



Development of a Community-Based Anticipatory Action Protocol for Landslide Early Warning Systems

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Abstract

Landslides pose significant risks to communities in Jombang Regency, East Java, particularly under prolonged rainfall. This study developed an operational anticipatory action protocol that integrates an Internet of Things (IoT)-based landslide early warning system with community observations and multi-channel risk communication in Jumok Hamlet, Sambirejo Village. The study used a community-based approach through a focus group discussion (FGD) with 30 purposively selected participants, field and geological surveys, protocol development, and qualitative validation by experts and community users. The protocol was structured around community-based early warning principles and translated hazard information into four graduated levels: Normal, Advisory, Watch, and Warning. The resulting protocol combines daily rainfall above 61 mm, three-day cumulative rainfall above 91 mm, ground movement above 2 cm/day, progressive crack widening, and soil saturation as operational indicators. The FGD identified widening ground cracks, prolonged rainfall, increasing soil saturation, unusual ground movement, and standing water during soil cultivation as locally recognized warning signs. Expert validation focused on information flow, operational procedures, and stakeholder coordination; user validation focused on SOP readability and usability. Feedback led to clearer trigger-to-action sequences and simpler, context-specific wording. The protocol has not yet been tested during actual landslide events. It links hazard indicators with predefined communication channels and anticipatory actions, including drainage management, mobilization of vulnerable groups, evacuation preparation, and self-evacuation. The study demonstrates how technological monitoring and locally observed indicators can be combined to translate warnings into coordinated community action.

Keywords: *Community-Based Early Warning, Disaster Preparedness, Early Action, Landslide, Rainfall Thresholds*

INTRODUCTION

Jombang Regency has a high risk of landslides in several districts. In 2014, a landslide occurred in Kopen Hamlet, Ngrimbi Village, Bareng District, killing 14 people and forcing nearby residents to relocate (Arfani, 2014). In addition, ground cracks have been observed in Sambirejo Village, Wonosalam District, since 2021 (PVMBG, 2024).

These cracks have continued to widen during periods of heavy and prolonged rainfall. In 2024, the ground cracks triggered soil creep in Sumberlamong Hamlet, damaging 12 houses and forcing residents living in the affected area to relocate (Kecamatan Wonosalam, 2024). That same year, landslides also occurred in surrounding hilly areas, damaging productive crops such as durian and clove. Landslides occurred again in 2025 in Jumok Hamlet, Sambirejo Village, Wonosalam District. The landslide damaged four houses and resulted in two fatalities (Syafii & Hartik, 2025).

The increasing frequency and severity of landslides have highlighted the need to shift disaster risk management from reactive emergency response to anticipatory action. International

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frameworks, particularly the Sendai Framework for Disaster Risk Reduction 2015–2030, emphasize that disaster losses can be significantly reduced when early warning information is translated into timely, coordinated action by at-risk communities ([UNDRR, 2015](#)). An effective Early Warning System (EWS) should not only detect hazards accurately but also enable communities to respond appropriately before disaster impacts occur.

Although IoT-based monitoring technologies have improved hazard detection, many landslide Early Warning Systems still focus primarily on monitoring performance rather than how warning information translates into coordinated community action. Existing approaches often provide limited guidance on integrating local observations, community decision-making, and inclusive communication into operational anticipatory action protocols.

This study addresses this gap by developing a community-based Anticipatory Action Protocol that combines technological monitoring, local knowledge, and people-centered communication into a practical operational framework. This study aims to develop a community-based Anticipatory Action Protocol that integrates IoT-based monitoring, local observations, and inclusive communication into an operational framework for Jumok Hamlet.

Unlike previous studies that primarily emphasize technical monitoring, this study explicitly links hazard thresholds with predefined community responsibilities, communication channels, and anticipatory actions for vulnerable groups.

LITERATURE REVIEW

Landslide

Landslides are defined as the movement of slope-forming materials, including rock, residual soil, or artificial fill, downward or outward under the direct influence of gravity ([Varnes, 1978](#); [Cruden & Varnes, 1996](#); [Highland & Bobrowsky, 2008](#)). Slope instability is triggered by internal structural degradation and external environmental drivers, primarily intense or prolonged precipitation, seismic shaking, stream erosion, and anthropogenic slope modifications ([Hungr et al., 2014](#)). Rain-induced slope failure occurs as water infiltrates porous soil layers, raising pore-water pressure, increasing total unit weight, and drastically reducing effective shear strength according to the Mohr-Coulomb failure criterion ([Terzaghi, 1943](#)).

