will be calculated using velocity equations.

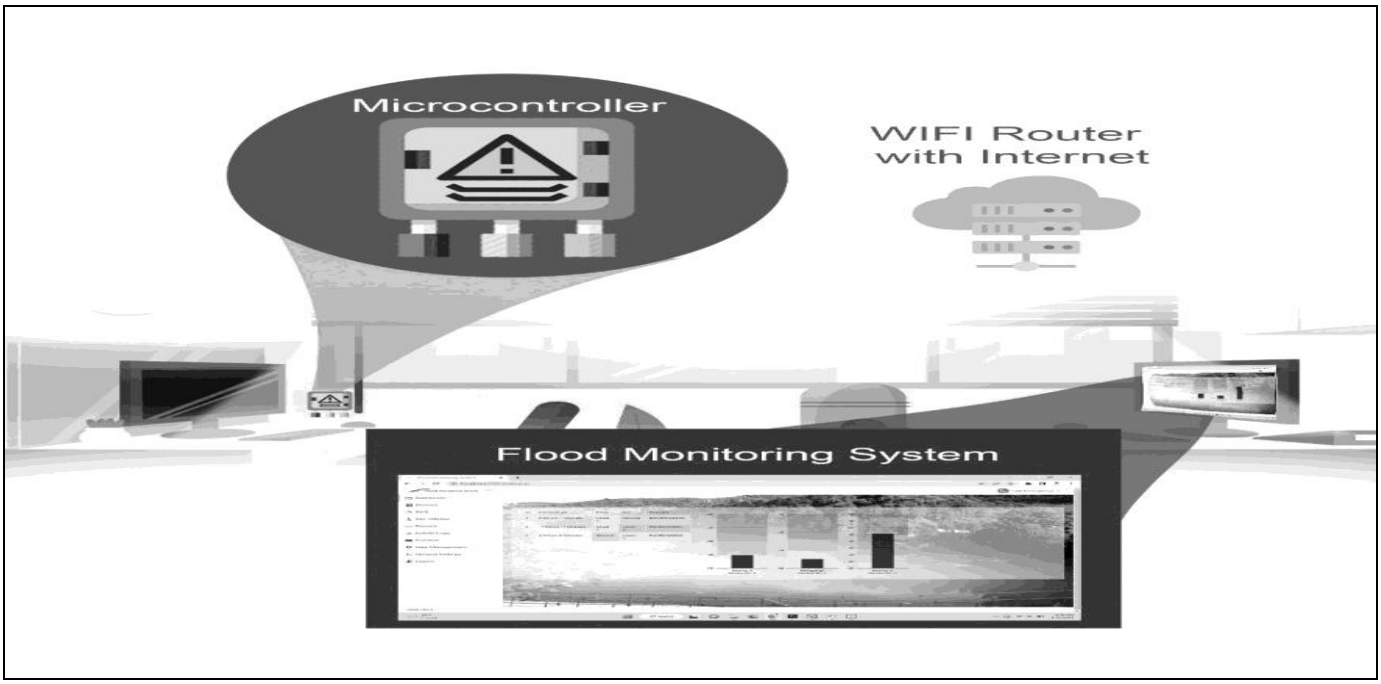

Fig 3 System Development of Kabankalan City Flood Alert Management System - Phase 1

Phase 1 of the system's implementation involves strategic placement of nodes, specifically at Camugao Bridge in Kabankalan City. The microcontroller processes data from ultrasonic sensors to determine necessary actions and sends this data to both the Flood Management Website and Mobile Application for real-time updates. Additionally, the microcontroller uses this data to command the GSM module to send critical level warnings to authorities.

