HAZARD AND VULNERABILITY ASSESSMENT FOR LANDSLIDE RISK MAPPING:
A CASE OF WEST JAVA PROVINCE, INDONESIA

Ngadisih, Netra Prakash Bhandary, Ryuichi Yatabe
Graduate School of Science & Engineering, Ehime University

Keywords*: hazard, vulnerability, risk mapping, landslide, West Java Province*

1. INTRODUCTION

West Java Province is the most landslide-risky area in Indonesia, so it needs risk mapping study. Landslide risk analysis in an area however is not easy, mainly because of the difficulties involved in landslide hazard and vulnerability assessments. For instance, lack of multi-temporal inventory map or records of triggering event is a major problem in landslide hazard mapping. Estimation of the consequences of landslide events (known as vulnerability assessment) is itself a complicated process. So, the risk analysis normally stops at the susceptibility analysis stage. This study aims to propose a simple technique to assess hazard and vulnerability, which we have employed for landslide risk analysis in an ideally hazardous part of volcanic mountains in the West Java Province.

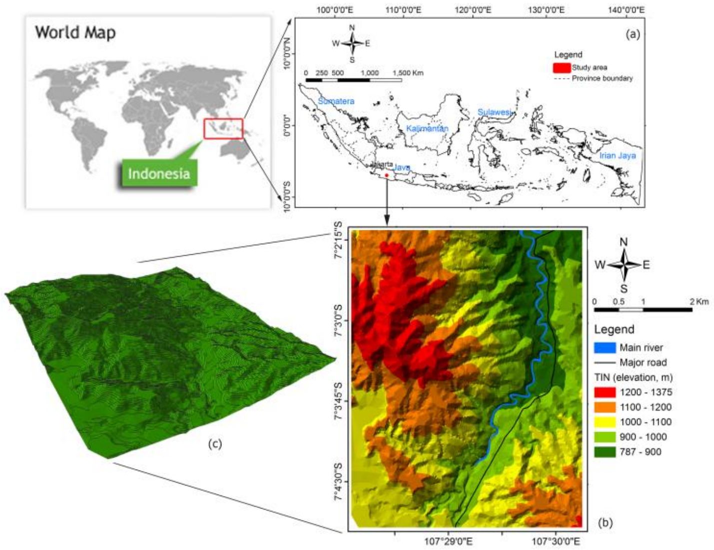

Fig 1 a) Location of the study area, b) Relief map of the study area; the elevation ranges from 787.8 m to 1,375 m; covering some parts of Pasir Jambu, Cililin, Soerang and Ciweday sub-districts, and a 3-D view of the study area

2. STUDY AREA

This study was carried out in the middle part of West Java Province, which covers a total of 20 km^2 between 7°05′00″ S to 7°02′30″ S latitudes and 107°27′50″ E to 107°30′00″ E longitudes (Fig 1). Geologically, the study area is composed of volcanic rocks erupted during Quaternary Period. Rocks such as andecite lava of sturdy pillar structure and sturdy sheet structure, rocks derived from pyroclastic flow and lahar, and intrusive rocks are commonly found in this area.

3. METHOD

This study adopts the concept of risk proposed by Varnes (1984). To achieve the primary objectives of this study, three databases were prepared: 1) landslide inventory, 2) database of landslide causing factors, and 3) database for risk calculation. The inventory map contains three groups of landslide population, i.e., 8 landslides of unknown incidents, which were obtained from aerial photo interpretation, 2) 18 landslides that occurred in 2010, and 3) 16 landslide incidents that happened from 2010 to 2012, which were identified in the field based on landslide archive.

