Landslide Vulnerability Mapping for Landslide Victim Relocation

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Abstract, some victims of landslides must be relocated if the location affected by a landslide impossible to be occupied again. The relocation site of the Sijeruk-Banjarneagara landslide victims had experienced a landslide again, due to the inappropriate location selection. It was necessary to mapping the landslide vulnerability for the selection of relocation sites so that the new location must safe from landslides. Settlements that were still located in the high-risk landslide were as the danger the occupants. The selection of relocation sites must be appropriate and the risk of landslides was low. This study aims to produce a vulnerability landslide map so that land suitability can be obtained for the development of settlements by referring to the threat of landslide hazards. Slope stability modelling uses the TRIGRS (Transient Rainfall Infiltration and Grid-Based Regional Slope-Stability) program version 2.0. The principles are modelling the effect of rainfall on regional slope stability. The data needed in modelling was digital elevation model (DEM), soil data index properties, soil engineering properties, and rainfall. The modelling results show that the safety factor values in the study were ranged from 0.8 to 10. Safe numbers below 1.2 means are prone to landslides. Slope stability map can be used to determine the location of the relocation of landslide victims.

1. Introduction
Some area in Indonesia had a medium to high scale landslide vulnerability. Landslide disasters had a high frequency of occurrence by causing victims of property, lives and infrastructure damage. The landslide disaster event disrupted the Indonesian economy sector, so disaster mitigation must be done to reduce the risk. This high landslide threat was caused by hilly topography and relatively steep slope and also other factors such as rainfall. Geological factors also affect the risk of landslides. To reduce the number of victims in landslide-prone, relocation was needed. The choice of location for relocation must be appropriate so that it was safe from landslide hazards, so it was necessary to map the landslide vulnerability level for the location to be used for relocation. Like the incident in Sijeruk Banjarneagara, the relocation site of the landslide victims returned to a landslide. Micro-landslide modelling was carried out with the TRIGRS program.

Based on landforms in Banjarneagara Regency, especially Karangkobar District, had steep slope topography. Karangkobar District was a sub-district in Banjarneagara Regency which was dominated by the threat of high and medium scale landslides. There were still settlements in the threat of high landslides. Settlement-based landslide mitigation planning needed to be done, so no major losses and fatalities in the event of a landslide.

Disasters were events or series of events that threaten and disrupt the lives and livelihoods of people caused by natural factors or non-natural factors and human factors resulting in human
casualties, environmental damage, property losses, and psychological impacts [1]. The disaster was a combination of three elements that disaster threat, vulnerabilities, and abilities triggered by an event.

Concerning Housing and Settlement as article 19 settlements were the implementation of houses and housing that were carried out to fulfill the needs of homes as a basic human need for the improvement and equitable distribution of people's welfare. The types and shapes of houses in residential were as in Article 21 include commercial, self-help, special, public, and statehouses with single, series and collated houses [2].

The results of planning houses and settlements must meet technical, ecological, administrative and spatial requirements. Technical requirements relating to the safety and comfort of the building, and the reliability of its environmental facilities and infrastructure. Ecological requirements were related to harmony and balance, both between the artificial environment and the natural environment and the socio-cultural environment, including the cultural values of the nation that need to be preserved. Administrative requirements relate to the granting of business licenses, location permits, and building permits and the granting of land rights. The physical characteristics that must be considered in a residential were so that it was habitable was free from the danger of topography. Chen et al. conduct research on the relocation of landslide disaster victims in Mrarakot typhoon, Taiwan. However, very little financial effort has been made by moving people from landslides prone to safety zones [3]. One of the main causes of relocation failures was considered physical structure, then addressing the emotional and psychological requirements of the community resettlement process [4]. The way to address the relocation issues and challenges best solutions, community-based strategies are most welcome solutions [5].

Mitigation was a series of efforts to reduce disaster risk, both through physical development and awareness and enhancement of the ability of the community to deal with danger threats (Law Number 24 Year 2007 concerning Disaster Management Article 1 paragraph 9). An early warning was a series of activities to give warning as soon as possible to the community about the possibility of a disaster at a place by an authorized institution. Whereas an early warning system was an effort carried out by the government together with the community in order to reduce the impact that might occur if a natural disaster landslides.

