TXT-tool 2.062-1.1 A Landslide Monitoring and Early Warning System

Teuku Faisal Fathani and Dwikorita Karnawati

Abstract

Landslides are one of most common major disasters in Indonesia due to the physical susceptibility of the region and socio-economical conditions within the country. Efforts are urgently needed to avoid or reduce the risk of landslides. Unfortunately, most landslide-susceptible areas have very fertile soils and abundant very good quality water. The susceptible areas are thus usually densely populated, with serious consequences with respect to slope instability. Despite efforts to establish slope protection zones that are restricted for any development and settlement, relocation programs cannot easy to be carried out due to socio-economic constraints. Therefore, landslide monitoring, prediction and early warning systems are urgently required to guarantee the safety of communities in such areas. A long running and sustainable community-based landslide monitoring and early warning system has been developed in Indonesia that includes collaboration among the local government, universities, private sectors, NGOs, and the disaster management community. The program has three stages: the development of a simple and low-cost landslide early warning system, the design and implementation of the warning system in real time, and the establishment of a socio-technical strategic approach to disaster risk reduction. These activities have already met community needs and helped save lives, and they continue to obtain solid community support. Now the further challenges are to expand the project coverage, and propose more effective landslide monitoring, early warning, analysis, and visualization. In addition, the capabilities in socio-economic risk assessment need to be expedited to help identify those most at-risk within the community. This chapter describes the achievements and the current activities of the IPL-158 Project "Development of Community-based Landslide Early Warning System".

T.F. Fathani (✉)
Center for Disaster Mitigation and Technological Innovation (GAMA-InaTEK), Department of Civil and Environmental Engineering, Universitas Gadjah Mada, Jl. Grafika No. 2, Yogyakarta 55281, Indonesia
e-mail: tfathani@ugm.ac.id

D. Karnawati
Center for Disaster Mitigation and Technological Innovation (GAMA-InaTEK), Department of Geological Engineering, Universitas Gadjah Mada, Jl. Grafika No. 2, Yogyakarta 55281, Indonesia
e-mail: dwiko@ugm.ac.id

K. Sassa et al. (eds.), *Landslide Dynamics: ISDR-ICL Landslide Interactive Teaching Tools*, https://doi.org/10.1007/978-3-319-57774-6_21

Keywords
Landslide monitoring · Early warning · Socio-technical strategic approach
Community participation · Risk assessment

Contents

1 Introduction

Areas prone to mass movement are widespread in Indonesia. The potential for landslides in several regions is controlled by geotechnical and geological conditions, with landslides often being triggered by earthquake activity and high rainfall intensity. The vulnerability to landslides is made worse by intensive land-use development. The urgent issues to be addressed are the dense populations residing in areas prone to mass movement and the difficulty, for socio-economic reasons, of relocating local people to safer areas. Meanwhile, the potential for mass movement occurrence has been rising due to increases in rainfall intensity, earthquakes, and the effects of human interference on slope stability (Karnawati et al. 2005; Karnawati and Fathani 2008). As one of the efforts to protect the people living in hazardous areas, a landslide monitoring and early warning system is highly needed, while simultaneously efforts to improve the community's resilience are carried out.

The early warning system is a set of instruments working simultaneously and coordinated for natural disaster mitigation. To set up a landslide monitoring and early warning system, a preliminary survey and investigation should be conducted to understand the physical characteristics and social conditions of the disaster area. The next phase is the design and the installation of the most adaptive landslide monitoring and early warning system, which must be conducted simultaneously with socialization and training so that the local people can operate and maintain the system independently (Fathani et al. 2008, 2010).

This paper presents a long-running and sustainable community-based landslide monitoring and early warning system developed in Indonesia. The first challenge was the development of a simple and low-cost system that is easily operated and can be maintained by the local community. A further advance was the design and implementation of real-time landslide monitoring, involving several trials of telemetry systems. In order to support this technical program, a socio-technical strategic approach was introduced by establishing collaborations between the local government, universities, private sectors, NGOs, and the disaster management community.

2 Stage of Development of the Landslide Monitoring and Early Warning System

One method for mitigating landslides disasters is the development of a highly adaptive monitoring and early warning system, so that the local people and governmental officers are capable of preparing and operating the system. Moreover, the local people, supported by the local government, are expected to be able to reproduce the system independently so it can be applied in other vulnerable areas. The following are steps in the development and application of landslide monitoring and early warning.

