

Landslide early warning system prototype with GIS analysis indicates by soil movement and rainfall

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Abstract. The aim of this paper is developing and testing of landslide early warning system. The early warning system uses accelerometers as ground movement and tilt-sensing device and a water flow sensor. A microcontroller is used to process the input signal and activate the alarm. An LCD is used to display the acceleration in x, y and z axis. When the soil moved or shifted and rainfall reached 100 mm/day, the alarm rang and signal were sent to the monitoring center via a telemetry system. Data logging information and GIS spatial data can be monitored remotely as tables and graphics as well as in the form of geographical map with the help of web-GIS interface. The system were tested at Kampung Gerendong, Desa Putat Nutug, Kecamatan Ciseeng, Kabupaten Bogor. This area has 3.15 cumulative score, which mean vulnerable to landslide. The results show that the early warning system worked as planned.

Keywords: early warning system; ground movement; landslide; tilt-sensing

1. Introduction

A landslide is the downslope movement of soil, rock, and organic materials under the effects of gravity and also the landform that results from such movement [1]. Landslides are known also as landslips, slumps or slope failure. In the beginning of 2017 several countries hit by landslide such as Colombia, Italy, Indonesia, New Zealand, India, Bosnia, Kyrgyzstan. In March 31, 2017 a massive landslide hit Mocoa Colombia and at least 254 people had been killed, more than 200 were missing and at least 400 were injured [2]. An early warning system can be used to minimize the impact imposed by landslide on human, damage to property and loss of life. The ability to monitor slope movements in timely fashion will inform the people of possible slope failures – giving them adequate lead time to relocate to a safer place.

This landslide early warning system integrates the rainfall sensor, accelerometer, and inclinometer with visual web-GIS (geographic information system) interface so that the factors causing the landslide and its effects (movement of the soil) can be monitor. The system is equipped with wireless telemetry so that the data obtained from accelerometers and rainfall gauges can be send to a remote monitoring or observation center and recorded [3]. Initial analysis on the rock structure/texture, classification on the soil slope, permeability, and weathering in landslide prone area were done in order to make it easier to obtain map and to determine the cost. Mapping, investigation, inspection, and monitoring [4], [5] are parts of this research process. The hardware and software design along with GIS analysis was done carefully to obtain efficient and feasible and slide monitoring system. The GIS analysis is presented in the form of spatial data and geographic maps in the web-GIS software interface in real time [6].



Landslide can be caused by two main factors, namely controlling factor and triggering factor. Both main factors will provide mutual synergy to form landslide if there is an excessive ability threshold. The controlling factor is the factors affecting the material condition such as geology, slope, lithology, shear (fault) and invariance on rocks. The triggering factor is the factor causing the movement of materials such as rainfall, earthquake, erosion of slope and human activities [7].

Slopes with inclination more than 20° have potential to move or for landslide, but slopes with inclination or sloping land has always prone to landslide depend on the geological conditions of the slopes [8]. According to type of movement there are 6 types of landslides i.e. translational, rotational, creep, topple, fall and flow as shown in Figure 1 [9].

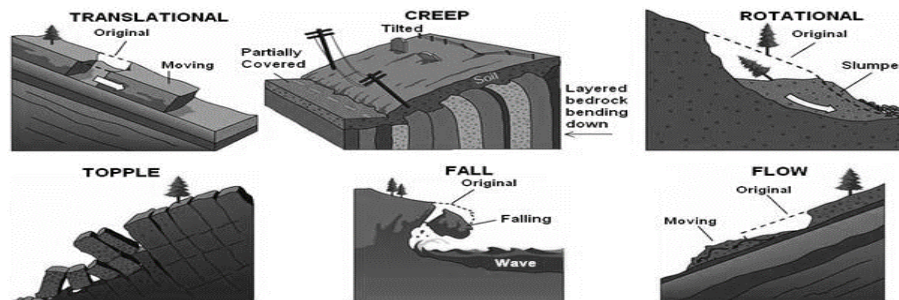


Figure 1. Types of landslides.

2. Research method

The landslide early warning system was developed in three stages: 1) GIS analysis and field study, 2) landslide detection and rainfall monitoring system development, and 3) web-GIS interface development.

2.1. GIS analysis and field study

Data such as slope inclination, soil lithology and texture, local geological data, local rainfall data, road map and land use were collected, analyzed, measured and mapped. Data processing stages are shown in Figure 2.