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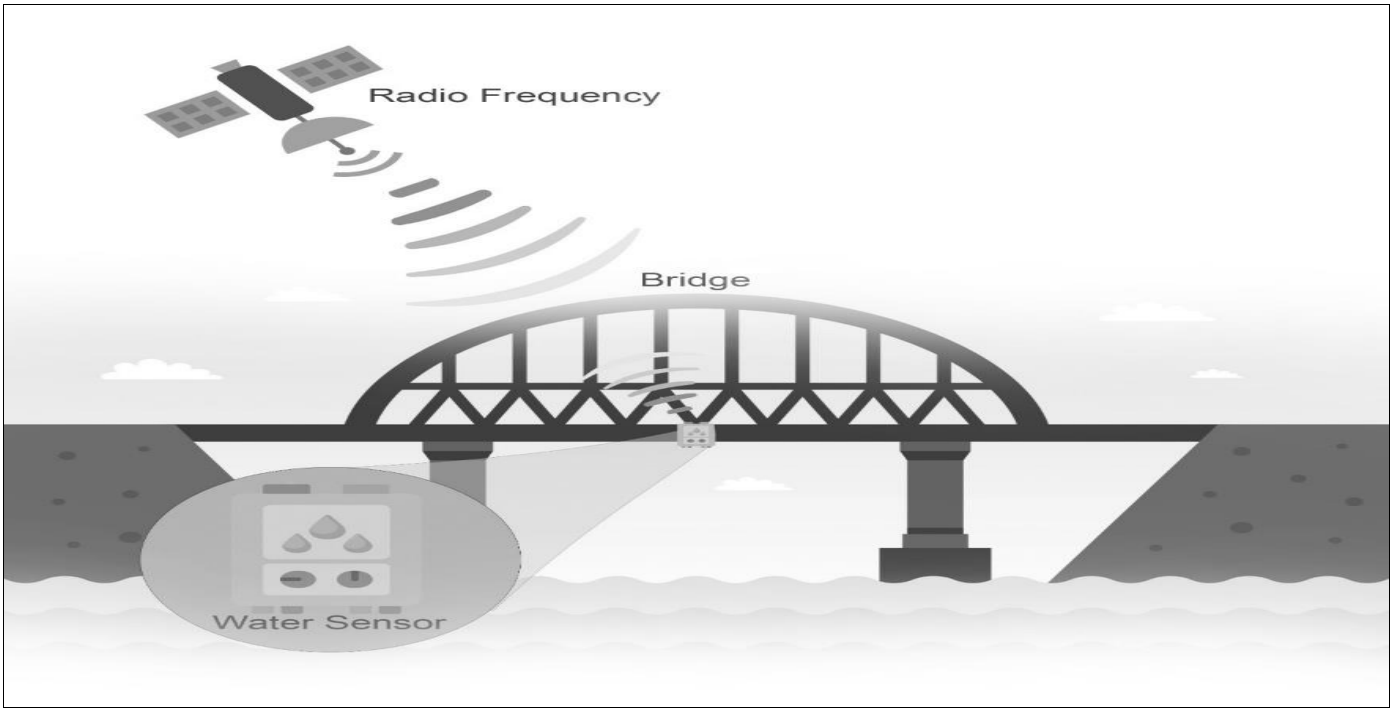

Fig 4 System Development of Kabankalan City Flood Alert Management System - Phase 2

Phase 2 of the development process is the development of Flood Monitoring/Management System as shown in Figure 5. The data measured by the sensor will be processed and reflected on its corresponding level on the flood water level interface. The computer used as screen should be connected to a stable network.

Fig 5 System Development of Kabankalan City Flood Alert Management System – Phase 3

Following deployment, the system will be utilized at the DRRMO, the server responsible for monitoring flood water levels. Authorities will receive and respond to emergency calls and send warning messages when water reaches critical levels. The DRRMO office's existing operations involve reliance on radio frequency for emergency response calls from residents, which are received by designated personnel who also issue warning messages and alerts when water levels become critical.