(a) Carry out surveys and field investigations of the geological and geotechnical conditions, the factors controlling the landslides, and social condition of the people in the vulnerable areas, to determine the most appropriate monitoring equipment and the best location for installing an early warning system.
(b) Design the most adaptive early warning system by taking into account the results of the geological, geotechnical and social surveys in several pilot locations in the study area.
(c) Carry out socialization and training to improve the capacity of the local people living in the pilot locations, so that they can operate and maintain the system.
(d) Install the early warning system and provide consultation on the maintenance of the instruments in the pilot locations in the landslide prone areas, followed by testing and calibration of the instruments to ensure the continuity and accuracy of the system.

The proposed landslide monitoring and early warning system is an integrated part of the technical and social network, and is based on community participation in the application of the most adaptive and appropriate technology (Fathani and Karnawati 2010, 2012). Through this system, the community is empowered to actively participate in the preparation of the technical network (consisting of the hardware for landslide monitoring and early warning), and the social networks are strengthened by Village Disaster Management Forums supported by local government (Karnawati et al. 2011).

Through the application of these systems, the technical network of landslide monitoring and early warning can be developed and the capacity building of the local people on disaster preparedness can be enhanced (Andayani et al. 2008). In the end, the local people are expected to be more motivated, more capable, and more empowered in participating in landslide disaster mitigation in their village.

The stages of development of a landslide early warning system, starting from the simple and low-cost manual monitoring system to the real-time monitoring system, are discussed in the following section. In addition, newly developed monitoring devices such as extensometers, tiltmeters, and raingauge, and the proposed network diagram of the telemetry system are described.

3 Simple and Low-Cost Technology for Landslide Monitoring

Since 2007, Universitas Gadjah Mada Indonesia has developed simple and low-cost equipment for landslide monitoring and early warning. At the initiation of quantitative investigations, two types of simple extensometers and raingauges were installed at several pilot areas in Central Java and East Java Provinces. The first type of extensometer is a handmade manual reading extensometer with an accuracy of 1 mm (Fig. 1). Another type is an automatic extensometer to monitor ground surface movement with an accuracy of 0.2 mm, in which the relative movement between two points is mechanically enlarged by 5 times and recorded continuously on paper (Fig. 2). Both types of extensometers, coupled with an automatic rainfall recorder, are connected to an alarm system in order to directly warn the local community to take necessary actions in dealing with a potential landslide disaster.

The implementation of this landslide early warning system, initially started by the Faculty of Engineering Universitas Gadjah Mada, had several failures before it finally succeeded through appropriate technology, the community's understanding of disaster preparedness, and the effectiveness of a socio-technical strategy approach to implement the system. In one example, this simple and low-cost monitoring equipment successfully saved 35 families in Kalitelaga village at Banjarnegera Regency, Central Java from a landslide on November 7, 2007 (Fathani and Karnawati 2010).

The installation of a simple and low-cost landslide monitoring and early warning system in