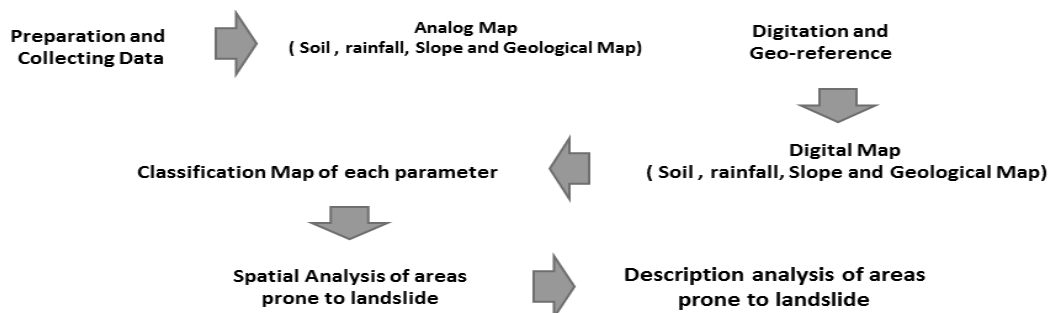


Figure 2. Flow chart of spatial data processing stages.

All the spatial data were inputted into the computer and converted into digital map, subsequently data attribute and each weighting parameter were also inputted into the computer. The parameters used to determine the vulnerability level are rainfall, type of soil, geology (rocks), land-cover, and topography. The scoring model is shown in equation 1.

$$\text{Cumulative Score} = (30\% \times \text{Rainfall Factor}) + (20\% \times \text{Soil Factor}) + (20\% \times \text{Geological Factor}) + (15\% \times \text{Land Use Factor}) + (15\% \times \text{Slope Factor}) \quad (1)$$

Rainfall is the dominant factor causing landslide disaster therefore the weight is higher than other parameters [10]. Rainfall has 30% weight, while soil and geology have the same weight that is 20%, land use and slope each has 15% weight.

Rainfall classification is shown in Table 1 and slope classification is shown in Table 2 [11].

Table 1. Rainfall classification [11].

No	Rainfall Intensity (mm/year)	Parameter	Permeability
1	2000 – 2500	Moist	1
2	2500 – 3000	Wet	2
3	> 3000	Very wet	3

Table 2. Slope classification [11].

No	Class	Slope (%)	Description	Score
1	I	0 – 8	Flat	1
2	II	8-15	Sloping	2
3	III	15-25	Rather Steep	3
4	IV	25-40	Steep	4
5	V	> 40	Very Steep	5

The soil classifications are: alluvial, score=1; association of brown and yellow latosol, reddish brown latosol association, reddish yellow latosol reddish complex and reddish brown latosol association, score=2; association of latosol brown and regosol, score = 3; andosol, podzolic yellowish, association andosol regosol, yellowish podzolic and red podzolic, score = 4; and regosol, score = 5 [11].

While the land cover/use classifications are: forest or dense vegetation and water bodies, score=1; shrubs, score=2; plantation or irrigated rice fields, score=3; industrial and residential area or village, score=4; and empty land, score=5 [11]. The classification as well for rock distribution types are: alluvial (Qav, Qa, a), score=1; Volcanic-1 (Qvsl, Qvu, Qvcp, Qvl, Qvpo, Qvk, Qvba), score=2; Sediment-1 (Tmn, Tmj), score=3, Volcanic-2 (Qvsb, Qvst, Qvb, Qvt) and Sediment-2 (Tmb, Tmbl, Tmtb), score=4 [11].

Based on the cumulative score results, the vulnerable (prone) landslide areas are grouped into three classes, namely (i) very vulnerable, (ii) vulnerable, and (iii) less vulnerable. The vulnerability grade scores are less vulnerable (≤ 2.5), vulnerable ($\geq 2.6 - \leq 3.6$), and very vulnerable (≥ 3.7).

2.2. Landslide detection and rainfall monitoring system hardware development

This landslide early warning system is divided into two parts, namely the transmitter located at the research location, and the receiver located on the remote monitor. ADXL335 accelerometers were used as ground movement and tilt sensor.

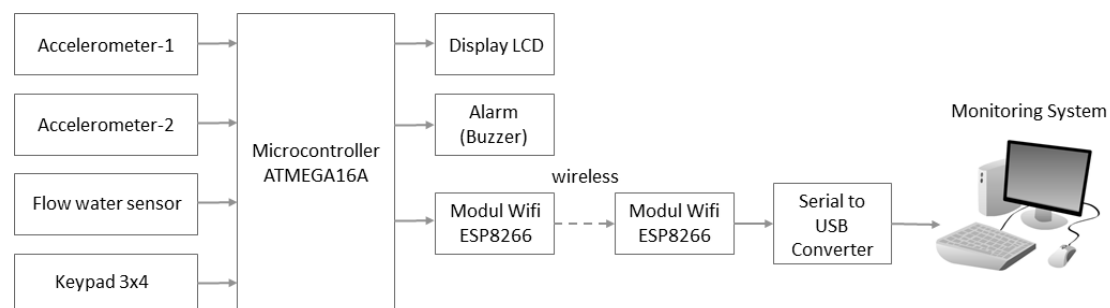


Figure 3. The landslide early warning system block diagram.