The susceptibility analysis was carried out through correlation between past landslides and eight spatial parameters related to instability, i.e., slope, aspect, relative relief, distance to river, geological units, soil type, land use, and distance to road. The obtained susceptibility map was validated using cross-time technique (Chung and Fabri, 2008), and was collaborated with the frequency-area statistics (Malamud et al., 2004) to respond to temporal and size aspect of hazard. As for the judgment of the consequences of future landslides, expert opinion was used considering available literature and characteristic of the study area. We have only considered economic loss in terms of physical damage of buildings, roads, and agricultural lands for the landslide risk analysis. To calculate risk index in this study, three vulnerability elements were considered and summed, and then multiplied by the hazard value. It is expressed as follows.

$$\text{Risk Index} = H \times (Vb+Vr+Va) \quad (1)$$

Where, H is hazard, Vb is vulnerability of buildings, Vr is vulnerability of roads, Va is vulnerability of agricultural lands. The risk index was then classified into four categories according to the percentage of cumulative value. Number of pixels of the element at risk zone was calculated to identify the most damaged by landslide events.

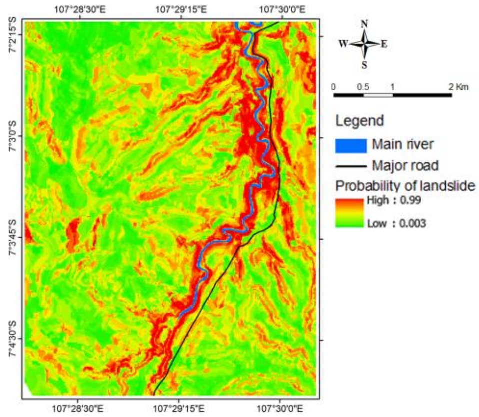

Fig 2 Landslide susceptibility map

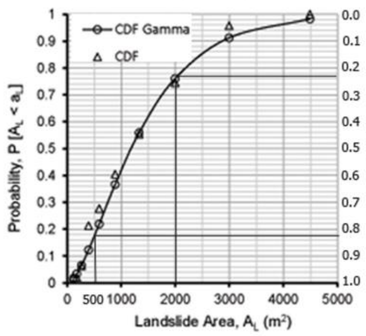

Fig 3 Cumulative distribution of landslide area

4. RESULTS AND DISCUSSION

Fig (2) shows that landslide probability is high along the main river. The river in the study area is dominated by V-shaped valley, which may be compared with the river evolution model proposed by Lévy et al. (2012) for Chacoura River valley for describing the pattern of susceptibility in the study area. In this work, we have used sixteen landslides that occurred from 2010 to 2012 for the validation of susceptibility model. The AUC of the model was found to be 0.831, which means the susceptibility model is capable of identifying landslide with 83.1% accuracy. In case of AUC of the validation, it was found to be 0.738, which is less than the AUC of the model. Here, the AUC of validation is lower by about 9% and it is acceptable as the validation dataset. The applied validation technique not only proves that the susceptibility model is acceptable, but also indicates the future landslide events. The landslides that occurred during 201–2012 represent ″landslides in the next 2 years″ and its predictive power is the landslides expected in the next 2 years (2012–2014).

Frequency-area statistics was derived from overall landslide population in inventory maps. In terms of hazard, this is addressed for calculating the probability of landslide will have an area smaller or greater than the given size. Firstly, create a probability density function (PDF), and then this was used for generating a cumulative density function (CDF) as seen in Fig (3). Based on the CDF, probability of landslide event in the area that exceeds the size of 500 m^2 and 2,000 m^2 were found to be 0.82 and 0.24 respectively. This study only considers the size of 500 m^2 for predicting the size of landslide events because a landslide of this size is capable of causing damage to infrastructures. The landslide hazard incorporates probability of location (spatial), time, and size, which may be generalized in terms of ″where″, ″when″, and ″how large″. The validated susceptibility maps has revealed where landslide will occur and when will be. By multiplying the validated susceptibility map and size probability (i.e., 0.82), hazard map of study area was produced. One of the benefits of the hazard assessment method adopted in this study is that it just needs two sets of landslide inventory maps.