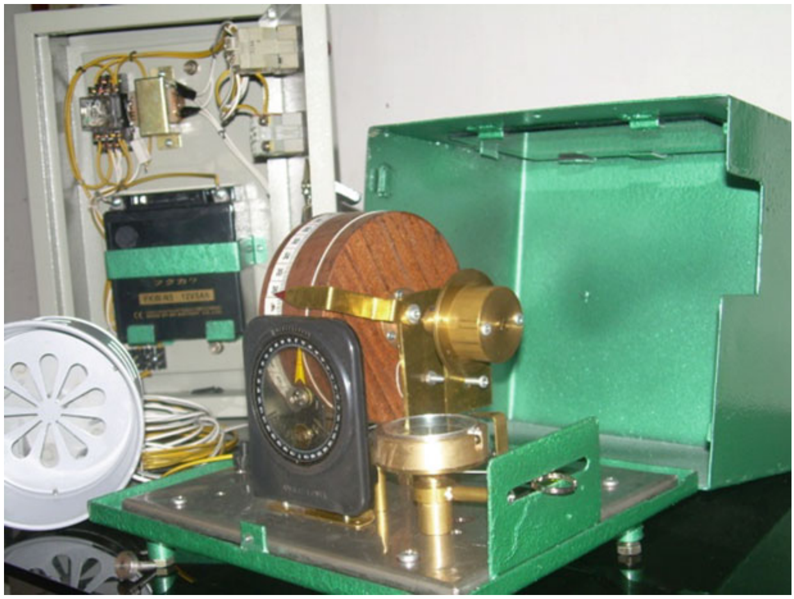

Fig. 1 Manual reading extensometer

Fig. 2 Paper recorded, automatic extensometer

Kalitelaga Village is shown in Figs. 3 and 4. Figure 3 shows an automatic extensometer installed in the upper part of an unstable slope in order to monitor the ground movement on a crack, in a location where houses are located on the lower slope. Meanwhile, Fig. 4 shows a manual reading extensometer at the upper part of a collapsed slope. This extensometer warned the local community about four hours before the occurrence of a landslide and saved 35 families living downslope.

In order to ensure that the simple landslide early warning system can work properly, the local authority (local government at a village level) should establish the warning information flow and command flow as shown in Fig. 5. Since this simple early warning system equipment (extensometer and automatic rainfall

Fig. 3 Placement of an automatic extensometer

Fig. 4 Manual reading extensometer on the upper part of a collapsed slope

recorder) directly sends the warning alert to local community, hence the community can immediately prepare for evacuation. The head of village then gives an order to the selected local operators to lead the evacuation process (if necessary). This command flow worked well during the occurrence of a landslide on November 7, 2007. The selected local operators (under the supervision of the head of village) can decide when and where to evacuate, and convince the evacuees to stay in a safer area while the local operator keeps monitoring the slope condition.

4 Real-Time Landslide Monitoring

4.1 First Stage of Development (2007–2009)

In line with the installation of simple monitoring equipment, on September 2007, the Asian Joint Research Project for Early Warning of Landslides has conducted a field survey to support the installation of real-time landslide monitoring equipment. A pilot area has been established in

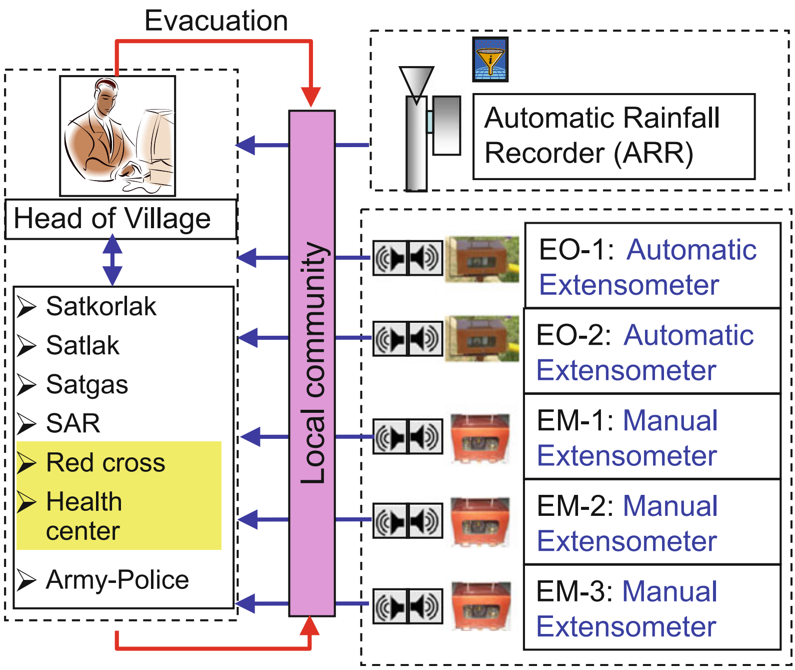

Fig. 5 Flow of warning information and evacuation command for a simple landslide early warning system at village level

Banjarnegara Regency, Central Java Province. Figure 6 shows the aerial photo and topography map of a landslide area mapped by using a photogrammetry system.

Based on the site investigation, it is clear that not only the rain intensity but also the morphology and geological conditions of the study area significantly control the occurrence of landslides. The unstable zone in the study area is situated on the lower slopes of the mountains, with slope inclinations of 20°–60°. The moving materials consist of colluvial deposits of silty clay overlying an inclined impermeable layer of clay, which is situated on the lower part of the andesitic breccia of the mountain. The moving zone is saturated for most of the rainy season due to its low position relative to the surrounding mountain slopes.

