Research Paper

Landslide Risk Reduction via Early Warning System in Sambirejo Village, Indonesia

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Abstract

Sambirejo Village, located in Wonosalam District, Jombang Regency, Indonesia, is an area with moderate to high landslide vulnerability, triggered by a combination of extreme rainfall, geological conditions, and land-use practices. This study aims to design and implement an Early Warning System (EWS) as a proactive measure for disaster mitigation and preparedness. The research methodology includes geological surveys and fracture mapping, landslide characterization, and the planning and installation of the EWS. The developed system comprises wireless sensors that monitor ground motion (extensometers), slope gradient (tiltmeters), and rainfall, all of which are connected to a real-time monitoring dashboard. The EWS successfully provides continuous data on ground motion and rainfall, which can be used to establish warning thresholds. For example, a "Warning" level can be activated if rainfall exceeds 50 mm/day, and an "Alert" level if the rate of ground motion exceeds 2 cm/day in combination with continuous rainfall. The highest alert, "Evacuation Warning," is issued if ground motion shows exponential acceleration. This mechanism provides a scientific basis for village governments and the Regional Disaster Management Agency (BPBD) to make timely evacuation decisions. The development and implementation of the EWS have proven to be an effective solution for mitigating landslide risks at the study site. The application of this technology can significantly reduce the potential for loss of life and property damage. Furthermore, the implementation of the EWS enhances the preparedness of both the local community and the Jombang BPBD in responding to landslide threats, thereby reducing the risk of casualties and material losses

Keywords: *Early Warning System, Landslide, Disaster Mitigation, Sambirejo Village*

INTRODUCTION

Landslides are among the most frequent geological disasters in Indonesia, particularly in hilly regions with high rainfall. East Java Province is one of the areas vulnerable to such events, with several districts, including Jombang, often experiencing ground cracks, subsidence, and slope movements.

One of the locations that has repeatedly experienced landslides is Jumok Hamlet, Sambirejo Village, Wonosalam District, Jombang Regency. Since early 2021, ground cracks have appeared and widened significantly following heavy rainfall in November 2022 and March 2024. This ground movement is classified as creep, which has the potential to develop into a rapid translational landslide. The impacts have been substantial, damaging 11 buildings, threatening six others, and disrupting village road infrastructure.

The primary causal factors include steep slope gradients, a thick and porous weathered soil layer, high rainfall as a triggering factor, and a poor drainage system that increases water infiltration into the ground. Given the ongoing risk, adequate mitigation measures are urgently needed to protect the community. One of the most promising solutions is the development of an Early Warning System (EWS). This study focuses on the design, development, and implementation

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of an EWS at the disaster site. The primary objective is to establish a real-time monitoring system for ground movement and rainfall, providing alerts to the community before a major landslide occurs.

The disasters that have occurred in Jombang Regency have the potential to cause loss of life, property damage, and significant psychological impacts on the community. These substantial impacts necessitate a systematic emergency response to mitigate the losses, particularly those resulting from landslides.

The Jombang Regency Government is responsible for disaster emergency management, aiming to ensure a swift, precise, and effective response to minimize casualties and losses. Its policies in disaster emergency management include the involvement of all stakeholders—government, business institutions, civil society organizations, the media, academics, and affected communities. They also cover the mobilization and optimization of resources, allocation and management of regional budgets, implementation of evacuation, search, rescue, and relief operations, as well as the fulfillment of basic needs and protection of disaster-affected communities.

Given the increasing incidence and trend of landslides, Jombang Regency requires a structured plan to serve as a reference for all stakeholders in managing disaster emergencies. One of the key efforts being pursued is strengthening preparedness and establishing a robust early warning system.

LITERATURE REVIEW

Study Area

The research site is administratively located in Jumok Hamlet, Sambirejo Village, Wonosalam District, Jombang Regency, East Java Province. Geographically, it lies at coordinates 7.725347° S and 112.352968° E. The area's morphology is characterized by hilly terrain with elevations ranging from 452 to 464 meters above sea level. The upper slope has a steep gradient of 20° to 32°, while the lower slope, where the settlement area is situated, is gentler with a gradient of 4° to 8°.

Geological Conditions

Based on the Geological Map of the Kediri Quadrangle, the bedrock in the study area belongs to the Young Anjasmara Volcanic Rock Formation (Qpva), which consists of volcanic breccia, tuff, lahar deposits, and lava. This bedrock is overlain by a thick (>3 meters) weathered soil layer composed of brownish clayey tuff, which is porous and easily saturated with water. The contact between the soft weathered soil layer and the more impermeable bedrock has been identified as a potential slip plane for landslides. Mixed gardens predominate on the upper slopes, whereas the lower slopes are primarily used for residential areas.