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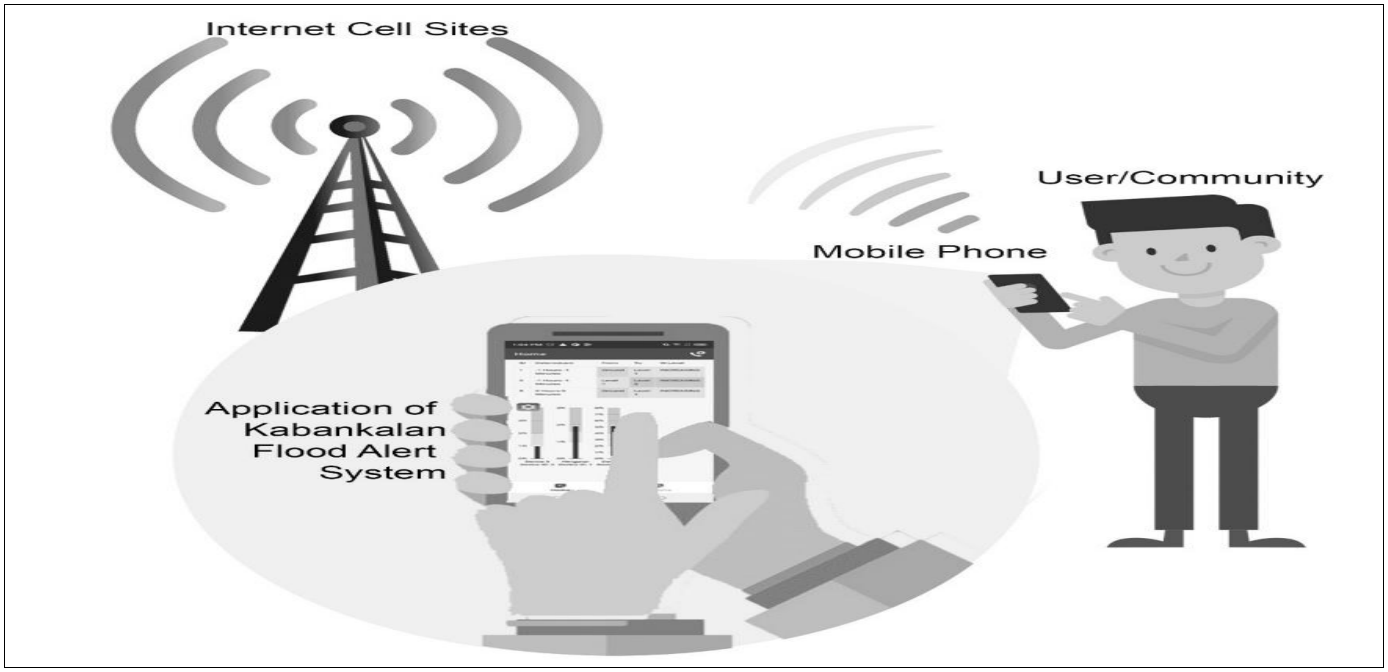

Fig 6 System Development of Kabankalan City Flood Alert Management System Phase 4

Upon successful implementation of the water level detection system and monitoring interface for DRRMO personnel, a complementary mobile application was developed to provide residents with real-time flood water level data. As illustrated in Figure 6, the mobile application offers features such as auto-click call options during emergencies and access to flood water level history. The developed mobile app will be made available to authorized personnel and residents, with its functionality dependent on mobile data connectivity. The DRRMO office's existing operations involve reliance on radio frequency for emergency response calls from residents, which are received by designated personnel who also issue warning messages and alerts when water levels become critical.