The existence of an impermeable clay layer underneath the colluvial deposits creates a saturated condition within the colluvial deposits that gradually increases and is maintained during the rainy season, until the rise of pore water pressure within the soil induces movement. Therefore, monitoring the pore water pressure in response to rain infiltration should be the main concern in establishing an early warning.

This monitoring system presents the results of real-time measurements, using long-span extensometers, raingauges, pore pressure sensors, and monitoring of the scene by an Internet Protocol (IP) camera. The real-time monitoring equipment consists of an outdoor unit and an indoor unit. The outdoor unit is fixed on a center pole and consists of a field server, two extensometers, a raingauge, an IP camera and a water pressure sensor (Fig. 7). The field server is a sensing device with real-time online data display system which gathers the data from multiple sensors and shows them in a webserver.

The extensometer is placed at two positions connected by a pulley and a super invar wire which can measure both extension (+) and compression (−). The indoor unit has two crucial components, i.e. a processing unit and a GPRS modem. The indoor unit collects the data, then processes and stores it on the monitor, and sends the data to the server every hour. This unit also can implement an early warning that can be adjusted depending on the site conditions.

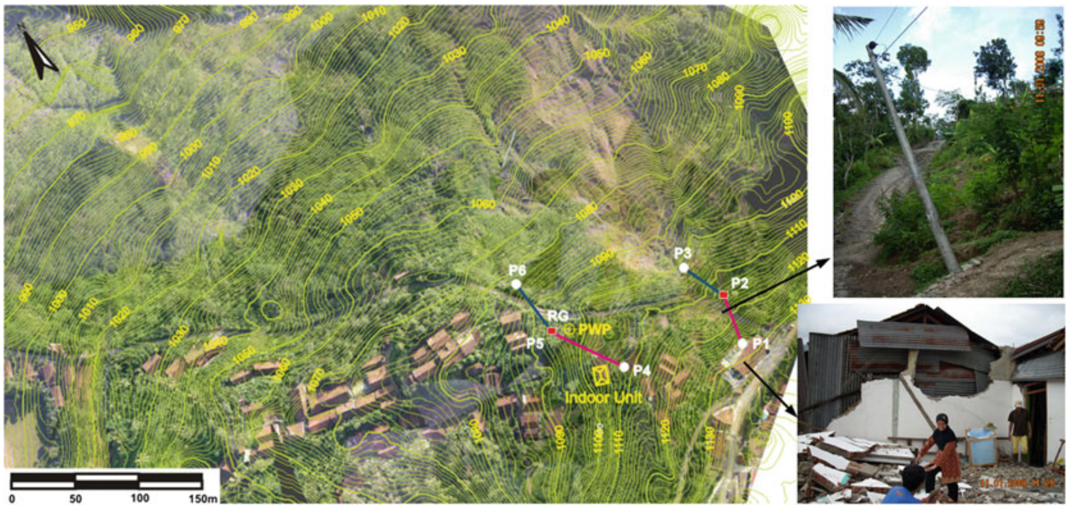

Fig. 6 Aerial photo with a topographic map and position of real-time monitoring equipment in the pilot study area in Banjarnegara Regency, Central Java Province. Landslide damage and fatalities are shown *on the right*

Fig. 7 Outdoor real-time monitoring devices in the pilot area

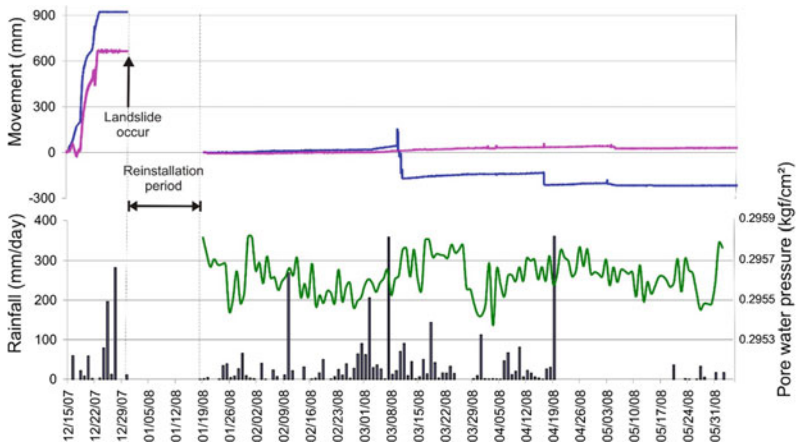

Fig. 8 Pilot area measurements from extensometers, a raingauge and pore water pressure sensor