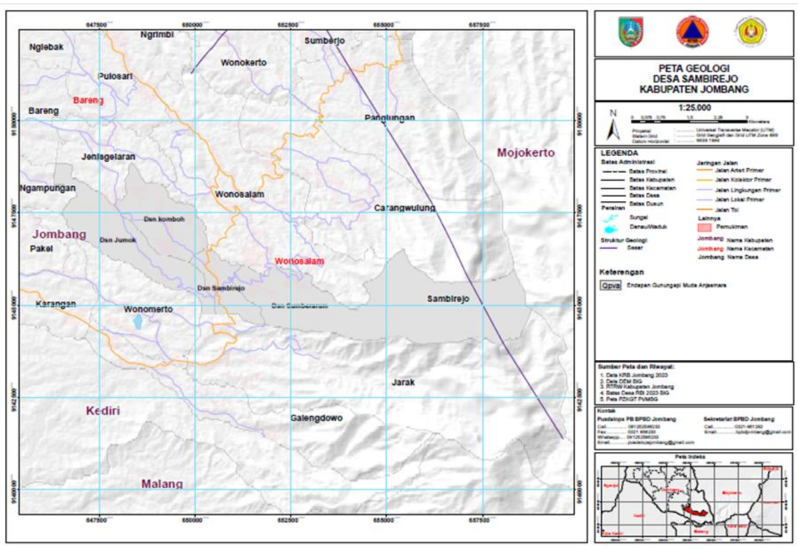

Figure 1. Geological map of Sambirejo Village

Early Warning System

Early warning is a key component of disaster risk reduction. It helps prevent the loss of life and reduces economic and material damages caused by disasters. To be effective, early warning systems must actively engage communities, promote education and awareness of risks, disseminate messages and warnings effectively, and ensure adequate preparedness (United Nations / ISDR Platform for the Promotion of Early Warning, 2006).

The goal of a people-centered early warning system is to empower individuals and communities at risk to take timely action that minimizes injuries, loss of life, and damage to property and the environment. A complete and adequate early warning system consists of four interrelated components: (1) hazard awareness, (2) vulnerability, (3) preparedness, and (4) response capacity. Best-practice early warning systems also maintain strong linkages and effective communication channels among all components.

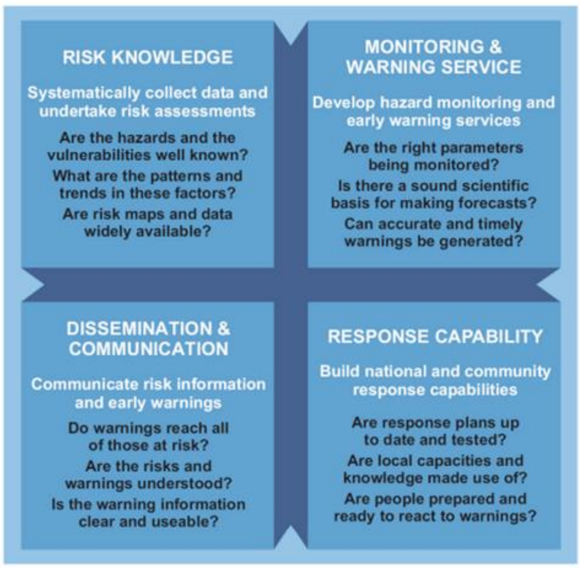

Figure 2. Four Elements of People-centred Early Warning Systems
Source: (United Nations / ISDR Platform for the Promotion of Early Warning, 2006)

Several key factors must be considered when designing and maintaining an effective early warning system. Well-developed governance and institutional arrangements are essential for the successful development and long-term sustainability of such a system. These arrangements form the foundation for the four elements of early warning outlined earlier. Effective governance relies on a robust legal and regulatory framework, a sustained political commitment, and well-functioning institutional structures. Good governance also promotes local decision-making and participation, supported by adequate administrative capacity and resources at both national and regional levels (United Nations / ISDR Platform for the Promotion of Early Warning, 2006).

