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Community Empowerment for Tidal Inundation Early Warning System in West Aceh Regency Indonesia

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ABSTRACT

Tidal inundation recurs at least twice annually in West Aceh Regency, yet Pasar Aceh Village previously had no Early Warning System (EWS), leaving residents unprepared for recurring flood damage. This community service program, conducted from August to November 2025 with 20 participants, implemented an integrated EWS through four activities: disaster mitigation socialization, EWS training, device installation, and simulation exercises. The program produced an EWS device, a disaster mitigation module, a web-based monitoring system, and a siren alert system. Community competence was evaluated using pre-test and post-test assessments, showing a significant increase in mean scores from 39.7 to 92.0 (a gain of 52.3 points). The installed EWS successfully delivered early warnings prior to flood events, strengthening community coordination and village disaster readiness while improving residents' sense of security in daily activities. These findings confirm that a technology-based community empowerment approach effectively enhances local resilience to tidal inundation, offering a replicable model for similar coastal disaster-prone areas.

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INTRODUCTION

Hydrometeorological disasters, particularly tidal inundation, pose a growing threat to coastal communities in Indonesia due to sea-level rise, climate change, land subsidence, and increasingly frequent extreme weather events (IPCC, 2023; Oppenheimer et al., 2019; Nicholls & Cazenave, 2010). These disasters dominate national disaster events in Indonesia (BNPB, 2024) and disrupt fisheries, trade, transportation, education, and public health in affected coastal areas (Rahman et al., 2024; Wisner et al., 2014).

West Aceh Regency exemplifies this vulnerability, with Pasar Aceh Village-located in a low-lying area adjacent to an estuary experiencing tidal inundation two to three times annually. Prior to this program, the village lacked any early warning system, and limited community knowledge of disaster mitigation and evacuation procedures further constrained adaptive capacity and preparedness (Mercer et al., 2012; Abedin & Shaw, 2023; Kelman, 2023).

Disaster risk reduction strategies have increasingly shifted from emergency response toward preparedness-based mitigation. An Early Warning System (EWS) an integrated mechanism for hazard detection, timely warning dissemination, and decision support (UNDRR, 2023) has been globally recognized as an effective means of reducing casualties and economic losses (WMO, 2023). For tidal flood contexts specifically, EWS relying on real-time water-level monitoring enables communities to act before inundation reaches residential areas, improving preparedness and reducing losses (Abedin & Shaw, 2023; Basher, 2024). However, EWS effectiveness in many regions remains constrained by limited monitoring infrastructure, unequal information access, sustainability challenges, and low community involvement (Kelman, 2023; Mercer et al., 2012), with outcomes ultimately dependent on the community's capacity to interpret and respond to warning information (Gaillard & Mercer, 2013; Shaw & Izumi, 2014; Maskrey, 2011). This underscores the need for EWS models that integrate technology with community empowerment rather than technology alone.

Recent advances in IoT-based sensors, telemetry, cloud computing, and real-time data communication have improved the speed and reliability of environmental monitoring for disaster mitigation (Hossain et al., 2024; Islam et al., 2024; Saputra et al., 2024), while IP camera-based visual monitoring further enhances field-condition verification (Dewi et al., 2023; Putra et al., 2024). Building on these developments, the 2025 Kosabangsa Program implemented an integrated EWS in Pasar Aceh Village using water-level telemetry sensors, a Single Board Computer (SBC) for data processing, GSM-based communication, IP cameras, and a cloud-based dashboard accessible to both the community and village authorities—accompanied by socialization, training, simulation exercises, and strengthened coordination with the Regional Disaster Management Agency (BPBD) of West Aceh Regency.

The main contribution of this program is the development of a Community Voice-Based Early Warning System (CV-EWS), which integrates real-time water-level monitoring with locally recorded voice warnings in place of conventional sirens or standardized alarms. By using familiar local language and voices, this approach is expected to enhance community comprehension, response speed, and trust in warning information, while IP camera verification adds a layer of real-time accuracy. Through this design, the community is positioned not merely as a recipient of warnings but as an active operator and sustainer of the system.

This program aims to implement an EWS as a means of empowering the Pasar Aceh community to mitigate tidal flood risks, strengthen collaboration among the community, village government, and BPBD, and establish a replicable community-based EWS model for other vulnerable coastal areas.

