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DEVELOPMENT OF EARLY WARNING SYSTEM FOR RAINFALL-INDUCED LANDSLIDE IN INDONESIA

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Abstract

A real-time monitoring for early warning of landslide has been developed in Banjaranegara Regency of Central Java, Indonesia. The fieldsensor gathers the data from multiple sensors i.e. long-span extensometers, min gauge, network camera and water pressure gauge. The results of real-time monitoring will be utilized to assess the effect of rainfall intensity on landslide activity by examining the relationship of landslide displacement and groundwater level fluctuation. Tank model is used to simulate the groundwater level for future rainfall events. The results indicated that the change of groundwater level of Banjaranegara Landslide can be predicted by using two cascading tank model. Furthermore, the movement of rainfall-induced landslide can be estimated by combining the predicted results of groundwater level and its relation with slope displacement. It was clarified that shallow groundwater level found in Banjaranegara Landslide more tends to be influenced by rainfall rapidly. The displacements of Banjaranegara landslide have a wide-range interval of about 300 mm, much higher than that happened at the deep-seated landslide. Finally, the change in displacement due to rainfall events can be used to determine the warning criteria for rainfall-induced landslides.

Keywords: landslide monitoring, slope movement, cascading tank model, groundwater fluctuation, warning criteria
1. Introduction

The occurrence of landslides in Indonesia have frequently increase in recent years due to the high rain precipitation, frequent earthquake vibrations as well as the extensive landuse changing and deforestation. This has resulted in tremendous loss of property and life, mainly in the hazard prone areas that do not have adequate provisions for early warning systems and disaster mitigation measures. Urgently, some efforts should be done to avoid or reduce the risk of landslides. Despite an effort to establish slope protection zone, which is restricted for any development and settlement, and the relocation program is not easy to be carried out due to socio-economical constrains. Therefore, there is a necessity to develop a real-time landslide monitoring system which can gather data from sensors in the field and publish them on the web for analysis by experts and for contribution towards rural community-based early warning of landslide.

The main objective of this research is to determine warning criteria for rainfall-induced landslide by developing a real-time monitoring system and assessing the effect of rainfall intensity on landslide activity by various setting methods. Considered setting methods used in this study are tank model method and effective rainfall method. These setting methods are commonly used for wide area in Japan (MLIT, 2004). The setting procedure can be fulfilled by examining the relationship of landslide movement parameters and available hydrological data. Preceding study about quantitative assessment on the influence of heavy rainfall on a large-scale deep-seated landslide at Zentoku, Japan has been performed by Hong et al. (2005). Accordingly, it is necessary to compare the analysis result of previous study with the assessment of rainfall-induced shallow landslide by deploying a real-time monitoring system in Banjarnegara Regency of Central Java Province, Indonesia.

2. Landslide Condition at the Study Area

A pilot area for landslide monitoring, prediction and early warning program has been established in Banjarnegara Regency, since year 2007. Based on the site investigation, it is clarified that not only the rain intensity but also the morphology and geological conditions of study area significantly control the occurrence of landslides (Fathani et al, 2008; Fathani and Karnawati, 2009). The unstable zone in this study area is situated at lower slope of mountains with the slope inclination of 20° to 60° (Fig. 1). Fathani and Karnawati (2009) revealed that the moving materials at the study area consist of colluvial deposits of silty clay overlying the inclined impermeable layer of clay, which is situated at the lower part of the andesitic breccias mountain. The clay layers are inclined at the same direction of the slope and this becomes the sliding surface for the above colluvial soils. The moving zone is saturated at most of the rainy season due to the lower position of the zone comparing to the surrounding mountainous slopes. The existence of impermeable clay layer underneath the colluvial soils creates the saturation condition within colluvial soil gradually increased and maintained during the rainy season, until then the rise of pore water pressure within this soil induces the movement. Therefore, monitoring of the groundwater table in response to the rain infiltration should be the main concern in establishing early warning for the slope movement.

3. Real-time Monitoring for Early Warning of Landslide

The Asian Joint Research Project for Early Warning of Landslides supported by International Consortium on Landslides (ICL), Disaster Prevention Research Institute (DPRI) Kyoto University, Gadjah Mada University and Asian Institute of Technology have developed a real-time monitoring system to support landslide early warning in Banjarnegara.
Regency of Indonesia. A fieldserver was used to collect data from several sensors and display them in a real-time web page. Two long-span extensometers placed above and below the data collection point in order to measure the rate of ground displacement. The rain gauge was installed in order to constantly measure the antecedent as well as current rainfall which affect the slope movement. At the same time, a water pressure gauge was also placed near the data collection point at a depth of 2.5 meters to measure the fluctuation of groundwater level. The data from the sensors and the images from the network camera are collected and stored in a database in an embedded Linux system. The placement of landslide monitoring devices in Kalitelaga Village, Banjarnegara Regency is shown in Fig. 1.