➢ *System Architecture*

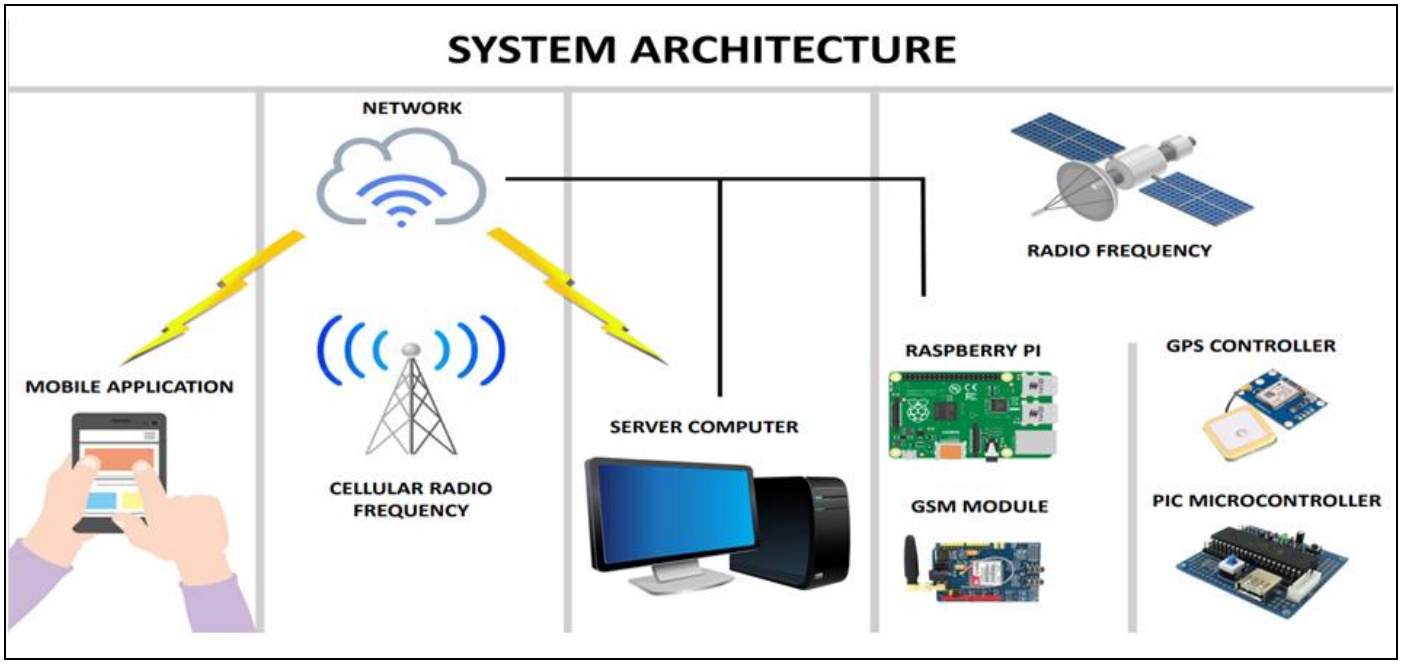

Fig 7 Proposed Network Diagram of Kabankalan City Flood Alert Management System

The diagram above shows how physically and technically the Kabankalan City Flood Management System will be implemented. The Nodes from the bridges will get the GPS coordinate from the satellite which will be used in the map. The sensor will send the data through the internet towards the server. The management information system will use this data on what action should be taken, including the SMS to the residents when flood level reaches the warning level through their registered numbers.

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➢ *System Architecture / Implementation*

The Three-Tier Web-based Software Architecture was adopted by the proponent for the Kabankalan City Alert Management Flood System. (1) PHP, a server-side HTML embedded scripting language used in developing the front-end of the system; (2) JQuery, a client-side scripting language used in developing the functional business logic of the system and application; and (3) MySQL, an open source database used for data storage.