METHOD

Location and Time of Implementation

This community service activity was conducted in Pasar Aceh Village, Johan Pahlawan Subdistrict, West Aceh Regency, Aceh Province, Indonesia, from August to November 2025. Two distinct locations were used depending on the type of activity. The socialization and Early Warning System (EWS) training sessions were held in the meeting hall of the Pasar Aceh Village Office, while the installation of the EWS device and the evacuation simulation were conducted directly at the village's pier/coastal area, the location most affected by tidal flooding and selected as the sensor installation point.

Participants and Recruitment Mechanism

This activity involved 20 residents as participants, reflecting the diversity of the village community composition, consisting of general residents, community leaders, and village officials, with varied occupational backgrounds including traders, fishermen, entrepreneurs, and laborers. Participants were selected purposively by the implementation team based on direction from the Keuchik (Village Head) of Pasar Aceh, who played a role in guiding the identification of suitable candidates. The selection process prioritized alignment between candidates' skills or social roles and the operational needs of the EWS program, ensuring that the selected participants had realistic capacity to sustain the system's operation and the dissemination of warning information after the program concluded.

Socialization on Tidal inundation Disaster Mitigation

The activity was implemented through four sequential stages: (1) socialization on tidal inundation disaster mitigation, (2) EWS training, (3) EWS device installation, and (4) EWS simulation. The details of each stage are presented below to support the reproducibility of the activity.

The socialization session was conducted over one day on 18 September 2025. Prior to the session, from August to September 2025 the implementation team carried out various preparatory activities, including designing the tidal inundation EWS, assembling some of the EWS's core components, preparing the disaster mitigation module, and developing the disaster mitigation questionnaire instrument. The material delivered covered general information on tidal inundationing, including its causes, frequency, and impacts, as well as the importance of disaster mitigation for coastal communities. The material was delivered through a combination of three methods: lectures, question-and-answer sessions, and group discussions with participants.

EWS Training

The training was conducted over one day on 24 October 2025. The training material covered basic knowledge of the tidal inundation Early Warning System (EWS), introducing the EWS device itself including its components, functions, operating mechanism, and the procedures to be followed once the EWS issued a warning. The training was delivered by a resource person from Universitas Gadjah Mada with expertise in tidal inundation EWS, facilitated by the implementation team from Universitas Cipta Mandiri.

EWS Device Installation

The tidal inundation EWS device was installed on 25 October 2025. One complete EWS unit, equipped with an additional camera specification, was installed at the Pasar Aceh Village pier. The installation was carried out jointly by the implementation team from Universitas Cipta Mandiri, the accompanying team along with one technician from Universitas Gadjah Mada, and members of the participant group from Pasar Aceh Village. Device installation was performed through three sequential steps: (1) installation of the water level sensor on a stable support structure; (2) placement of the IP camera and GSM router with an adequate power supply; and (3) initial calibration against the reference water level threshold. Following installation, functional testing of the system was carried out, comprising: data transmission testing; simulation of early warning alerts on the monitoring dashboard; and inspection of signal stability and power supply reliability.

EWS Simulation

The tidal inundation EWS simulation was conducted on 26 November 2025, involving the community service implementation team, participants from Pasar Aceh Village, and the West Aceh Regional Disaster Management Agency (BPBD). The disaster response simulation employed a scenario in which a tidal inundation occurred in Pasar Aceh Village, with seawater levels reaching the predetermined critical threshold that triggered the EWS siren. Upon the siren sounding, participants were directed to gather and secure their valuables, then proceed to a predetermined safe location via prepared evacuation routes.

Tools and Materials

The EWS unit was designed and assembled by the technical support team from Universitas Gadjah Mada. The system architecture consists of five integrated main components, as summarized in Table 1.

Table 1. Components and functions of the EWS

Component	Function
Water Level (WL) Telemetry Sensor	Continuously monitors river/sea water level; connected to the SBC and GSM router.
Single Board Computer (SBC)	Processes data from the sensor and transmits it to the cloud server via a secure protocol.
GSM Router	Transmits data in real time to the central server.

Component	Function
Night Vision IP Camera	Provides visual confirmation of field conditions to validate tidal inundation/river flood events.
Cloud Server & Web Dashboard	Displays water level graphs, warning status, and camera recordings (accessible at https://ews-smog.pemantauan.online/).

Data Flow Architecture

Sensor measures water level → SBC reads the data → data is transmitted via the GSM network → server processes and stores the data → dashboard displays status → notifications can be further integrated (SMS/WhatsApp/Regional Disaster Management Agency, BPBD).