Fig. 1. Placement of long-span extensometers (P1 to P6), rain gauge (RG), water pressure gauge (PWP) and indoor unit.

The real-time monitoring for early warning system consists of a fieldserver as its core component, which collects data from the following sensors: long-span extensometers, rain gauge, water pressure gauge and network camera (as shown in Fig. 2). The network diagram of telemetric system is shown in Fig. 3. Fieldserver and other associated electronic and network devices are located in an outdoor box mounted on a fixed pole at position P2/P5 as shown in Fig. 1. The super invar wires of the extensometers are extended from above and below the fixed position, such that they can measure slope movement in both directions at the two places. The fixed position is at pole P2/P5, and the extensometer wires are being extended from poles P1/P4 and P3/P6.

The extensometer placed at two positions connected by a pulley and a super invar wire which can measure both extension (+) and compression (−). Indoor unit collects the data, then process and store data on the monitor, and send the data to server regularly. This unit also implements early warning that can be adjusted depending on the site condition.

At the beginning of installation, the system applies an algorithm based on local observations to provide warning messages at several levels. However, the correct warning criteria considering site characteristics have not been determined yet in this stage. The warning levels are determined by data from two extensometers, and the rain gauge. The warning criteria are described as follows (Honda et al., 2008):
Fig. 2. Fixed pole with extensometers, rain gauge, water pressure gauge, network camera, and the outdoor box with fieldserver.

Fig. 3. Network diagram of telemetric system for real-time monitoring of landslide.

a. Warning I (First Warning, Yellow): if \( R_{24} > 100 \text{mm} \) & \( R_{24} > 250 \text{mm-R72} \)

b. Warning II (Prepare for evacuation, Orange): if \( R_{24} > 150 \text{mm} \) & \( R_{24} > 350 \text{mm-R72} \) \( \| \) (Warning I \& (\( E_1 > 2 \text{mm/hr} \) or \( E_2 > 2 \text{mm/hr} \))

c. Warning III (Evacuation, Red): if (Warning I \| Warning II) \& (E1 > 5 \text{mm/hr} \| E2 > 5 \text{mm/hr})
R24 and R72 are antecedent rainfall in 24 and 72 hours respectively, and E1 and E2 are displacement rates. An audio interface has been provided on the remote server placed in indoor unit, which is designed to emit different warning tones depending on emergency levels. Besides provision to connect a loud speaker to emit different warning tones, a graphical interface is provided at the local site for local community to observe the data which shows the warning levels using different colors. The graphical interface also shows the image from network camera, the data from sensors in the form of simple graphs and tables.

4. Tank Model for Groundwater Level Simulation

The required data to be designated for further analysis are sustainable precipitation and groundwater level data which confirm the relation between the rainfall activity and the fluctuation of groundwater level in a borehole. By using Tank model, the simulation of groundwater level induced by rainfall activity can be performed. Tank model in this research is modeled by two cascading tanks considering specific geological formation and shallow groundwater level at the landslide area. Fig. 4 shows the structure of Tank model and parameters used in the analysis of Banjarnegara Landslide.

Fig. 4. Structure of Tank model and calculated parameters for Banjarnegara landslide.

First tank is used to simulate the runoff on the ground surface and the infiltration into the sliding mass. The second tank represents the input and output of water in the borehole. The total height of water at the second tank (h₂) is considered as the simulated groundwater level. This simulation needs consistent and continuous rainfall data and groundwater level. Thus, rainfall event from August 28 until December 12, 2008 has been analyzed which are adequately supported by continuous groundwater level data (Fig. 5).

The heights and the coefficients of the outlets are determined by trial and error until the simulated water level in the second tank presents a good corresponding relation with the real measured groundwater level as shown in Fig 5.