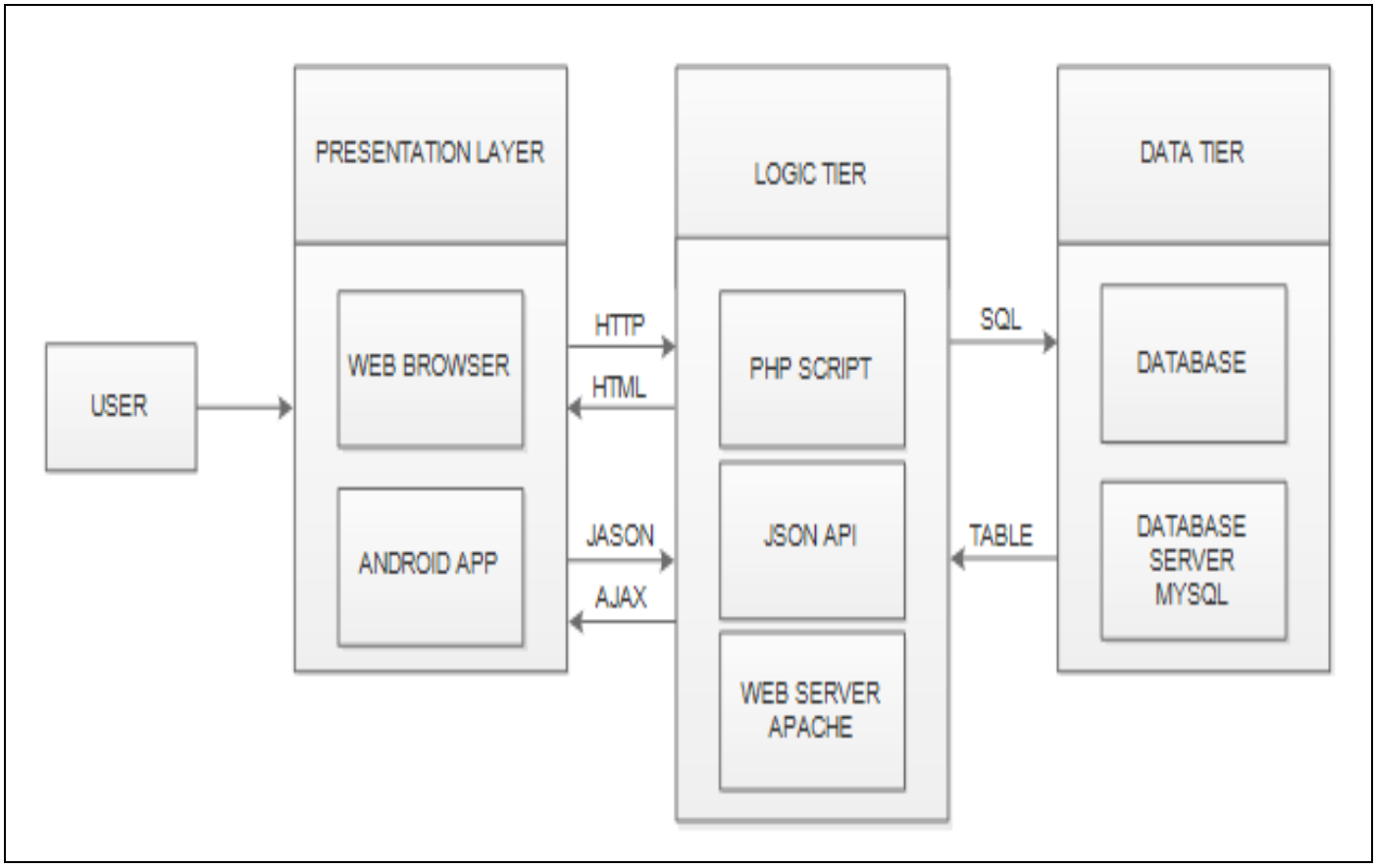

Fig 8 Proposed Three-Tier Web based Architecture of Kabankalan City Alert Management System

The user accessed the system in the presentation tier by using any compatible web browser and an Android phone to use the application. Interaction with client-side scripts (e.g., JQuery) was supported, and user inputs for various form controls were accepted. All requests are provided and displayed in HTML format. Apache enabled application capability in the application tier by conducting comprehensive data processing from the presentation tier. It accepted user queries and requested relevant data from the data tier. As a result, thousands of concurrent users, multithreading, and caching were supported. It also computed and processed the generated data before returning to the display tier with HTML. The interaction with database was done using MySQL queries. The returned data were interpreted by the application tier and displayed in the presentation tier.

➢ *System Interfacing*

The flood monitoring system was designed with a GSM module that enables the sending of alerts to authorities in case of potential flood hazards. The system also featured an ultrasonic sensor that measured water levels in real-time. The overall interfacing of the system demonstrates how various components were connected to essential parts of the system. The ultrasonic sensor was connected to the Microcontroller board, which processed sensor data and sent alerts via the GSM module. The system's power source ensured reliability even during power outages. Its design ensured ease of installation and use, requiring no technical expertise or specialized equipment. The flood monitoring system demonstrated a high level of accuracy and reliability in detecting potential flood hazards and sending alerts to authorities, making it an effective tool in disaster risk reduction and management.