Internet of Things

The Internet of Things (IoT) is a concept designed to expand the benefits of continuous internet connectivity (Jansen, 2013). An object is considered part of the IoT if it is an electronic device connected to a local or global network through embedded, always-on sensors. IoT operates by utilizing programmed commands, where each instruction automatically enables interaction and communication between connected devices, with the internet serving as the medium of connection. The main components of IoT include: (a) Hardware Platform, (b) Gateway, (c) Software, and (d) Cloud Services, which run in the cloud for data collection and analysis.

The IoT has begun to be adopted by certain groups and technology developers due to its ability to transfer data over a network without requiring human interaction (Sung et al., 2015). Because of these advantages, IoT is increasingly being developed as a solution to environmental problems (Sung et al., 2015).

Landslide

Landslides are the movement of slope-forming materials, which may consist of bedrock, weathered soil, embankments, or a combination of these materials, that move downward or outward from the slope (Vernes, 1978). According to Karnawati (2005), a landslide is the downward or outward movement of a slope by a mass of soil or rock, or a mixture of both in the form of debris, caused by the disturbance of slope stability.

Landslides are also defined as the movement of slope-forming material caused by shear failure along one or more sliding surfaces (Hardiyatmo, 2012). The total displacement of material prior to a landslide is influenced by the amount of strain required to reach the peak shear strength of the soil within the landslide zone. Some mass movements, such as soil creep, occur very slowly and are barely noticeable. In contrast, others, such as rapid landslides, can move at high speeds and are often clearly identified by visible surface displacement. In conclusion, landslides are geomorphological processes involving the downslope movement of soil and rock, occurring at rates ranging from very slow to very rapid, under the influence of gravitational forces. Two main types of factors contribute to landslide events: controlling factors and triggering factors. Controlling factors include rock conditions, slope geometry, geological structures, vegetation cover, and land use. Triggering factors, on the other hand, include rainfall, land conversion, water infiltration, vibrations, and human activities.

RESEARCH METHOD

This research was conducted through several main stages:

1. Field and Geological Survey: Conducting surface geological mapping to identify lithology, geological structures, and landslide characteristics. Field observations focused on mapping the distribution of cracks, measuring the direction and width of cracks, and documenting their impacts.
2. Design and Installation of the EWS: This stage involved designing the system architecture,

selecting sensors, and installing them in the field. The system consists of:

- Sensors: A digital extensometer to measure the rate of crack opening, a tiltmeter to monitor slope inclination, and a digital rain gauge.
- Datalogger and Communication Module: A microcontroller was used to acquire data from all sensors and transmit it periodically to a server via a cellular network (GSM/GPRS).
- Power Source: The system is powered by a solar panel to ensure continuous operation.
- Monitoring Platform: Data received by the server is processed and displayed on a web-based dashboard accessible in real-time by stakeholders (BPBD and the community).

3. Data Communication: Data communication is the process of transmitting and receiving data or information between two or more devices, such as computers, smartphones, and other communication tools connected to a network, either locally or via the internet. Data communication can also occur between databases on the same server or across different servers.

   To enable data communication between two devices, an intermediary tool is required—one example being an API (Application Programming Interface). APIs enable users to share data, allowing devices to integrate. Through integration, when data is modified on one device, it is automatically updated on the other.

   According to Cooksey (2014), there are two categories of data integration:

   - Client-driven Integration – Users interact with the client and make changes to the data. The client is immediately aware of the changes and calls the API to request data from the server, which then responds. In this type of integration, there is no delay because the data request process occurs each time a change is made.
   - Server-driven Integration – Users interact with the server and make changes to the data. The server processes the changes and sends a response to the client via the API. However, the client must be able to detect the changes. If the server fails to process the update, the client may not receive the changes.

4. Community Outreach and Involvement: The outreach activities involved residents and village government officials residing in the vicinity of the EWS device. Participants were provided with detailed information about the device's function and operation, along with specific guidelines on appropriate conduct and use. These included prohibitions against relocating, removing, or damaging the device, as well as instructions to report any disruptions or malfunctions promptly.

FINDINGS AND DISCUSSION

Characteristics of Ground Movements

A thick layer of weathered clay tuff, overlying volcanic breccia, dominates the lithology of the study area on steep slopes. Additionally, high rainfall and inadequate drainage systems are significant contributing factors to landslides.

Soil samples collected from the site reveal a diverse mineral composition. The significant presence of clay minerals is particularly relevant to the landslide mechanisms in the region. Clay minerals, particularly those in the smectite group, such as montmorillonite, exhibit high swelling and shrinking properties when interacting with water. During periods of heavy rainfall, water infiltrates the soil, causing the clay minerals to expand, which increases both the soil's volume and mass. This process drastically reduces the soil’s shear strength, thereby making it highly susceptible to landslides along the failure plane.

