

Flood Relief Management System for Multi-Agency Disaster Response

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ABSTRACT

Flooding places recurrent pressure on disaster-response agencies in Malaysia, where fragmented communication, delayed resource distribution, and limited operational visibility can reduce the effectiveness of relief activities. This study develops and validates a Flood Relief Management System (FRMS) that integrates real-time water-level monitoring with centralized coordination of humanitarian resources and rescue activities. The system combines an ESP32 microcontroller, a non-contact ultrasonic water-level sensor, a local liquid-crystal display and traffic-light alert module with a web dashboard supported by MySQL and Firebase databases. Development followed an Agile, stakeholder-informed process and was validated through user acceptance testing involving 15 stakeholders from government, non-governmental organizations, emergency services, community leadership, and flood-affected groups. Three operational workflows were assessed. Live telemetry and threshold configuration achieved a 100.0% task-completion rate with a median execution time of 4.5 s and a usability rating of 4.8/5. Donation and resource tracking achieved 93.3% completion in 8.2 s with a rating of 4.6/5, while rescue dispatch routing achieved 86.7% completion in 10.5 s with a rating of 4.5/5. Page loading remained below 1.2 s in the tested configuration. The findings indicate that a lightweight, shared digital platform can improve situational visibility and support more coordinated multi-agency flood relief operations.

1. Introduction

Flooding remains one of the most consequential hazards affecting communities, infrastructure, and public services, particularly in rapidly urbanising and climate-exposed regions. Research on urban flood resilience and vulnerability shows that effective disaster management requires not only hazard reduction but also rapid communication, preparedness, and coordinated response among institutions and communities [15-17]. In Malaysia, recurrent monsoon flooding creates a demanding operational setting in which public agencies, rescue services, non-governmental organisations (NGOs), and affected communities must exchange information and mobilise resources within short response windows.

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Digital flood-management research has produced increasingly capable tools for environmental monitoring and decision support. Government-operated sensor networks can provide continuous water-level observations and local warning signals [4], while web-based platforms can disseminate end-to-end flood-risk information to decision makers and the public [2]. Spatial and multicriteria approaches are also widely used for flood-risk mapping, hazard prioritisation, and emergency-shelter location-allocation [5,12-14]. These technologies strengthen situational awareness, but their operational value depends on how effectively data are translated into coordinated actions during an active disaster.

A related body of research emphasises that flood response is shaped by governance arrangements, community engagement, and local knowledge. Institutional fragmentation can create overlapping responsibilities and discontinuities in information exchange [7], while community-centred studies show that local participation and trusted leadership are important for translating technical warnings into practical action [6,9-11]. Consequently, a flood-response platform should support both technical monitoring and the shared operational needs of government agencies, NGOs, rescue teams, and communities.

The research gap addressed in this study is the limited integration between real-time flood monitoring and transparent multi-agency relief coordination. Existing solutions frequently concentrate on hazard prediction, mapping, or warning dissemination, whereas the immediate operational problems of resource tracking, rescue coordination, and shared visibility remain comparatively fragmented. Addressing this gap is significant because delays or duplication in relief logistics can weaken the practical benefit of otherwise timely environmental information. Therefore, this study aims to develop and validate a Flood Relief Management System (FRMS) that combines low-cost water-level sensing, centralized web-based monitoring, humanitarian resource tracking, and rescue-team coordination in a single stakeholder-oriented platform. The study contributes a practical socio-technical design that connects environmental telemetry with multi-agency disaster-response workflows [1-4].

2. Methodology

2.1 Research Design and Stakeholder Requirements

The study adopted a stakeholder-informed system-development approach combining requirements elicitation, iterative software engineering, and operational validation. The supplied source manuscript states that semi-structured interviews, focus group discussions, and a structured questionnaire were used to identify coordination barriers and current flood-response practices among municipal personnel, community leaders, NGOs, rescue actors, and flood-affected participants. Qualitative inputs were thematically coded to translate operational needs into system requirements, while the questionnaire was used to establish baseline perceptions of existing response processes. [AUTHOR TO VERIFY/PROVIDE: the number of interview participants, focus-group participants, questionnaire respondents, sampling procedure, and any reliability statistics reported for the instrument.] Community-oriented and participatory methods are consistent with established flood-risk and disaster-risk-reduction research [6,9-11].

2.2 FRMS Hardware and Software Architecture

The FRMS hardware node was designed as a low-cost sensing and local-alert unit. It comprises an ESP32 microcontroller, an HC-SR04 ultrasonic sensor for non-contact water-level measurement, a 16x2 liquid-crystal display for on-site readings, and a traffic-light light-emitting-diode module for

visual risk indication. The microcontroller is programmed using the Arduino Integrated Development Environment. Non-contact water-level sensing is appropriate for local flood monitoring because it limits direct sensor exposure to water, debris, and sediment, while comparable sensor-network frameworks have demonstrated the operational value of automated water-level monitoring [3,4].