Specification of the siren which used in this EWS: an outdoor, solar-powered (15 Wp solar cell) type, enabling it to operate independently without relying on the village electrical grid.

Evaluation Instruments and Data Analysis

Data on participants' knowledge, preparedness, and other related variables were obtained through a questionnaire technique. The instrument used consisted of pre-test and post-test disaster mitigation questionnaires administered to all 20 participants before and after the program. Each questionnaire comprised 23 items measured on a Likert scale, covering six measurement aspects: understanding of disaster mitigation, understanding of early warning systems, early warning equipment, disaster simulation, the role of government, and community capacity in system management and maintenance. Scores were obtained by summing the scores of all items per respondent.

Data tabulation, descriptive statistics (mean and standard deviation), and the calculation of the Normalized Gain (N-Gain) score were performed using Microsoft Excel 2019. The N-Gain score was calculated using the following formula (Hake, 1998):

$$N - Gain = \frac{Posttest\ Score - Pretest\ Score}{Maximum\ Possible\ Score - Pretest\ Score} \quad (1)$$

The resulting N-Gain score was categorized into three levels: high ($g \geq 0.7$), medium ($0.3 \leq g < 0.7$), and low ($g < 0.3$) (Hake, 1998).

To examine the significance of the improvement between pre-test and post-test scores, statistical hypothesis testing was conducted using JASP (version 0.97.1.0-Windows). A Shapiro-Wilk normality test was first applied to the gain-score distribution to determine the appropriate hypothesis test. As the data did not deviate significantly from a normal distribution, a Paired Sample t-Test was used as the inferential test, with a significance threshold of $p < .05$. The effect size (Cohen's d) was also calculated to determine the practical magnitude of the observed change (Cohen, 1988).

RESULTS AND DISCUSSION

To address the problems faced by the community partners in Pasar Aceh Village, four main activities were implemented: tidal inundation disaster mitigation socialization, Early Warning System (EWS) training, installation and implementation of EWS devices, and EWS simulation activities.

Community Understanding of Tidal Inundation Disaster Mitigation

The activity was conducted at the meeting hall of the Pasar Aceh Village Office and was attended by 20 participants. The socialization activity provided information regarding the causes of tidal inundation, appropriate mitigation strategies to reduce disaster risks and impacts, early signs of disasters, self- and family-evacuation procedures during tidal inundations, and the identification of safe areas or evacuation locations. The community was also informed about potential losses caused by disasters. The socialization process emphasized the important role of the community as the first responder during disaster events before external assistance arrives. The evaluation results showed an increase in community understanding of disaster mitigation by 49,8% (Table 2).

During the activity, participants actively asked questions, participated in discussions, and shared field experiences related to previous disaster events. This finding is consistent with Harald Spahn (2007), who emphasized that community involvement plays an essential role in maximizing the effectiveness of Early Warning Systems (EWS) to support disaster mitigation. Furthermore, Aprianti and Kusumawardani (2025) stated that disaster risk reduction does not solely depend on technological development but also relies on social infrastructure that ensures warning information is trusted, understood, and followed by communities.

The Early Warning System training was conducted at the Pasar Aceh Village Office meeting hall and involved 20 participants from various community backgrounds, including village officials, disaster mitigation groups, and residents living in tidal inundation-prone areas. The training provided information regarding the importance of an Early Warning System for tidal inundation mitigation, types and levels of warning information, and appropriate responses after receiving early warnings during disaster situations. The questionnaire results indicated an increase in community understanding of EWS by 63,3% (Table 2).

Figure 1. Early Warning System (EWS) Training Activities for the Community in Pasar Aceh Village

In addition, participants were introduced to EWS components, their functions, and operational procedures, including sensors, supporting poles, sirens/speakers, system operation mechanisms, and EWS maintenance procedures. The improvement in understanding of early warning equipment reached 65,97% (Table 2). This result is in accordance with Kurnia et al. (2025), who reported that training activities significantly improve community knowledge and preparedness. The improvement demonstrates that the integration of technological implementation and community empowerment activities can enhance public knowledge and preparedness in dealing with tidal inundation disasters in West Aceh. During the training session, community members actively participated in discussions and expressed strong interest in understanding how the EWS technology operates in Pasar Aceh Village.