The position of the long-span extensometer poles (P1–P6), raingauge, pore water pressure sensor and indoor unit are shown in Fig. 6. Three poles (P1–P3) were installed on December 15th, 2007. The installation process had faced some problems, as the slide occurred on day the system was set up. As shown in Fig. 8, starting from December 23rd, 2007, the extensometer had been saturated (up to 660–920 mm of displacement), therefore it could not measure the movement when the landslide occurred on December 30th, 2007. The landslide destroyed the center pole (P2), buried the lowest pole (P3) and also struck several houses, farm land and a district road.

On January 19th, 2008, the monitoring system had been reinstalled at a new location about 150 m from the previous destroyed place (Fig. 6). Three new poles (P4–P6) were erected with two long-span extensometers, a raingauge and an IP camera connected to the center pole (P5). A pore water pressure sensor was placed inside a well near P5, while the indoor unit was located in a house belonging to a volunteer resident near P4.

The result of measurement of two extensometers, daily rainfall and pore water pressure fluctuation are shown in Fig. 8. The accumulated movement of the extensometer starting from January 19th until May 31st 2008 reached about 30 and 220 mm for Extensometers P4–P5 and P5–P6, respectively. Meanwhile the maximum rate of rainfall had reached 200–360 mm/day. It can be seen that the extensometer movements on March 7th and April 13th, 2008 were strongly related to the occurrence of rainfall.

4.2 Second Stage of Development (2010–2012)

A field survey to support the establishment of the new real-time landslide monitoring and warning system was conducted. This system presents the results of real-time measurements from an upper ground and underground extensometer, a tiltmeter, groundwater measurements and a raingauge. The monitoring equipment is connected with a data logger and integrated in a field server. This sensing device provides a real-time online data display; the system collects the data from multiple sensors and shows them in a webserver. This unit also implements early warnings that can be adjusted depending on the site conditions.

Fathani et al. (2011) have determined the warning criteria for rainfall-induced landslides in Central Java by deploying this real-time monitoring system and assessing the effects of rainfall intensity on landslide activity using various setting methods. Rainfall thresholds and slope movement acceleration are used to determine the early warning criteria and time for evacuation.

Figure 9 shows a network diagram of a telemetry system for real-time monitoring of landslides. The system comprises three sensors—an extensometer, a tiltmeter and a raingauge, and other sensors may be added, such as pore water

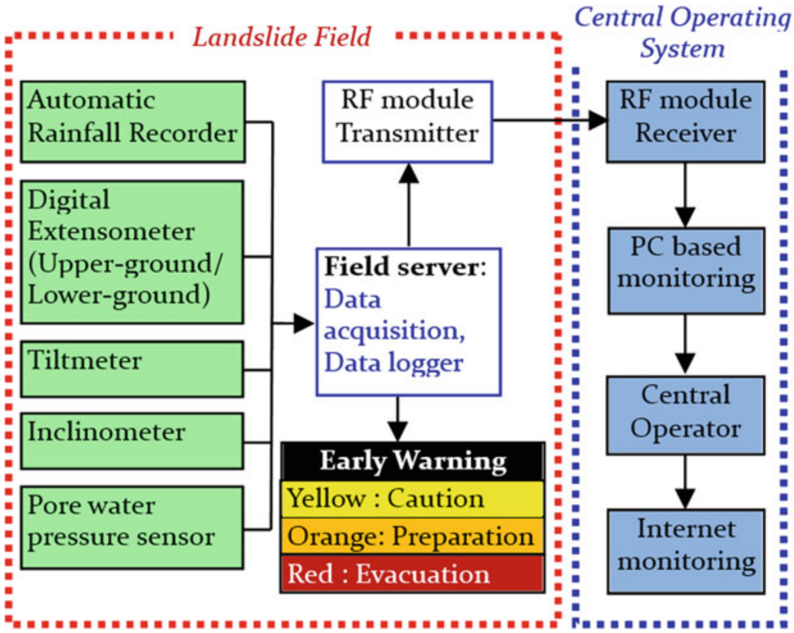

Fig. 9 Network diagram of a telemetry system for real-time monitoring and early warning of landslides

pressure and inclinometer sensors. The collected data, processed by a microcontroller, is sent point to point in a wireless network. The data is received by a field server; its functions are to receive, store, analyze and resend data to the central server, and decide when to send an early warning to the local residents. The maximum distance of the radio frequency is 2 km Line of Sight (LOS) between the sensor and local server, while the distance from the local server to the central server is from 15 to 20 km (LOS).