Community-based Early Warning System

A people-centered Early Warning System has become the international standard for reducing disaster risk. ISO 22327:2018 provides practical guidance for community-based landslide Early Warning Systems. It emphasizes participation at every stage of the warning process, from risk assessment and warning dissemination to monitoring, preparedness, evacuation, and recovery ([International Organization for Standardization, 2018](#)).

The International Federation of Red Cross and Red Crescent Societies (IFRC) Early Action Protocol provides a trigger-based structure for pre-activation, activation, and response, with pre-agreed actions linked to available lead time ([International Federation of Red Cross and Red Crescent Societies, 2020](#)). Both frameworks recognize that an Early Warning System's effectiveness depends not only on monitoring technology but also on communities' capacity to understand threat signs and early warnings and translate them into coordinated action.

Effectiveness also depends on trust, inclusive communication, and institutional coordination ([Gumiran & Daag, 2021](#); [Marchezini, 2023](#)). In this study, ISO 22327:2018 guides the people-centered EWS design, while the IFRC framework guides the translation of warnings into pre-agreed actions.

Geographical landslide early warning systems combine rainfall, forecasts, susceptibility information, and forecasting models, and require verification to assess reliability and false alarms

(Guzzetti et al., 2020). Hidayat et al. (2019) showed that observed and forecast precipitation, combined with slope-stability modeling, can provide warning lead time, while Yuniawan et al. (2022) demonstrated that rainfall-threshold formulation affects warning performance.

Together, this literature shows that monitoring is necessary but insufficient: threshold exceedance must still be converted into understandable messages, responsibilities, and timely action. Recent empirical studies have further emphasized that community-based EWS effectiveness depends on trust, inclusive communication, and pre-agreed actions (Piciullo et al., 2018; Chaves-Gonzalez et al., 2022).

Anticipatory Action

Anticipatory Action is an approach that links early warning information with flexible funds to trigger actions that mitigate the impact of predictable shocks on the most vulnerable people (Food and Agriculture Organization of the United Nations and World Food Programme, 2023). Anticipatory action rests on three pillars: early warning systems or risk analysis with triggers, pre-agreed action plans, and pre-allocated funds that can be immediately disbursed once a trigger is reached.

To realize the potential of anticipatory action, countries must mainstream the practice, increase funding flexibility, and build strong partnerships with climate scientists, local governments, and communities (Chaves-Gonzalez et al., 2022). Anticipatory action delivers mostly positive results at the household level, such as reducing debt accrual, preserving livestock, keeping children in school, and lowering psychosocial stress (Weingärtner et al., 2020).

RESEARCH METHOD

Study Area

The study was conducted in Jumok Hamlet, Sambirejo Village, Wonosalam District, Jombang Regency, East Java. The area is hilly, with elevations of 452–464 meters above sea level. Sambirejo has experienced both soil creep and sliding, and an IoT-based EWS using rainfall, soil-moisture, and vibration-related monitoring was installed in 2025 (Paripurno et al., 2025).

Focus Group Discussion and Qualitative Analysis

A Focus Group Discussion (FGD) was held on 28 July 2026 in Jumok Hamlet, involving 30 purposively selected participants from landslide-prone households, women's and farmer groups, the village disaster preparedness team, village government, and Jombang Regional Disaster Management Agency (BPBD Jombang).

The FGD used a semi-structured guide addressing previous landslide experiences, locally recognized precursory signs, warning communication, preparedness, and response actions. The discussion was conducted in one session lasting approximately 120 minutes and was documented through field notes. Analysis involved initial coding of statements on hazard indicators, warning communication, preparedness, and response, followed by comparison and consolidation into themes.

Themes were developed iteratively, reviewed for internal consistency, and triangulated with field observations and secondary geological data. The resulting themes informed the Anticipatory Action Protocol. Participants received an explanation of the study purpose, procedures, voluntary participation, and data use, and provided informed consent before the discussion.

Field and Geological Survey

Surface geological mapping characterized lithology, geological structures, and landslide features. Field observations focused on identifying and mapping ground cracks, measuring their

orientation and width, and documenting their associated impacts.