Rainwater infiltration will fill the air pores in the soil so that the soil mass increases and affects the saturation of the soil. Increased saturation of land affects changes in the ability of the soil to absorb water suction. Changes in groundwater level result in changes in parameters on soil properties, both property and technical parameters [6].

Mapping of land movement vulnerability was one of the efforts to predict the occurrence of ground movements for preparedness against the threat of land movement. The land movement vulnerability model must be able to provide information on when and where land movements will occur in a hilly area. The Center for Volcanology and Geological Disaster Mitigation [7], made a Vulnerability Map for the Soil Movement of the Sukabumi region using a geographic information system based weighting approach. Mapping the vulnerability of regional land movements due to rainfall using deterministic and empirical ground motion modelling had been carried out by many previous researchers. TRIGRS was one model of slope stability that was widely used to map the vulnerability of shallow ground movements. The study of soil movements triggered by rain in an area was interesting as an effort to estimate the potential of ground movements triggered by rain. To determine the causes of landslides, especially seen from topographic and rainfall factors, numerical modelling using TRIGRS was one method that can be applied to spatial areas as [8, 9].

The ability of the TRIGRS model to predict shallow ground motion due to rain was influenced by the resolution of temporal rainfall variations [10, 11], resolution of spatially geotechnical parameters [12] and resolution of digital elevation models. This software was developed for landslide prediction using the Matlab program and the programming language used was FORTRAN. Rain in the ground causes infiltration of water to the surface, which was distinguished into a partially saturated zone and a saturation zone. Part of the saturation zone was generally above the groundwater level with a partially filled pore with water. This zone was also called the aeration zone and water that spreads from the ground surface goes down through the main root zone. The thickness varies depending on the type of soil and vegetation. In this zone, the space between the particles was partly filled with water and partly filled with air [13]. The data needed to be the nature of the geotextile, slope (DEM), and rainfall. [14] examined the limitations of TRIGRS, development, examples of modelling the effect of variations in
rainfall on landslide susceptibility. Modelling the slope stability with TRIGRS based on rainfall infiltration with the intensity and duration of rainfall that occurred [15].

2. Research Methodology

The research location was in Tangkil Village, Pulung District, Ponorogo. This location on April 1, 2017, experienced a landslide. This landslide incident happened to the settlement, causing a large amount of material losses and fatalities.

Modelling of regional slope stability was carried out with the TRIGRS program. The primary data of the study were soil geotechnical data including soil type weight, cohesion value, deep friction angle, soil permeability, soil depth, and groundwater depth. Primary data were obtained by field investigations, field testing, and laboratory testing carried out by the Sabo Research and Development Laboratory. While secondary data in the form of topographic maps were obtained from BIG (Geospatial Information Agency).

Map results from modelling slope stability can be used to determine the location of the relocation of landslide victims. Landslide victims need to be relocated if it was not possible to be occupied again. A concept that was in accordance with the regional development plan as a settlement based on landslide disaster mitigation was needed. Landslide risk analysis was carried out to find out were as that had the threat of landslides, both from low to high scale. If there was a threat of landslides, it can be avoided for relocation sites, so that the area used for the relocation site must be safe from landslides.

3. Results and Discussion

Sites for the relocation of landslide victims need to be analyzed for land suitability for settlement development by referring to the threat of landslide hazards. Suitability analysis can be from aspects of the slope, elevation, land use, hydrology, soil, and the threat of landslides. Analysis of the suitability of the area for disaster evacuation was also carried out to determine to be used as an evacuation site for landslides. The mitigation concept used for settlement planning which developed into spatial plans, activities, evacuations, facilities, facilities and infrastructure, circulation, and vegetation plans. The spatial plan was supported by plans for facilities and infrastructure for evacuation activities such as early warning systems (EWS) for landslides.