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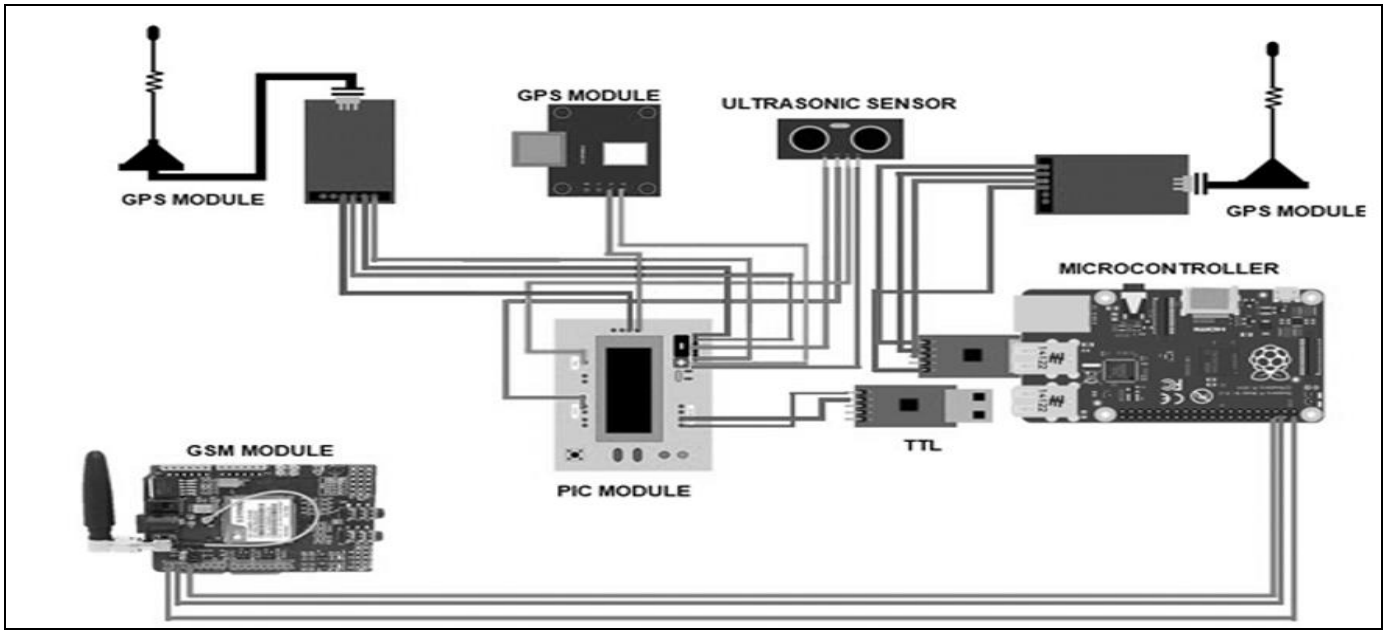

Fig 9 System Interfacing

➢ *System Testing*

The development of the Kabankalan City Flood Alert Management System involved rigorous testing phases. Unit testing ensured that individual components functioned properly, while integration testing verified seamless communication between components. Troubleshooting and debugging addressed errors and issues encountered during testing, enhancing the system's performance.

Acceptance testing, conducted through simulated flood scenarios, demonstrated the system's accuracy and reliability in detecting and reporting flood levels. The system successfully sent warning SMS to registered personnel, confirming its effectiveness in providing timely flood warnings. The Kabankalan City Flood Monitoring System met the expectations of residents and DRRM officials, offering direct access to emergency responders during flood emergencies. Evaluation results showed high acceptability and strong correlation with respondent expectations in terms of design, materials, cost, and system performance.

III. RESULTS AND DISCUSSIONS

The development of Kabankalan City Flood Management System aimed to provide a flood management system to both the DRRMO staff and personnel and the authorities and residents as the basis for their decision-making during floods and calamities, through the use of Microcontroller as the main controller is interfaced with the other components and boards such as the GSM module, the ultrasonic sensors as water-level monitoring sensor, the PIC module, and the GPS module. The system used is a combination of electronics/electrical, programming, and interfacing.