The study obtained geological and geomorphological data for the study area from assessments conducted by the Center for Volcanology and Geological Hazard Mitigation (PVMBG), Indonesia. These data were used to characterize the study area's geological setting, geomorphological conditions, and terrain characteristics, particularly those associated with landslide susceptibility.

Development of Anticipatory Action Protocol

The Anticipatory Action Protocol was developed following the principles of ISO 22327:2018, which emphasizes a people-centered Early Warning System supported by clear operational procedures. The protocol includes the following components:

1. **Trigger Mechanism:** Predictive rainfall forecasts from the Indonesian Meteorological, Climatological, and Geophysical Agency (BMKG) are combined with real-time observations from local monitoring sensors and direct observation in the field by the community to create a multi-level warning mechanism. The protocol was designed to be activated when predefined rainfall thresholds are exceeded, such as daily rainfall above 61 mm or cumulative three-day rainfall above 91 mm. Rainfall information came from BMKG weather forecasts and real-time rainfall measurements from a rain gauge sensor integrated into the existing IoT-based landslide early warning system. The operational rainfall thresholds were adopted from [Hidayat et al. \(2019\)](#), who compiled 83 landslide events from various locations in Indonesia during the development of the Indonesian landslide early warning system, with emphasis on major and fatal events in Java. The threshold used the median of one-day and three-day cumulative precipitation associated with the events. The median was selected to reduce false alarms and minor landslide occurrences. Together, these thresholds provide up to four days of operational lead time to implement early mitigation measures ([Hidayat et al., 2019](#); [Yuniawan et al., 2022](#)).
2. **Multi-Channel Warning Dissemination:** Warning messages were designed to be distributed simultaneously through WhatsApp groups, automatic sirens, and other community communication channels to ensure that all residents receive timely information.
3. **Village Disaster Preparedness Team:** Formalizing roles for hazard monitoring, traffic control, logistics management, and evacuation support.

Validation Process

The validation process consists of two stages:

1. **Expert validation** was conducted by five experts, comprising two representatives from BPBD Jombang with practical experience in landslide response and routine access to rainfall and weather forecast information provided by the Indonesian Meteorological, Climatological, and Geophysical Agency (BMKG), two disaster management academics, and one disaster communication expert with a research and professional focus on community participation. Validation was qualitative. The experts reviewed the protocol to assess the clarity of information flow, operational procedures, stakeholder coordination mechanisms, and the protocol's overall applicability. The team incorporated their feedback to refine the protocol before community testing.
2. **User validation** was conducted with 15 community members representing landslide-prone households, women's groups, farmer groups, and the Village Disaster Preparedness Team. Participants assessed the readability and usability of the Standard Operating Procedures (SOPs), including whether the instructions were clear, comprehensible, and practical for implementation across different educational backgrounds. The team reviewed feedback qualitatively and used it to simplify wording and improve the presentation of actions,

particularly at higher warning levels.

FINDINGS AND DISCUSSION

Geological Characteristics, Geomorphology, and Landslide Risk Assessment

The study was conducted in Sambirejo Village, Wonosalam District, Jombang Regency, approximately 20 km south of Jombang City. The area is located on the slopes of Mount Anjasmoro at elevations ranging from 452 to 464 m above sea level. The landscape consists of volcanic hills with steep to very steep slopes (20° – 32°).

According to the regional geological map, the study area comprises the Young Anjasmoro Volcanic Formation (Qpva), consisting of volcanic breccia, tuff, lahar deposits, and lava flows. Relatively fresh lahar deposits form the bedrock and are exposed along the Kali Maling River at the base of the slope. Above the bedrock lies a weathered volcanic breccia layer that forms the main moving mass. This layer is highly weathered and covered by more than three meters of weathered clay-rich tuff soil, making it highly susceptible to landslides (PVMBG, 2024).