Implementation of the Early Warning System (EWS)

The EWS implementation was carried out by experts and lecturers from Universitas Gadjah Mada and directly observed by the local community. The EWS device was installed at the coastal pier area of Pasar Aceh Village, located at coordinates 4.1425° N and 98.1311° E. The implementation process consisted of several stages. The initial stage focused on identifying tidal inundation-prone areas and determining the appropriate location for EWS installation. The developed system consisted of a water level telemetry sensor to monitor water elevation, a Single Board Computer (SBC) as a data processing unit, a GSM router for data transmission, an IP Night Vision camera for field monitoring, and a cloud-based dashboard for real-time data visualization. The system continuously measured water level changes, transmitted data to the central server, and displayed warning status through the monitoring dashboard, which can support decision-making processes for disaster mitigation.

Figure 2. Implementation of an Early Warning System (EWS)-Based Disaster Mitigation Technology in Pasar Aceh Village

The implementation process included water level sensor installation, data communication device setup, monitoring camera installation, equipment calibration, and system testing. The test results showed that all system components functioned properly and were able to transmit water level data in real-time to the monitoring server. The developed dashboard displayed water level variations, real-time field conditions through monitoring cameras, and warning status information that could be accessed by trained users, including the Head of the West Aceh Regional Disaster Management Agency (BPBD), the village head, the leader of the Pasar Aceh Village Disaster Mitigation Group, and the Kosa Bangsa Team of Universitas Cipta Mandiri. The implementation of EWS technology provided significant benefits by enabling communities and village authorities to monitor water level conditions quickly and accurately. Furthermore, the developed EWS was equipped with a monitoring camera, allowing clearer visualization of sea-level rise conditions.

Early Warning System Simulation at the Coastal Pier of Pasar Aceh Village

The Early Warning System (EWS) simulation activity was conducted to evaluate community understanding and preparedness in responding to potential tidal inundation disasters. The simulation involved direct practice of EWS operational mechanisms, including water level detection, data transmission through the monitoring system, visualization of field conditions through the monitoring dashboard, and dissemination of warning information to the community. This simulation provided practical experience for residents regarding the procedures required when the early warning system indicates potential disaster conditions.

Community understanding was assessed through several simulation activities, including tidal inundation evacuation exercises and the ability of residents to perform their roles in coordinating disaster response activities. Participants were trained to recognize warning levels generated by the system and understand the importance of preventive actions before tidal inundation occurs. The EWS simulation improved community knowledge and skills by 49,7% (Table 2).

Figure 3. Community-Based Early Warning System (EWS) Simulation for Enhancing Tidal inundation Preparedness in Pasar Aceh Village

The simulation also emphasized the important role of the community EWS team in improving understanding and technical skills for managing the EWS system. The group was responsible for maintaining EWS equipment and developing basic skills in operating the technology. Through the EWS simulation, the community group established through this program demonstrated increased capacity and skills, reaching 33,33% improvement (Table 2). The implementation of EWS simulations provided significant benefits in strengthening the capacity of Pasar Aceh Village communities in disaster mitigation and emergency response. This program also involved local government institutions, particularly the Regional Disaster Management Agency and West Aceh local government. Government representatives actively participated in the implementation and simulation process, supported EWS dissemination activities, and developed emergency response plans for tidal inundation disasters. Following program implementation, government involvement increased by 46,67%. This finding is supported by Aprianti and Kusumawardani (2025), who stated that EWS effectiveness is strongly influenced by strong institutional coordination.

The pre-test and post-test scores of the 23-item disaster mitigation questionnaire showed a substantial and highly consistent increase across all 20 participants. The mean score rose from 38.65 (SD = 2.52) in the pre-test to 90.10 (SD = 3.91) in the post-test, yielding a mean gain of 51.45 points (SD = 5.50). All participants demonstrated improvement, with individual gains ranging from 39 to 60 points-a notably narrower range than observed in the previous cohort, indicating a more uniform response to the intervention.

The Normalized Gain (N-Gain) score, calculated in Microsoft Excel (Hake, 1998), yielded a mean value of 0.84, falling within the "high" category ($g \geq 0.7$). Of the 20 participants, 19 (95%)

achieved a high N-Gain category and only 1 (5%) fell into the medium category, with no participant in the low category—indicating an even more consistent improvement across the group compared to the previous implementation cycle.