Table 2 Comparative acceptability level of Old Flood System vs. New Flood System Rated by the Community

Function	Mean Old	Interpretation	Mean Proposed	Interpretation
Flood Monitoring Application Interface	4.2307	Excellent	4.2396	Excellent
Communication with DRRMO	3.6608	Very Good	3.6686	Very Good

Table 2 shows the comparative survey of the traditional flood system to the proposed system as rated by the community. In terms of the flood monitoring application interface, the mean score for the proposed system is 4.2396, indicating that it is rated as excellent by respondents. This is only slightly higher than the mean score of 4.2307 for the traditional flood system, which is also rated as excellent. These results suggest that the proposed system is at least as acceptable to users as the traditional system in terms of the flood monitoring application interface. Relative to the communication with the Disaster Risk Reduction and Management Office (DRRMO). The mean score for the proposed system is 3.6686, which is only slightly higher than the mean score of 3.6608 for the traditional flood system. Both scores are rated as very good. The results suggest that although there is not a big difference in the average scores between the traditional flood system and the proposed system, respondents who participated in the survey rated the proposed system slightly higher in both categories. This implies that they may see some benefits or advantages in the proposed system compared to the traditional one.

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Table 3 Comparative Result of Old Flood System vs. New Flood System Rated by the DRRM Staff

Function	Mean Old	Interpretation	Mean Proposed	Interpretation
Recording and Monitoring Flood Levels	3.9057	Very Good	4.1226	Very Good
Call for emergency response	3.8868	Very Good	4.0566	Very Good
Sending of Warning message to the community	4.1887	Excellent	4.2830	Excellent

A comparative survey was conducted among DRRM staff to evaluate the traditional flood system and the proposed system. The results are as follows:

Recording and Monitoring Flood Levels: The proposed system (mean rating: 4.12) outperformed the traditional system (mean rating: 3.91), both rated "very good". This suggests the proposed system has better technology or methods for tracking water levels.

Emergency Response: The proposed system (mean rating: 4.06) received a higher rating than the traditional system (mean rating: 3.89), both rated "very good". This implies the proposed system is more effective and efficient in alerting emergency responders.

Sending Warning Messages: The proposed system (mean rating: 4.28) excelled over the traditional system (mean rating: 4.19), both rated "excellent". This suggests the proposed system's advanced communication technology makes warning messages more accessible and understandable to the community.

Overall, the proposed system demonstrated advantages over the traditional system in recording and monitoring flood levels, emergency response, and sending warning messages, indicating its potential to be more effective in alerting the community and reducing flood-related risks.

➢ *Technologies and Features Needed to Address the Identified Shortcomings of the Current Flood Systems*

Based on the interview among DRRM staff, the following are the noted important aspects that should be incorporated into the proposed system in order to improve the current and traditional flood system. These include:

- *Recording Feature.*

The current system lacks a recording system for previous flood levels, and there is no historical data available. As a recommendation, the DRRM suggests that the proposed system should incorporate a feature for recording previous flood levels.

- *System to Alert the Recipients.*

Prompt and immediate notification to the community regarding flood levels is crucial. The traditional system, which uses a trumpet, may not be effective in providing real-time alerts. Therefore, it is recommended that the proposed system should utilize a system that can quickly and efficiently alert recipients about flood levels.

- *Real-time Updates.*

The current flood systems lack real-time updates of flood levels, and the community may only access updates through social media such as Facebook or not receive updates at all. According to the DRRM staff, the proposed system must have an application that allows recipients to view real-time updates of the flood level.

Best Features of the Proposed Flood Control System in Terms of Response Time for Sending Alerts and Warnings to Residents as Feedback by the Stakeholders

Based on the interview among DRRM staff and recipients, the following are the best features of the proposed flood control system in terms of response time for sending alerts and warnings to residents:

- *Use of SMS to Alert the Recipients of Flood Levels.*

The use of SMS to alert recipients of flood levels was found to be highly effective. This feature allows for quick and efficient communication of critical information directly to the recipient's mobile device, enabling them to take immediate action to protect themselves and their property.