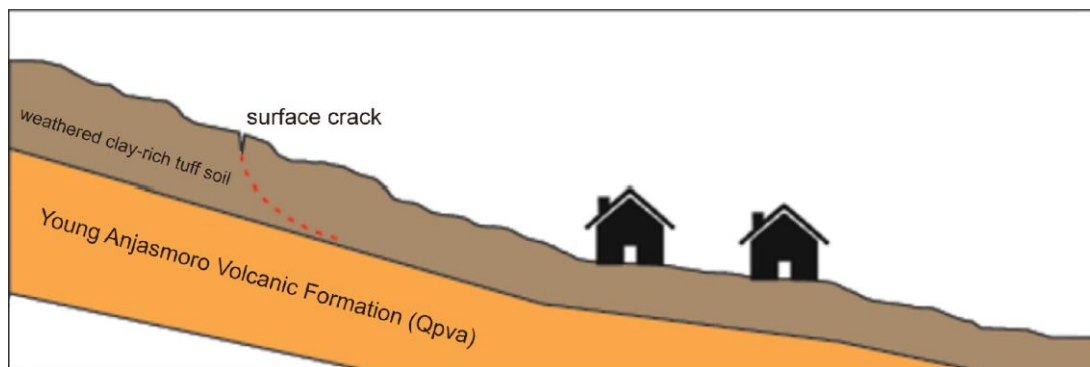


Figure 1. 2D Cross-Section of a Soil Crack in Jumok Hamlet

Surface cracks have been observed in the residential area of Jumok Hamlet since 2021. These cracks continue to widen during every rainy season. The cracks are approximately 0.5–1.0 m long with widths ranging from 1–3 cm. Based on assessments by the Indonesian Center for Volcanology and Geological Hazard Mitigation (PVMBG) and BPBD Jombang, the area is classified as having moderate to high landslide susceptibility.

Slope Failure Mechanism

Jombang has a tropical wet climate (Schmidt–Ferguson Type B), with average annual rainfall of about 1,800 mm and temperatures ranging from 20°C to 34°C . During prolonged heavy rainfall, water infiltrates the ground through existing surface cracks. The expansive clay minerals absorb water, causing soil expansion, increasing the weight of saturated soil, increasing pore water pressure, and reducing soil cohesion and internal friction angle.

As a result, the soil shear strength decreases significantly according to the Mohr–Coulomb failure criterion. This reduction in shear strength is considered the main triggering mechanism for soil creep and subsequent landslide movement.

IoT-based Early Warning System

An Internet of Things-based landslide early warning system has been installed in Jumok Hamlet, using ground movement, inclination, soil moisture, and rainfall indicators. Automated ground-movement sensors and rainfall gauges transmit data to a centralized platform that generates automatic warning notifications when predefined thresholds are exceeded.

An advisory level can be issued when daily rainfall exceeds 61 mm. A watch status may be initiated if ground displacement surpasses 2 cm per day under sustained rainfall conditions. The highest alert level, Warning (evacuation warning), is activated when ground movement demonstrates exponential acceleration (Paripurno et al., 2025).

Community-based Early Warning System

A community-based early warning system is built on systematic community observation and monitoring of environmental conditions in landslide-prone areas. The FGD identified several locally recognized indicators of impending landslides. Participants consistently reported widening ground cracks, prolonged heavy rainfall, increasing soil saturation, and unusual ground movement as the most reliable warning signs.

Farmers also described standing water during soil cultivation as an indicator of excessive soil saturation. These indicators can serve as locally relevant landslide-triggering parameters for assessing changes in slope conditions and potential escalation of landslide risk. Graduated warning levels based on predefined thresholds provide a clear framework for translating changes in environmental and ground conditions into appropriate preparedness and anticipatory actions.

This approach enables communities to take timely risk-reduction measures before a hazardous slope failure occurs. It strengthens local capacity for early action and helps reduce potential impacts on people, livelihoods, livestock, and assets. Based on these findings, a four-level Early Action Protocol was developed. Table 1 presents the Early Action Protocol by hazard level.

Table 1. Early Action Protocol Based on Hazard Levels

Warning Level	Monitoring Period	Trigger Parameters	Monitoring Method	Early Warning Response Actions
Normal	Dry season with no rainfall for more than one month	Daily rainfall (Rd) < 61 mm	- BMKG weather outlooks - Routine visual inspections by residents	- Prepare evacuation routes and assembly points - Routine communication and equipment maintenance - Community outreach and disaster education
Advisory	Rainy-season transition	- Rain duration >1 hour	- BMKG short-term forecasts - Community members directly observe on-site conditions - Farmers check the soil conditions on their farmland to determine whether elongated ground cracks are present.	- Activate communication channels - Check preparedness teams - Issue early alerts to community groups - Cover open ground cracks with tarpaulins - Manage surface water drainage