One example of a failed relocation was the location of the victims of the Sijeruk landslide, Banjarnegara. The relocation position of the Sijeruk landslide victims in 2004, experienced a landslide again in 2008 (Figure 1). That means the location selection for relocation was not safe from the landslide. Land suitability analysis for relocation locations was not appropriate. From the results of the location plots on the landslide vulnerability level map, it turns out that the relocation point was in a zone prone to landslides.

![Figure 1. Relocation of Sijeruk-Banjarnegara landslide victims that had returned landslides, and plots of relocation points on landslide hazard level maps](image-url)
3.1. Tangkil Landslide, Banaran, Ponorogo

Landslides in Tangkil Hamlet, Banaran Village, Pulung Sub-District, Ponorogo District occurs on April 1, 2017, at 07.30 WIB. The incident claimed about 30 lives with the number of houses affected by 32 houses. Subsequent landslides occurred on April 9, 2017, at 11:30 WIB, the landslide occurred in Krajan Hamlet, Banaran Village, with the widening of the landslide affected were resulting in around 37 houses damaged [16]. The landslide in Tangkil Hamlet resulted in huge casualties and material losses. From the picture can be seen the condition of the slope and type of soil. The slope of the landslide location after the landslide was around 50° (Figure 2). Tangkil Hamlet landslide was included in the type C volcano morphology, Mount Ngliman. The area of the landslide had morphology in the form of hills and valleys that become rivers. The lithology is volcanic breccia that further weathering condition. Dark brown color with matrix grain size from clay domination clays, fragment size from 10-50cm, fragment condition had also experienced high weathering until the initial rock minerals were no longer visible. The weathered rock conditions make the soil thicker than more than 10 meters.

From figure 3, it can be seen that the victims were not only were as of that experienced landslides, but also the area buried by landslides. From the picture, it can be seen that the houses did not in experience landslides but were buried by landslides. In the landslide hazard map, the area was likely not prone to landslides but was buried by landslides. Thick soil makes it easily saturated with water, so if high rainfall will easily experience landslides. If it had high slope levels, it will easily to landslides.

Figure 2. Landslide conditions in Tangkil Village, Ponorogo
3.2. Modelling of Regional Slope Stability

Some input variables in TRIGRS were taken based on field observations. For example the value of the depth of the groundwater and the soil depth. The surface of the groundwater in Tangkil Village was at depth of -3.5m, while the depth of the soil layer was -5m based on the field of landslides on the landslide crown. For parameter values of shear angle and friction angle (c, \(\phi\)) taken from the lab test results. The value of volumetric water content was approached by SWCC (Soil Water Characteristic Curve) with fitting obtained by simulating soil samples at SEEP / W software. The variable geotechnical value of land for TRIGRS input can be seen in table 1. Rainfall intensity values were taken based on rainfall data at several rain stations around Pulung District 4 days before the landslide. The value of the diffusivity variable (D1) was obtained by doing calculations.

Table 1. Input variable in TRIGRS

| No | Variable                                      | Value unit     |
|----|-----------------------------------------------|----------------|
| 1  | Saturated permeability coefficient (Ks) m/s    | 3.867e-07      |
| 2  | Diffusivity Saturated (Do)                    | 6.805e-06      |
| 3  | Volumetric water content (\(\theta_s, \theta_r\)) | 0.58, 0.13     |
| 4  | Volume weight (\(\gamma_b\)) N / m           | 1.66e + 04     |
| 5  | Cohesion (c), friction angle (\(\phi\)) N / m | 0.200e + 03, 1.8\(^{\circ}\) |
| 6  | The slope of the curve (\(\alpha\))           | -2.017         |
| 7  | Rainfall (ri) m / s                           | 2.9e-7         |
| 8  | Permeable (Zmax) soil depth m                 | 5              |
| 9  | Groundwater level, m                          | 4              |

Source: Lab test results

The topographic aspect was an important thing for the selection of settlement locations. In addition, the condition of oxygen levels. The higher location, the available oxygen levels will be lower. Their height place affects the comfort level, especially for residential. The suitability of the development of settlements in Tangkil Village showed if this area dominated by marginal suitability for the development of settlements. This was because an altitude of 750 to 1000 msl dominating this as a. Elevation less than <750m was comfort for settlements [17].