5. Landslide Early Warning Criteria

5.1 Groundwater Level Fluctuation and the Activity of Sliding Block

In this part of analysis, the groundwater level fluctuation and the deformation of landslide observed by extensometer are correlated linearly. The data considered in this analysis is groundwater level measurement during rainstorm activity which significantly influence the
landslide deformation. Series of data between January 18, 2008 and March 31, 2008 have been chosen considering the most significant deformation occurred corresponds to rainfall event. Unfortunately, there is no adequate groundwater level data in this time interval. Thus, previously built Tank model was used in order to simulate the groundwater level.

![Graph showing simulation result of groundwater level](image)

**Fig. 5. Simulation result of groundwater level by using two cascading Tank model.**

The relationship between daily displacement and groundwater level which have been found in shallow landslide at Banjarnekega shows different characteristic from large-scale deep-seated Zentoku landslide in Japan (Fig. 6). The displacement of Banjarnekega landslide gradually increase and the rate of displacement sharply increase as the peak of heavy rain occurred on March 7, 2008. The displacement of shallow landslide at Banjarnekega obviously much higher than the displacement occurred at deep-seated Zentoku landslide. However, corresponding to the fluctuation of water level, the displacement shows a poor correlation.

There are major differences between Zentoku landslide and Banjarnekega landslide on size of landslide, geological features, depth of groundwater level and the rate of displacement. These differences affect the characteristic of landslide movement due to groundwater level fluctuation. The depth of groundwater level at Banjarnekega landslide region is about 1.0 to 1.5 m, which is much shallower than groundwater seated at Zentoku landslide of more than 9.5 m depth. Shallow groundwater level more tends to be influenced by rainfall rapidly.

In addition, the displacements of Banjarnekega landslide have a wide-range interval of about 300 mm, much higher than that happened at Zentoku landslide with the interval of just about 3 mm, and it is continuously moving by the increment of rainfall intensity. Fig. 7 shows the gradual movement of Banjarnekega landslide as a sign of visco-plastic phase of landslide body. This could be happened due to weak soil strength that forms Banjarnekega landslide compared with the geological settings of Zentoku landslide which formed by crystalline schist consisting of Green schist, Pelitic schist, Psammitic schist and is mantled by colluviums (Hong et al., 2005).
Fig. 6. Comparison between large-scale deep-seated Zentoku Landslide and small-scale shallow landslide at Banjarnegara concerning the daily rainfall, groundwater fluctuation and displacement.

Fig. 7. Displacements characteristic of Banjarnegara landslide as a sign of visco-plastic phase of landslide body.

5.2 The Relationship between Cumulative Rainfall and Landslide Displacement

The correlation between rainfall event and landslide displacement was examined since the activity of the landslide notably affected by the rainfall. Noticeably, Banjarnegara Landslide tends to creep continuously depends on the rainfall activity. Fig. 8 shows the daily rainfall and cumulative rainfall between January 18, 2008 and December 8, 2008. By comparing Fig. 7 and Fig. 8, the displacement shows a good correlation with the cumulative rainfall. The rate increases as the rainfall activity gaining. This is an evident that rainfall is the governing factor of landslide triggered movement.
5.3 The Relationship between Effective Rainfall and Rate of Landslide Movement

The real-time monitoring of landslide movement by using two long-span extensometers, rain gauge and water pressure gauge has been done continuously in Banjarnegara Landslide since December 2007 until now. Thus, the displacement and rate of landslide movement can be observed. The quantitative analysis of rainfall is important since Banjarnegara landslide movement is highly affected by rainfall.

Effective rainfall is defined as the sum of antecedent effective rainfall and the accumulative rainfall during a series of rain. Yano (1990) proposed a method to predict landslide event by identifying the critical antecedent rainfall. The following is the equation of proposed effective rainfall:

\[ R_W = \sum \alpha_i \times R_i \]  \hspace{1cm} (1)

where \( R_W \) = effective rainfall; \( R_i \) = hourly rainfall of \( i \) hour before the hour; \( \alpha_i \) = reduction coefficient; \( \alpha_i = 0.5^{i/T} \); \( T \) = half-time period. The relationship between rate of landslide movement and the effective rainfall is shown in Fig. 9. The maximum coefficient of correlation \( (R^2 = 0.4647) \) reached when the half-life period equal to 2 days (Fig. 10).

![Figure 9](image.png)  
Fig. 9. Relationship between rate of landslide movement and effective rainfall.

![Figure 10](image.png)  
Fig. 10. The relationship between half-life period and correlation coefficient.