The data received is then stored in a digital storing media (memory card). The central server consists of receiver equipment and a specific Personal Computer (PC) to monitor the data visually. The PC, which is connected to the internet, will upload all of the data to a web server; therefore, the data can be monitored from any place with internet access.

5 Landslide Monitoring Devices

The landslide monitoring devices (left side of Fig. 9) were developed by Universitas Gadjah Mada, in cooperation with the International Consortium on Landslides (ICL), DPRI Kyoto University, National Board for Disaster Management (BNPB) and Ministry for the Development of Disadvantaged Regions (KPDT). Fathani and Karnawati (2012) proposed that the newly developed monitoring devices consist of an extensometers, raingauges, tiltmeters, inclinometers and pore water pressure sensors (Fig. 10).

An extensometer is a device to monitor ground surface movement in landslide-prone areas. It measures relative surface movement between two points at a ground crack on moving land. The digital extensometer can measure lateral ground movement and slope along X and Y axes. The working principle of the extensometer involves installing this device between two points, one of which is installed on the moving ground. An invar wire is connected to the ground crack on one end and to the potentially unstable ground on the other end.

When the ground moves, the invar wire will pull a spring mechanism. The sensor will then read this movement. The newly developed upper ground extensometer has been installed to monitor ground movement in a mining site in South Kalimantan. The international mining company prefers to utilize a rotary light signal instead of a

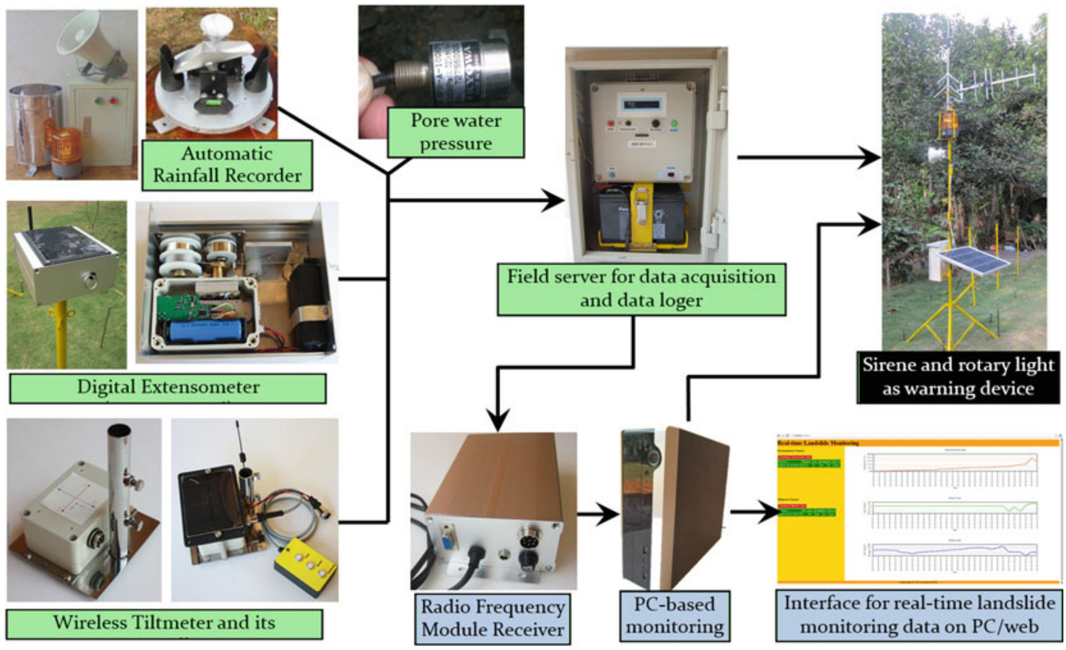

Fig. 10 Newly developed devices for landslide monitoring on a network diagram of a telemetry system

sound alarm system, due to the noise from heavy equipment at the mining site.