					- Advise households to prepare emergency preparedness kits and secure important documents.
Watch	Rainfall persists for about one day and may continue	- Daily rainfall > 61 mm - Ground movement > 2 cm/day	- BMKG short-term forecasts - Post-rain physical verification of crack expansion from safe distances by community members - Real-time IoT sensor telemetry (inclination/displacement)	- Mobilize vulnerable groups (elderly, children, and persons with disabilities) - Prepare evacuation site and logistics. - Livestock evacuation	
Warning	- Rainfall persists for two days and may continue - Ground cracks are progressively widening - High soil saturation/seepage	- Daily rainfall > 61 mm or cumulative three-day rainfall > 91 mm - Exponential increase in ground movement - High level of soil saturation	- BMKG short-term forecasts - Farmers check for soil saturation and standing water during tilling on their farmland - IoT automated threshold alerts	- Sound EWS sirens, <i>kentongan</i> , and mosque loudspeakers - Execute immediate self-evacuation along designated routes to safe assembly zones - Prepare livestock feed assistance	

Source: Authors' synthesis based on FGD findings, IoT-based monitoring, BMKG forecasts, and rainfall thresholds reported by [Hidayat et al. \(2019\)](#) and [Yuniawan et al. \(2022\)](#)

Expert feedback focused on the flow from forecasts, sensor observations, and community signs to warning levels, operational responsibilities, and stakeholder coordination. The protocol was refined by clarifying trigger-to-action sequences, the Village Disaster Preparedness Team's role, and communication channels for each level. User validation focused on SOP readability and usability and led to simpler, context-specific wording and clearer action instructions, particularly for Watch and Warning. Because validation was qualitative, no numerical score is reported.

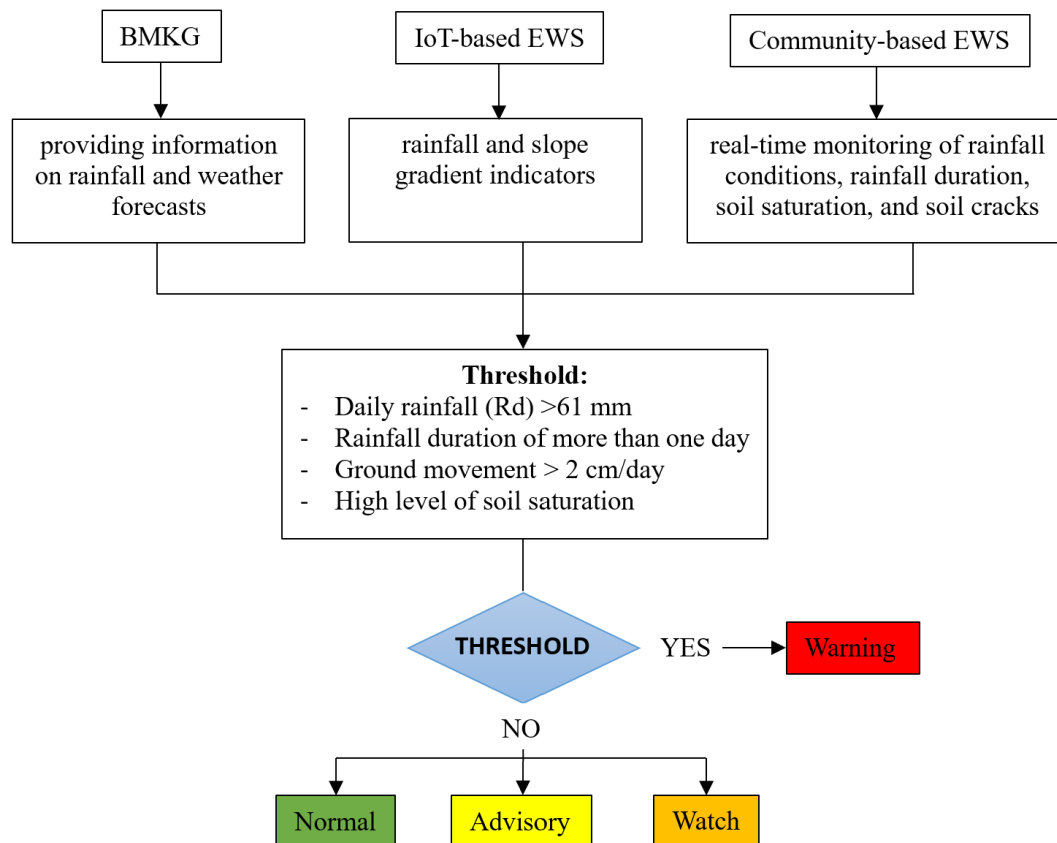


Figure 2. Integration of IoT-based and community-based early warning systems into four warning levels

Source: Authors' synthesis based on the IoT-based EWS, BMKG forecasts, and community observations

Dissemination of Hazard Warnings

Hazard and early warning information must be disseminated effectively to the wider community to ensure early actions are appropriately targeted and implemented promptly. Landslide hazard information can be communicated according to the corresponding warning level.