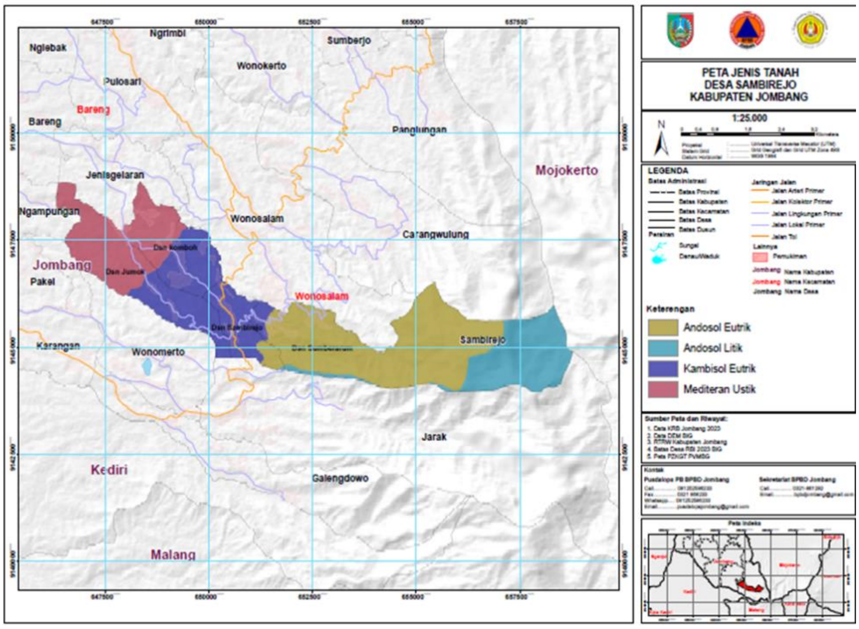

Figure 3. Land Type Map of Sambirejo Village

Implementation and Performance of the Early Warning System

The Early Warning System (EWS) has been successfully installed at critical points in Jumok Hamlet. The system operates autonomously and transmits data hourly to a central server. A monitoring dashboard presents the data graphically, displaying trends in ground movement (in millimeters per day), inclination changes (in degrees), and cumulative rainfall intensity (in millimeters per day).

This system enables continuous monitoring of landslide-triggering factors. Based on the collected data, simple warning thresholds can be established. For example, an Advisory level may be issued if rainfall exceeds 50 mm/day. In contrast, a Watch level may be activated if the ground movement rate exceeds 2 cm/day under persistent rainfall. The highest alert, Warning (evacuation), is triggered when ground movement exhibits exponential acceleration.

This mechanism provides a scientific basis for the village government and BPBD to make timely evacuation decisions.

CONCLUSIONS

The landslide in Sambirejo Village was caused by a combination of geological factors, including a thick layer of weathered clay tuff overlying volcanic breccia, a steep slope, and the triggering effects of heavy rainfall and an inadequate drainage system. The significant presence of clay minerals accelerates slope deterioration when the soil becomes saturated with water.

This study demonstrates the feasibility of a low-cost IoT-based early warning system (EWS) for rural areas in Indonesia, which can be scaled to other high-risk villages. The development and implementation of the system have proven to be effective solutions for mitigating landslide risk in this location. It provides real-time, accurate, and continuous monitoring data on critical parameters. This information is essential for stakeholders to issue timely warnings, enabling communities to evacuate before a disaster occurs. Therefore, the application of this technology can significantly reduce potential loss of life and property damage.

LIMITATIONS & FURTHER RESEARCH

This study identified a significant challenge: many residents lacked sufficient understanding of how the Early Warning System (EWS) functions. In particular, elderly residents often lacked access to adequate devices that provided them with relevant information directly. Given the essential role of disaster early warning systems in risk reduction, future research should focus on enhancing community engagement through targeted education and outreach programs.

Educational materials should clearly explain the concept and purpose of the EWS, the various types of warnings, and the appropriate response actions. Moreover, outreach and education activities should be culturally sensitive and adapted to local community contexts to ensure effective communication and comprehension.

In addition, the government, through the Regional Disaster Management Agency (BPBD), should provide continuous mentoring, capacity-building programs, and simulation exercises that actively involve community members. To maintain the effectiveness of the EWS, government agencies and relevant institutions must regularly disseminate accurate, accessible, and comprehensible information about the system to the public.

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