This extensometer has a mechanical system and an electrical system. The mechanical system consists of a spring and the spring housing with an invar wire roller. The system is used to measure the ground movement. The extensometer comprises two sensors: (1) an absolute rotary encoder sensor and (2) a tilt sensor. The absolute rotary encoder sensor, combined with the pulley and spring system, can measure a ground crack with an accuracy of 0.1 mm. A tilt sensor with a Micro-electromechanical System (MEMS) is used to measure a change in the slope inclination. The computed data, i.e., ground movement data (mm) and slope inclination data (degree) are then sent to a field server to be stored and processed.

A tiltmeter is a device to monitor the change in the slope in a landslide-prone area. The new developed tiltmeter may measure a slope along X and Y axes with an accuracy up to 0.1°. Other than measuring a slope, the tiltmeter can measure the diagonal angle of the ground movement direction. The preliminary model of the developed wireless tiltmeter is shown in Fig. 10. The tiltmeter will be further developed using a sensor with higher resolution i.e., 0.01°.

The raingauge that has been developed uses the common tipping-bucket system (Fig. 10). This raingauge uses a sensor that calculates the number of times the buckets tip and converts it to rainfall units (mm/h). This data is transmitted to the data logger, with a memory card as the storage media. Aside from that, the rainfall intensity can be seen on the LCD monitor. The raingauge is fitted with an alarm that gives an audio and visual warning when the rainfall intensity exceeds a certain threshold. The alarm can be adjusted with a keypad in the data logger.

6 Strategic Approach: Community-Based with Linkages to Local Government and the University

Universitas Gadjah Mada has been developing and implementing a community-based landslide risk assessment and early warning project over the last several years in collaboration with

International Consortium on Landslides (ICL), Disaster Prevention Research Institute (DPRI) Kyoto University, National Board for Disaster Management (BNPB), Ministry for the development of Disadvantaged Regions (KPDT), local governments and several private companies and NGOs. This effort has been sustained by the local government, university, the community and related stakeholders for years, and it has resulted in both increased capability and capacity at the local/village level to reduce disaster risk and increase community resilience. This landslide early warning system has been implemented at Java, Kalimantan and Sulawesi Islands in Indonesia and will also be installed in a mining area in Myanmar (Fig. 11).

Based on this extensive experience, landslide early warning systems should be based on the most appropriate and adaptive technology, with the participation and involvement of communities. Therefore, both technical skills and communication skills are the main requirements to foster the success of the early warning system program. The system should include some technical aspects such as geological surveys and site selection, the design of monitoring equipment that is simple (low-cost) but effective, the determination of early warning levels (warning criteria), equipment installation, and operation and maintenance, at the field site, and social aspects such as social mapping and evaluation, public consultation and dissemination of the program, and community empowerment, including technical training and evacuation drills for landslide hazard preparedness.

Over the years, these efforts have resulted in the successful implementation of a landslide early warning system at the community level. The pilot projects are now supported by the community, local government and local universities. Further challenges are to expand the project coverage within and outside of the pilot areas, and to store and process the data for a more effective monitoring, early warning, analysis, and visualization.