The web layer uses Hypertext Markup Language and Cascading Style Sheets for interface presentation, with PHP and JavaScript Object Notation used for dynamic data exchange. A MySQL relational database is synchronized with Firebase to support rapid access to sensor readings and administrative information. The architecture enables the dashboard to display water-level conditions, issue threshold-based alerts, and provide a shared digital space for resource and rescue coordination. This lightweight approach follows the broader principle of using web-based flood information systems to disseminate timely risk information to multiple stakeholders [2].

2.3 Agile Development Process

System development followed six iterative Agile phases. The first phase focused on planning and requirement elicitation, during which stakeholder inputs were translated into user stories and a prioritized product backlog. The second phase converted selected user stories into sprint-level engineering tasks. The third phase covered interface and system design, including wireframes, Unified Modelling Language diagrams, software blueprints, and code implementation. The fourth phase progressed from unit and integration testing to user acceptance testing (UAT). The fifth phase prepared the system for deployment after staged verification. The sixth phase used sprint reviews and retrospectives to capture stakeholder feedback and refine subsequent priorities. This iterative structure was intended to keep the technical implementation aligned with the operational needs identified during stakeholder engagement [1].

2.4 User Acceptance Testing

Operational validation was conducted with a panel of 15 stakeholders drawn from government institutions, local and international NGOs, emergency rescue services, community leadership, and flood-affected groups. Participants completed three predefined workflows on the FRMS dashboard: Task A, accessing live water-level telemetry and configuring alert thresholds; Task B, monitoring emergency donations and managing resource-allocation information; and Task C, coordinating rescue-team dispatch to critical locations. The evaluation recorded median task-execution time, task-completion rate, and a five-point usability rating. Dashboard loading latency was also observed to assess technical responsiveness during the simulated high-traffic validation scenario. The use of stakeholder panels for evaluating flood-related decision systems is consistent with participatory and multicriteria disaster-management practices [5,12,13].

3. Results and Discussion

3.1 Technical System Implementation

The completed FRMS integrates local water-level sensing with a web-based coordination environment. The ESP32 acts as the central controller for the ultrasonic sensor, local display, and traffic-light warning module. Water-level readings are transmitted to the cloud-connected database, allowing the same information to be viewed remotely through the dashboard. This combination provides a dual alert pathway: immediate visual feedback at the sensing site and remotely accessible

telemetry for disaster-response stakeholders. Figure 1 is intended to show the physical integration of the hardware components described in the source manuscript.



Fig. 1. Physical assembly of the FRMS hardware node including the ESP32 microcontroller, HC-SR04 ultrasonic sensor, 16x2 LCD screen, and traffic-light LED alert module

The dashboard complements the hardware node by presenting the current water-level threshold, recent telemetry, and operational information through a centralized interface. In the tested configuration, telemetry was refreshed at 10-second intervals. The interface also supported resource tracking and rescue coordination, extending the system beyond conventional early-warning functions. Figure 2 is intended to present the original dashboard interface used in the study. The design reflects the value of web-based flood-information platforms for rapid dissemination while extending that function toward shared operational coordination [2].

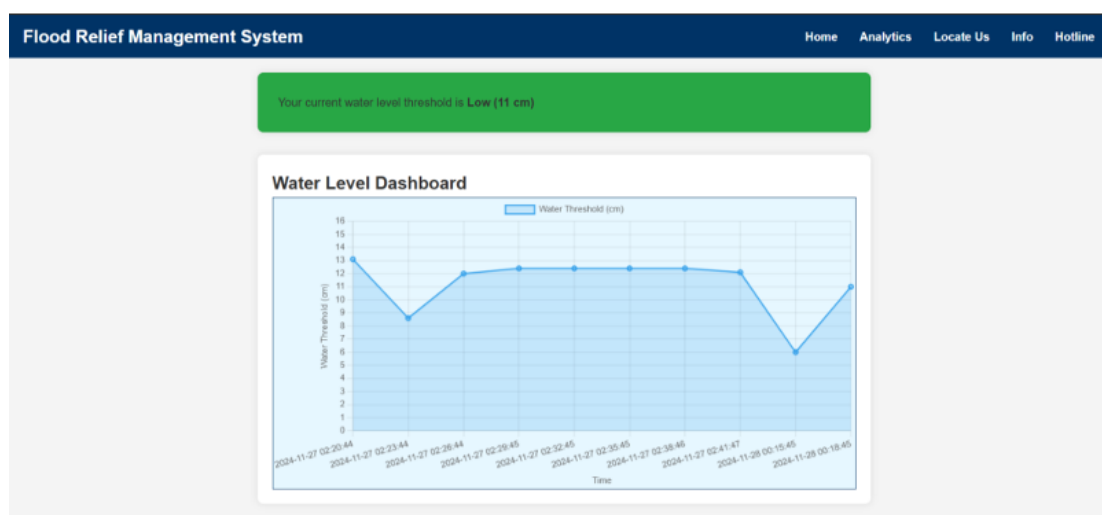


Fig. 2. Centralized web dashboard of the FRMS showing real-time water-level telemetry and active hazard-classification notifications

3.2 User Acceptance Testing Results

Table 1 summarizes the UAT results for the three operational workflows. Task A recorded the strongest performance, with all 15 participants completing the live-telemetry and threshold-configuration workflow. Tasks B and C involved more complex coordination steps and therefore produced slightly longer execution times and lower completion rates.