A water flow sensor is used as rainfall sensor. An ATmega 16A microcontroller is used as the processor. The ESP8266 (telemetry system) transmit the data to the receivers located in remote location through wireless networking. The receiver receives the data transmitted by the transmitter and displays the data on the computer for remote monitoring purposes. The transmitter and receiver have point-to-point connections. The whole system is shown in Figure 3.

2.3. Web-GIS interface development

Web-GIS is web-based geographical information system of some related components. The web-GIS is combination of digital map and geographical analysis, computer programming and interconnected database.

3. Results and Discussion

Each part of the landslide early warning system i.e. accelerometer, rainfall sensors, LCD (liquid crystal display), wireless telemetry, topographic and hill model analysis, risk/landslide risk analysis, I/O software, web-GIS display was tested individually followed by overall system testing.

The landslide parameters used are rainfall, geology, soil type, slope inclination, and land use.

3.1. Rainfall

Rainfall is one of the climate elements that have big roles on the landslide. Infiltrations of water into soil layer filled the soil and weaken the slope-forming material to trigger a landslide. Heavy and high intensity rain can trigger land movement. The rainfall map of the research area is shown in Figure 4a. The rainfall is classified as high intensity.

3.2. Geology

The geology map of the research area is shown in Figure 4b. The rocks composed from volcanic materials such as glass fragments, fine dust and sand. This area is very water-resistant and can be very slippery in water-saturated conditions resulting from high rainfall.

3.3. Type of soil

The type of soil of the research area is shown Figure 4c. The type of soil is latosol with high permeability. It means that it has ability to pass water at rain and add the soil weight. Therefore, in certain inclination, it is prone to landslide.

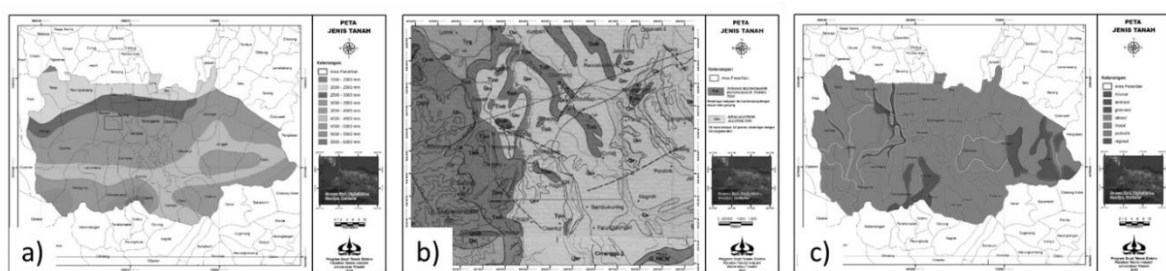


Figure 4.a) Rainfall map of Kabupaten Bogor, b) geological map of research area, c) type of soil map of Kabupaten Bogor.

3.4. Slope inclination

In May 2016, topography data were collected in the research area using GPS from the edge of main access roads until to the edge of Cisadane River. The topography model can be seen in Figure 5.

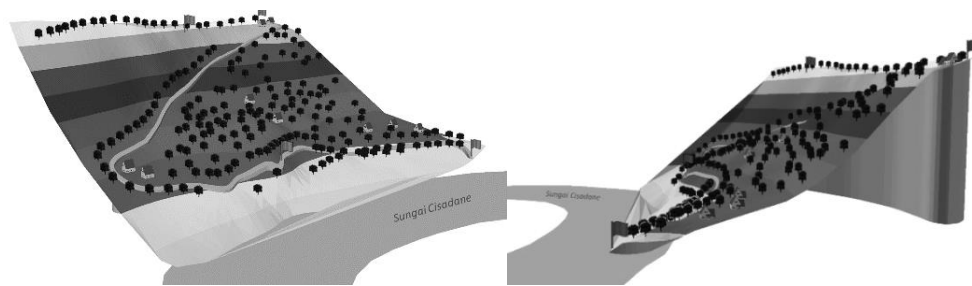


Figure 5. The 3D topography map (a) view from west and (b) view from east.