Under normal conditions, information on potential landslide risks, possible impacts, evacuation routes, and designated assembly points can be disseminated through face-to-face preparedness meetings and drills conducted within community groups, as well as through community WhatsApp groups. At the Advisory level, hazard and early warning information is disseminated through WhatsApp groups at the neighborhood (RT) level and through word-of-mouth communication.

At the Watch level, hazard and early warning information is disseminated through community WhatsApp groups and mosque loudspeakers available within each neighborhood. Where conditions remain safe and feasible, direct door-to-door communication can also be conducted for households located in areas with a high potential for impact.

At the Warning level, information is primarily disseminated through mosque loudspeakers, traditional wooden alarm instruments (kentongan), and sirens integrated into the Internet of Things (IoT)-based Early Warning System (EWS). The IoT-based system automatically activates siren alerts when predefined thresholds for rainfall, ground movement, and slope inclination are reached.

This multi-channel communication approach reduces dependence on internet connectivity. It helps ensure that warnings reach community members with limited internet access, as well as

older persons, persons with disabilities, and other individuals with specific communication needs. By integrating technological monitoring with community-based communication and preparedness mechanisms, the system supports rapid information dissemination, timely decision-making, and more effective evacuation before landslides occur.

The system also communicates hazard and early warning information to persons with disabilities to ensure inclusive access to critical risk information. Depending on individual communication and support needs, information is conveyed through family members, caregivers, or designated support persons. This multi-channel, inclusive dissemination strategy aims to ensure warning messages reach different population groups and support timely, appropriate, context-specific anticipatory actions across varying levels of landslide risk.

Compared with [Paripurno et al. \(2025\)](#), which focused primarily on installing and evaluating an IoT-based EWS, this study advances the framework by explicitly linking sensor thresholds and community-observed indicators to graduated warning levels, predefined communication channels, and anticipatory actions.

This integration addresses the gap identified by [Guzzetti et al. \(2020\)](#) and [Hidayat et al. \(2019\)](#) that monitoring alone is insufficient unless threshold exceedance is translated into understandable messages, assigned responsibilities, and timely community action. This study's novelty lies in operationally integrating technological monitoring, local knowledge, and inclusive multi-channel communication into a single community-based Anticipatory Action Protocol.

CONCLUSIONS

This study developed a community-based Anticipatory Action Protocol that integrates IoT-based landslide monitoring with people-centered communication and preparedness procedures. The protocol combines rainfall thresholds, ground-movement indicators, community observations, and graduated warning levels to support timely preparedness and evacuation decisions.

Rather than serving solely as a technical monitoring system, the proposed framework provides operational guidance for translating early warning information into coordinated community action. The protocol has practical implications for BPBD Jombang, village governments, and Village Disaster Preparedness Teams by providing a structured framework for warning dissemination, preparedness coordination, evacuation planning, and support for vulnerable groups.

LIMITATIONS & FURTHER RESEARCH

This study has several limitations. It was conducted in a single hamlet, and the proposed protocol has not yet been evaluated during actual landslide events. The rainfall thresholds have not been calibrated using long-term local landslide-event datasets. The effectiveness of communication channels depends on reliable electricity, sensor performance, internet connectivity, and community participation. WhatsApp and mosque loudspeakers may also have limited reach under certain conditions, and the focus group size limits the range of community perspectives.

Further research should evaluate the protocol's effectiveness and reliability through long-term field monitoring, repeated simulations, and implementation during actual landslide events. Future studies should assess the accuracy of trigger thresholds, warning lead time, community response, evacuation compliance, and communication effectiveness for vulnerable groups, including persons with disabilities, older persons, and children.

Research should also examine the institutional and financial sustainability of anticipatory action. Such evidence will support refining and potentially replicating this community-based early warning approach in other landslide-prone areas of Indonesia.

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