Table 1
Summary of stakeholder UAT
Task execution times and usability ratings

Task ID	Operational Workflow Description	Median Execution Time (s)	Task Completion Rate (%)	Usability Rating (1-5 Scale)
Task A	Live telemetry and threshold alert configuration	4.5	100.0	4.8
Task B	Humanitarian donation and resource tracking	8.2	93.3	4.6
Task C	Search-and-rescue dispatch routing	10.5	86.7	4.5

Task A achieved a 100.0% completion rate with a median execution time of 4.5 s and a usability rating of 4.8/5. Task B achieved 93.3% completion, a median execution time of 8.2 s, and a usability rating of 4.6/5. Task C achieved 86.7% completion, a median execution time of 10.5 s, and a usability rating of 4.5/5. Page loading remained below 1.2 s in the tested configuration. These results indicate that the core monitoring function was highly accessible, while resource and dispatch workflows remained usable despite requiring more operational steps. The pattern also suggests that future interface refinement should focus primarily on reducing interaction complexity in the logistics and dispatch modules rather than on the telemetry display itself.

Stakeholder feedback in the source manuscript further indicated that a shared database improved visibility of relief information and could reduce duplication in supply distribution and delays in dispatch coordination. These observations are consistent with research emphasizing the need for interoperable flood-information platforms and clearer institutional coordination [2,7]. Because the UAT panel was limited to 15 participants, however, the findings should be interpreted as preliminary evidence of usability rather than population-level proof of effectiveness.

3.3 Implications for Multi-Agency Flood Governance

The FRMS contributes to disaster-response practice by linking environmental telemetry with coordination functions that are usually handled across separate organisational channels. Flood-governance research has documented the difficulties created by fragmented responsibilities and overlapping institutional arrangements [7], while community-engagement studies emphasize that effective risk management requires information to remain understandable and actionable for non-specialist users [9-11]. By presenting sensor readings as qualitative threshold states and combining them with shared logistics information, the FRMS provides a practical interface between technical monitoring and operational decision making.

The system also illustrates a broader shift toward integrated digital flood management. Recent research has explored advanced spatial decision models, machine learning, digital twins, and other data-intensive approaches to flood-risk assessment and emergency planning [5,8,12-14]. The present study does not attempt to replace these predictive approaches. Instead, it addresses a

complementary problem: how to make timely data immediately usable by multiple relief actors once a response is underway. This distinction is important because technically sophisticated forecasts provide limited humanitarian value if agencies cannot translate them into coordinated action, resource visibility, and locally accessible warnings.

4. Conclusions

This study developed and validated a Flood Relief Management System that integrates low-cost water-level sensing, local threshold alerts, a centralized web dashboard, humanitarian resource tracking, and rescue-dispatch coordination. The system was implemented using an ESP32 microcontroller, an ultrasonic sensor, a local display and traffic-light alert module, together with a web stack supported by MySQL and Firebase. User acceptance testing with 15 stakeholders demonstrated strong usability across the three evaluated workflows. Live telemetry and threshold configuration achieved 100.0% task completion in a median of 4.5 s, while donation and resource tracking achieved 93.3% completion in 8.2 s and rescue dispatch achieved 86.7% completion in 10.5 s. Usability ratings ranged from 4.5 to 4.8 out of 5, and page loading remained below 1.2 s in the tested configuration.

The principal contribution of the FRMS is the operational integration of environmental monitoring with multi-agency relief coordination. Rather than treating flood sensing as an isolated early-warning function, the system connects telemetry with the information needs of government agencies, NGOs, rescue teams, and communities. This design can support clearer situational visibility and more transparent coordination during active flood response.

The study remains limited by its small validation panel and the localized nature of the current sensor configuration. Future work should evaluate the system with larger and more diverse user groups, conduct field trials across multiple flood-prone locations, incorporate wider meteorological and basin-level data, and examine intelligent routing or decision-support functions. Scaled deployment should also address network resilience, cybersecurity, sensor maintenance, governance responsibilities, and long-term operational funding. These extensions would help determine whether the proposed platform can evolve from a local prototype into a robust regional disaster-response infrastructure [4,8,15].

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