5.4 Rainfall Threshold for Rainfall-induced Landslide

Rainfall threshold will be further used for determining the early warning criteria and time for evacuation. In this study, rainfall threshold distinct the considerably rate of landslide movement \((v)\) by three categories:
Category I : $2 \text{ mm/hour} < v < 5 \text{ mm/hour}$
Category II : $5 \text{ mm/hour} < v < 10 \text{ mm/hour}$
Category III : $v > 10 \text{ mm/hour}$

Fig. 11 shows the rainfall threshold built from the effective rainfall by using 2 days half-life period. Accordingly, the rainfall threshold by the simpler way proposed by D’Orsi et al. (1997), has been examined in this study. This method uses daily rainfall (mm/24 h) and accumulated rainfall in 96 hours (mm/96 h), as shown in Fig. 12.

![Fig. 11. Rainfall threshold based on effective rainfall.](image)

![Fig. 12. Rainfall threshold using the correlation between daily rainfall and accumulated rainfall in 96 hours.](image)

The above correlations shown in Fig. 11 and Fig. 12, can be applied to determine the warning criteria for rainfall-induced shallow landslide in Banjarne area region. To provide an early warning for local community, an alarm is connected to the fieldserver of the system and the certain level of alarm (first warning - prepare for evacuation - evacuation) is automatically warn the local community when the critical rainfall (daily, effective or accumulative) which can trigger landslides and/or the critical conditions of slope movement occurs. By modifying the warning criteria, this system can be applied to not only for rainfall-induced landslides, but also for earthquake-induced landslides (Karnawati and Fathani, 2008).

Village action plan (including the contingency plan) for disaster prevention and response program is accordingly developed by the newly established Task Force Team in the study area (Karnawati et al., 2008). Obviously, one of the most important programs to guarantee the effectiveness in implementing this early warning system in the rural area is public education and evacuation drills, and these programs need to be conducted regularly to improve the awareness and preparedness of local community for any possible landslide disaster.

6. Conclusions

This study has examined and compared a quantitative assessment on the influence of heavy rainfall on a large-scale deep-seated landslide at Zentoku in Japan with the assessment of rainfall-induced small-scale shallow landslide at Banjarne area Regency of Indonesia by deploying a real-time monitoring system. There are major differences between large-scale deep-seated Zentoku landslide and small-scale shallow landslide at Banjarne area on size of landslide, geological settings, depth of groundwater level and displacements characteristic. The displacement occurred on small-scale shallow landslide is much larger than the displacement on a large-scale deep-seated landslide. The tank model can be used to simulate the fluctuation of groundwater level,
based on the rainfall data. Setting method using effective rainfall seems to be a good alternative for predicting future displacement of rainfall-induced shallow landslide. Early warning criteria for rainfall-induced landslides were developed in this study based on rainfall thresholds that has been built from the effective rainfall by using 2 days half-life period and accumulated rainfall in 96 hours.

Landslide monitoring, prediction and early warning system are urgently required to guarantee the safety of community living in hazard prone area. This real-time monitoring and early warning system of landslide can be proposed as a model for implementation at landslide prone community worldwide. Based on three years continuous monitoring of landslide in Banjarnegara, the GPRS internet link is not so stable in the field application, hence the data coming from landslide field to UGM server is sometimes interrupted. Therefore, the application of other telemetry media, i.e. by radio frequency, needs to be considered. Nevertheless, by implementing this system, the local community will be able to monitor landslide activity to support early warning in order to decide the proper time for self evacuation.

Some lesson learned that can be derived from this program is that landslide early warning system should be based on the appropriate and most adaptive technology with the involvement of community participation. Therefore, both technical skill and communication skill are the main requirements to achieve the success of early warning system program. The system should include some technical aspects such as the geological surveys and site selection, design of the most adaptive monitoring equipment, determination of early warning criteria (as discussed in this study), operation/maintenance at the field site, as well as the social aspects such as social mapping, public consultation, community empowerment including the technical training and evacuation drills for improving the community resilience against landslide disaster.

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References


application of sensor Asia, Proceeding of World Conference on Agricultural Information and IT.
Yano K. (1990): Study of the method for setting standard rainfall of debris flow by the reform of
Janeiro Landslide Watch System, Proceeding of 2nd Pan-American Symposium on Landslides,
Rio de Janeiro, pp. 21-30.
Province, Indonesia, The Yogyakarta Earthquake of May 27, 2006, Star Publishing Company
Inc.: Belmont, CA., pp. 8-1 to 8-8.
community-based landslide early warning system in Indonesia, Proceeding of the 1st World