3.5. Land cover

In the research area, most of land cover type is housing and mixed plantation. This housing area is distributed evenly in overall research area. The housing is located in steep to very steep inclination, which mean very vulnerable to landslide.

3.6. Landslide area analysis

The cumulative score shows that the research area can be categorized as vulnerable to landslide.

$$\begin{aligned} \text{Cumulative Score} &= (30\% \times 3) + (20\% \times 2) + (20\% \times 4) + (15\% \times 4) + (15\% \times 3) \\ &= 0.9 + 0.4 + 0.8 + 0.6 + 0.45 = \mathbf{3.15} \end{aligned} \quad (2)$$

Based on ground check at several landslide points in RT 01/01KampungGerendong, Desa Putat Nutug, Kecamatan Ciseeng, Kabupaten Bogor which is located ± 2 km from the research area, there was a landslide on the night of April 7, 2016 caused by heavy rain, so the main road body collapsed.

The landslide early warning system was tested in the research area for three hours in sunny weather. In this test, the sensor was placed on the 1 m length rod, planted in the ground with 0.5 m depth. The rain monitor showed no changes.

The tests were conducted at 4 locations to obtain pattern of land movement. The best results can be seen in Figure 6.

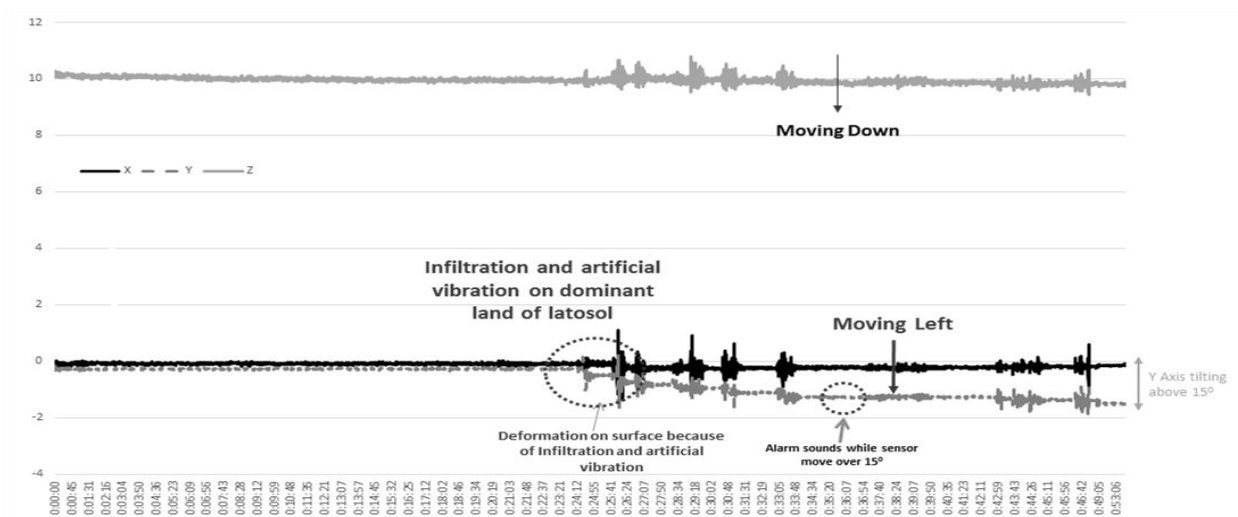


Figure 6. Measurement result and analysis.

From the data in figure 6, it can be seen that there is a spike on each axis indicating the presence of vibration generated from heavy vehicles passing through the roads. To stimulate soil movement, an artificial infiltration in the form of water spray was given towards the rod. Vibration/pounding to

deform the ground surface in order to move/tilt the sensor. This is shown on baseline curve Y and X moving downwards. When there was movement that caused 15° angle the alarm was activated.

4. Conclusion

A landslide early warning system with accelerometers and a rainfall sensor equipped with Wi-Fi for remote monitoring purposes was developed. The advantages of this system are real time monitoring, remote monitoring, and can be used to monitor multiple points in observation area at once. The system was tested in Kampung Gerendong, Desa Putat Nutug, Kecamatan Ciseeng, Kabupaten Bogor. The coordinate of point study area is $6^\circ 28' 14.16''$ South and $106^\circ 40' 8.40''$ East. The results show that the system can display and store slope and acceleration data caused by soil movement and deformation, as well as display and print graph of acceleration, angle and rainfall during monitoring. The web-GIS interface can help interpretation of landslide reconstruction pattern through the data received from the system and it can correlate with other reference data such as geological map, structure, rainfall and other information in spatial form (map).

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