- *Use of Mobile Application to View the Real-Time Update of Flood Levels.*

The use of a mobile application that provides real-time updates of flood levels was also deemed highly effective. This feature enables residents to access up-to-date information on flood levels in their area, allowing them to make informed decisions regarding evacuation or other safety measures.

Table 4 Effectiveness of the Proposed System in Enhancing Flood Management in Kabankalan, in Terms of its Ability to Reliably Record and Monitor Flood Levels, Speed and Effectiveness of Emergency Response, and Timely and Accurate Distribution of Warning Messages to the Community

Items	Mean	Interpretation
Flood Monitoring Applications	4.2396	Highly Effective
Recording and monitoring of flood level	4.1226	Very Effective
Call for emergency response	4.0566	Very Effective
Sending of warning message to the community	4.2830	Highly Effective

The effectiveness of the proposed flood control system in enhancing flood management in Kabankalan was evaluated based on its ability to reliably record and monitor flood levels, speed and effectiveness of emergency response, and timely and accurate distribution of warning messages to the community. The results are as follows:

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The flood monitoring application of the proposed system received a mean score of 4.2396, indicating high effectiveness in enhancing flood management. This feature enables real-time monitoring and tracking of flood levels, facilitating quick and effective responses to potential hazards.

The recording and monitoring of flood levels garnered a mean score of 4.1226, signifying very effective enhancement of flood management. This feature provides accurate recording and tracking of flood levels, offering valuable data for future flood management efforts.

The emergency response call feature obtained a mean score of 4.0566, denoting very effective enhancement of flood management. This feature allows for swift and efficient alerting of emergency responders in the event of a flood, enabling immediate action to mitigate potential damage and save lives.

The sending of warning messages to the community achieved the highest mean score of 4.2830, indicating high effectiveness in enhancing flood management. This feature facilitates rapid and precise distribution of warning messages to the community, empowering residents to take necessary actions to protect themselves and their property.

These findings collectively suggest that the proposed flood control system is highly effective in enhancing flood management in Kabankalan. By integrating innovative technologies with real-time monitoring and tracking capabilities, the system provides accurate and timely information to emergency responders and the community, thereby improving the speed and efficacy of flood management efforts.

IV. CONCLUSION AND RECOMMENDATION

➢ *Conclusion*

The findings of this study indicate that the proposed flood control system is at least as acceptable to users as the traditional system and exhibits advantages in certain aspects, particularly in its capacity to record and monitor flood levels, initiate emergency responses, and disseminate warning messages to the community. The system's integration of features for recording previous flood levels, real-time alerting, and provision of live updates to the community underscores its potential to enhance the current flood management framework.

The proposed flood control system has demonstrated high effectiveness in improving flood management in Kabankalan, notably in reliable flood level recording and monitoring, swift and effective emergency response, and timely warning dissemination. The utilization of SMS alerts for flood level notifications and the mobile application for real-time updates were identified as standout features, contributing to expedited response times for alert and warning dissemination to residents. These results imply that the proposed system holds promise for saving lives and mitigating property damage through more rapid and efficacious responses to potential flood hazards.

➢ *Recommendations*

Based on the survey results, the following recommendations are proposed for further development of the project:

- The Kabankalan City Flood Monitoring System could serve as a foundational model for future flood monitoring initiatives in the city and beyond, with further research exploring avenues to enhance system accuracy, reliability, and cost-effectiveness.
- Installing multiple sensors in flood-prone areas would provide comprehensive water level and flood hazard data, enabling targeted mitigation strategies.
- Regular maintenance and calibration of system components are crucial for optimal performance and reliability, involving periodic inspections, repairs, and software updates.
- Implementing a more stable and durable power source, such as a higher-rated solar source, would enhance system reliability.
- Developing an alternative local network would facilitate communication during network outages, ensuring uninterrupted system functionality.

By implementing these recommendations, the accuracy, reliability, and effectiveness of the flood monitoring system can be improved, contributing to enhanced disaster risk reduction and management efforts in Kabankalan City and beyond.

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