Based on the limit equilibrium approach slope stability analysis, the slope will landslide if it had an FS value <1. According Ward et al. (1979), category of SF value was high if < 1.2, middle class if 1.2 - 1.7, and low if > 1.7 (Table 2). However, [18] mentioned that erroneous errors in determining FS in
spatial were as ranged from 20% to 30%, so the determination of landslide potential can be assessed from FS value.

The results of the stability modelling simulation with TRIGRS showed FS values in the study area had ranged from 0.83 to 10 (Figure 4). Using the classification in Table 2, the TRIGRS simulation results show that there were parts of the region experiencing high landslide potential. From Figure 4, the area that experienced landslides was mainly the upper part of the steep slope. The top of the slope usually part of the landslide crown which a source, and the movement from the top of the slope.

Some previous studies [11] explain that the results of modelling will be more accurate by using higher spatial resolution for rainfall and soil data in zones that had high geomorphological variation. Topography and DEM influence on TRIGRS prediction results. The use of smaller sized grids of 10 - 15m will provide better predictive results [19].

The greatly factor influences the threat level of landslides was topographic conditions, although there were still other factors causing landslides besides topography. The spaces used for evacuation spaces were open spaces in were as those were predicted to be safe from landslide hazards. The topographic component consists of land slope and altitude. The slope of the land was a major factor in the occurrence of landslides due to the influence of gravity, so that compared with other factors in calculating the likelihood of landslide threats; the slope of the slope produces the highest weight value.

**Table 2.** Classification model for potential and probability of landslide [18]

| Classification   | Potential for landslides | Landslide Probability P |
|------------------|--------------------------|-------------------------|
| High             | < 1.2                    | > 60%                   |
| Middle class     | 1.2 - 1.7                | 30 - 60%                |
| Low              | > 1.7                    | < 30%                   |

**Figure 4.** Slope stability map of Tangkil Village, Ponorogo

Community activities cannot be separated from economic activities. The economic support in the location of the Ponorogo landslide was very dependent on agriculture, especially horticulture plants. The relocation were a was certainly not far from their lading, because they make a living from the
farm. The level of marginal and inappropriate conformity was not permitted for settlement development or as a cultivation room in accordance with Minister of Public Works Regulation No.22 / PRT / M / 2007 because it had the threat of moderate and very high landslides. Development of settlements was only allowed in were as with a low threat of landslides.

The extent of the area that had the threat of medium and high scale landslides makes the suitability of the area for settlements to be limited. There were also existing settlements which were in the threat of high landslides. The threat of a disaster must be avoided or engineered if the settlement will be carried out. This disaster threat analysis greatly determines the level of land suitability for settlement development. Landslide threats were used as a limiting factor in the analysis process because of the influence that was very difficult to remove and greatly affects land suitability.

4. Conclusion
Many landslides area were not suitable to be used as residential so that residents need to be relocated. Before relocation, it was necessary to map the landslide vulnerability level for the selection of relocation sites, so that the new location was safe from landslides. So in the relocation site, the landslides will not occur again. Settlements that were still located in the high-risk landslide were as endanger the occupants. The relocation must be in a safe location from landslides. The relocation of Sijeruk landslide victim did not in a safe area. The location for relocation experience landslide again. Modelling slope stability using the TRIGRS program in principle was measuring the effect of rainfall on regional slope stability. The data needed in modelling was digital elevation model (DEM), soil data index properties, soil engineering properties, and rainfall. Field data collection activities, in the undisturbed soil sampling and geotechnical laboratory testing on soil samples, to obtain the values of physical properties and soil engineering. The modelling results show that the safety factor values in the study were ranged from 0.8 to 10. Safe numbers below 1.2 means are prone to landslides. The relocation was a must had a safe number above 1.2. so we suspect the relocation site was the safe area from the landslide.

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