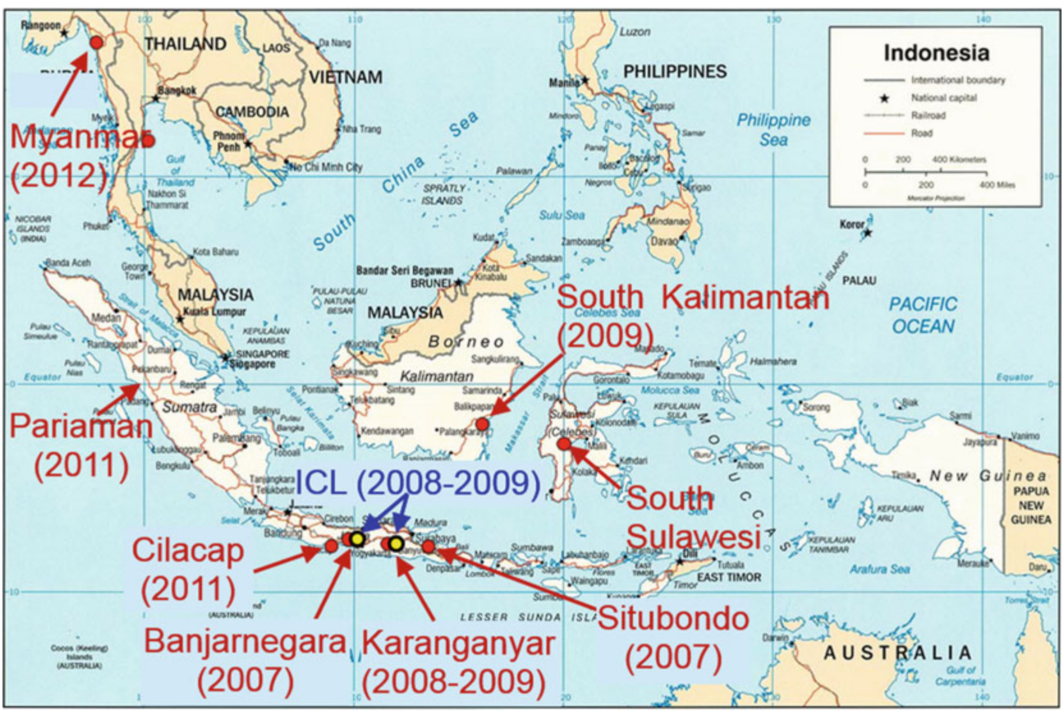

Fig. 11 Locations with the landslide early warning system installed (2007–2012)

Acknowledgements This research was conducted as a part of the Asian Joint Research Project for Early Warning of Landslides supported by the International Consortium on Landslides (ICL), Universitas Gadjah Mada (UGM), and the Disaster Prevention Research Institute of Kyoto University (DPRI/KU). The projects were financially supported by the Ministry of National Education, National Board for Disaster Management (BNPB), and Ministry for the Development of Disadvantaged Regions (KPDT). This research is recognized by ICL as IPL-158 Project.

References

Andayani B, Karnawati D, Pramumijoyo S (2008) Institutional frame work for community empowerment towards landslide mitigation and risk reduction in Indonesia. In: Proceedings of the 1st world landslide forum, IPL–ISDR, Tokyo, pp 57–59

Fathani TF, Karnawati D (2010) Early warning of landslide for disaster risk reduction in Central Java Indonesia. In: Sassa K, Yueping Y (eds) Early warning of landslides. Geological Publishing House, Beijing, pp 159–166

Fathani TF, Karnawati D (2012) Lessons learned in the development of landslide early warning system in Indonesia. In: Proceeding of IPL symposium 2012, UNESCO HQ, Paris, pp 30–34

Fathani TF, Karnawati D, Sassa K, Fukuoka H, Honda K (2008) Development of landslide monitoring and early warning system in Indonesia. In: Proceedings of the 1st world landslide forum, IPL–ISDR, Tokyo, pp 195–198

Fathani TF, Karnawati K, Sassa K, Fukuoka H (2010) Low-cost and adaptive technology to support a community-based landslide early warning system in developing countries. In: Kameda H et al (eds) Disaster reduction hyperbase-Asian Application (DRH-Asia) (EDM-NIED Editorial Team), pp 89–97

Fathani TF, Karnawati D, Legono D, Faris F (2011) Development of early warning system for rainfall-induced landslide in Indonesia. In: Proceeding of the 2nd international workshop on multimodal sediment disaster: Asian Cloud Network on Disaster Research, Tainan, Taiwan, pp 103–113

Karnawati D, Fathani TF (2008) Mechanism of earthquake induced landslides in Yogyakarta Province, Indonesia. The Yogyakarta Earthquake of 27 May 2006. Star Publishing Company Inc., Belmont, pp 8-1–8-8

Karnawati D, Ibriam I, Anderson MG, Holcombe EA, Mummery GT, Renaud JP, Wang Y (2005) An initial approach to identifying slope stability controls in Southern Java and to providing community-based landslide warning information. Glade T, Anderson MG, Crozier MJ (eds) Landslide hazard and risk. Wiley, New York, pp 733–763

Karnawati D, Fathani TF, Wilopo W, Setianto A, Andayani B (2011) Promoting the hybrid socio-technical approach for effective disaster risk reduction in developing countries. In: Brebbia CA, Kassab AJ, Divo EA (eds) Disaster management and human health risk II. WIT Press, Southampton, pp 175–182