Table 2. Analysis of Community Understanding and Skills Improvement in the Implementation of the Early Warning System (EWS) in Pasar Aceh Village (n = 20)

Assessment Aspects	Pre-intervention persentage (%)	Post- intervention persentage (%)	Percentage Improvement (%)
Disaster mitigation knowledge	48,4	98,2	49,8
Understanding of early warning systems	35,7	99	63,3
Early warning system equipment utilization	25,2	91,17	65,97
Disaster simulation practices	35,3	85	49,7
Government support and involvement	55	88,33	33,33
Community capacity in EWS management and maintenance	32	79	46,67
Average	**38,6**	**90,1**	**51,5**

Prior to hypothesis testing, a Shapiro-Wilk normality test was conducted in JASP on the gain-score distribution. The result indicated that the data did not deviate significantly from a normal distribution (W = 0.971, p = .780). Accordingly, a Paired Sample t-Test was used as the appropriate inferential test. The result showed a statistically significant difference between pre-test and post-test scores, t (19) = 41.83, p < .001, with a very large effect size (Cohen's d = 9.36), confirming that the observed improvement was both statistically robust and practically substantial.

Table 3. Paired Sample t-Test Results for Pre-Test and Post-Test Disaster Mitigation Scores

	Mean	SD	n	t	df	p
Pre-test	38.65	2.52	20			
Post-test	90.10	3.91	20			
Difference (Pre – Post)	51.45	5.50	20	41.83	19	< .001

Note. Cohen's d = 9.36 (very large effect, Cohen, 1988).

The exceptionally consistent improvement observed across all 20 participants reflected in both the narrow gain range and the high proportion of "high" N-Gain scores (95%) suggests that the program's combination of socialization, hands-on EWS training, device installation, and simulation was highly effective in building disaster mitigation knowledge among this cohort. This finding reinforces earlier conclusions that participatory, hands-on training is more effective than passive information delivery in translating disaster knowledge into actionable preparedness (Mercer et al., 2012; Abedin & Shaw, 2023; Gaillard & Mercer, 2013).

The normal distribution of gain scores in this dataset, in contrast to the non-normal distribution observed previously, suggests a more homogeneous learning response among participants—possibly reflecting a more even baseline of disaster awareness across the group, or a more standardized delivery of training materials during this implementation cycle. The single participant falling into the "medium" N-Gain category (gain = 39 points) nonetheless still demonstrated substantial improvement, suggesting that even the most modest response to the intervention remained practically meaningful.

The extremely large effect size (Cohen's d = 9.36) indicates that the magnitude of improvement was not only statistically significant but also of considerable practical importance far exceeding conventional thresholds for a "large" effect ($d \geq 0.8$). This reinforces the conclusion that the integrated EWS implementation, encompassing both technological deployment and structured community training, produced a substantial and consistent enhancement in participants' disaster preparedness competence.

Despite these strong outcomes, the limitations identified previously regarding participant scope, technical maintenance, GSM dependency, and institutional sustainability remain equally relevant to this implementation cycle, underscoring the continued importance of structured follow-up, formal BPBD integration, and a dedicated maintenance scheme to ensure that these short-term gains translate into durable, long-term community resilience.

CONCLUSIONS

The Kosabangsa community service program in Pasar Aceh Village successfully strengthened community preparedness for tidal inundation through the implementation of a Community Voice-Based Early Warning System (CV-EWS), integrating water-level telemetry sensors, real-time monitoring dashboards, and locally familiar voice-based alerts. Across four stages—socialization, training, device installation, and simulation—community knowledge and preparedness improved significantly and consistently, with mean scores rising from 38.65 to 90.10 (Paired Sample t-Test, $t(19) = 41.83$, $p < .001$, Cohen's d = 9.36) and a high mean N-Gain score of 0.84, demonstrating that combining technological deployment with community participation can meaningfully enhance coastal disaster resilience.

These outcomes nonetheless reflect a short-term evaluation with a limited, purposively selected sample ($n = 20$), and the system's continued reliability remains constrained by its dependence on GSM connectivity and ongoing device maintenance-risks compounded by the absence of a formal maintenance scheme. Future implementation should therefore prioritize periodic refresher training, formal integration with BPBD through a documented maintenance agreement, a dedicated maintenance budget (e.g., via Dana Desa), and longitudinal or control-group evaluation to confirm sustained impact. With these measures, the CV-EWS model holds strong potential for replication in other tidal-flood-prone coastal areas with similar vulnerability profiles.

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