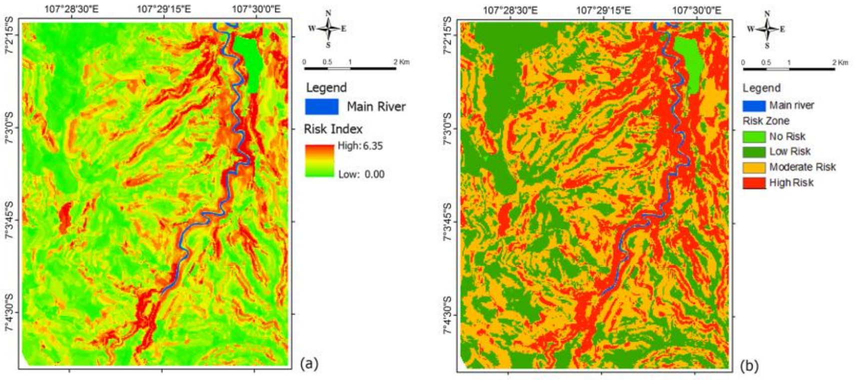

Fig 4 a) Risk index map, and b) Risk map produced using integrated approach

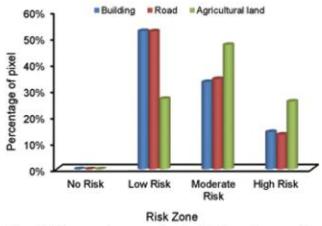

Fig 5 Percentage pixel of the element at risk in each risk zone

Table 1Relative value of losses

Position of Building to hillside	*Vulnerability*
Top	0.1
Flank	0.9
Bottom	0.5
Type of road	*Vulnerability*
Rural	0.1
District	0.5
County	0.9
Agricultural land	*Vulnerability*
Forest	0.1
Rice field	0.5
Farming	0.9

For risk analysis, in addition to hazard assessment, estimation of losses resulting from future landslides is also required. As a preliminary study, heuristic approach was used to quantify the degree of physical damage in the area. Relative values of losses ranging from 0.1 to 0.9 were given to each element at risk as shown in Table 1. Risk index was calculated by using Eq (1) with the help of raster calculator in ArcGIS environment. By using cumulative distribution method, the risk index (Fig 4a) was reclassified into four zones as shown in Fig 4(b). In this study, the mining areas and water bodies were not considered in risk calculation, so they are included in no risk zone.

Fig (5) shows that moderate and high risk zones are dominated by the pixels of agricultural land, whereas the low risk zone consists mostly of building and road pixels with only about 30% agricultural area pixels. This trend indicates that any future landslides will cause major loss in agricultural lands and less damage to roads and buildings. Agricultural activities in the study area have largely contributed to increase in hazardous area, which was noticed during the field investigation and analysis. The terraced system of agricultural activities has resulted in instability of terrains, while crops affect hydrological (soil moisture) and mechanical (root reinforcement) condition, which may adversely affect the stability of a slope. Plants like paddy, herbs, fruit crops, vegetable crops, houseplant, tea plant, etc. cannot reinforce the soil due to its feeble and small root system. Furthermore, these crops cannot reduce the negative effects of water by reducing soil moisture through transpiration because of poor canopy system. Mitigation efforts should be prioritized in the agricultural lands, which can be done either using structural or bio-engineering methods. Like agricultural activities, roads also contribute to instability of slopes. Roads and road structures may be damaged by slope movements and slope failures. Preventive or risk reduction measures for this include diversion of flow of stream and river channels away from roads to prevent undercutting of slopes in road cuts, improvement of surface drainage systems to reduce downward percolation of rainwater into slopes, retaining wall for interrupted slopes, and a review of the strategy for road networks Likewise, building construction activities on mountainous areas also lead to increased or new hazardous areas, which contribute to increased landslide risk for the buildings as well as surrounding. This study is expected to serve as a basis for developing a new building code or a new land use plan so as to reduce the risk to buildings in landslide prone areas.

5. CONCLUSIONS

The final output is a risk map, which identifies high, medium, and low risk zones of the future landslides (i.e., 2-year period) that may have an area greater than 500 m^2. In this risk map, farmlands have been identified to be the most risky elements, while road structures and buildings have been found to be less risky elements.

REFFERENCE

Chung, C.-J., Fabbri, A.G., 2008. Predicting landslides for risk analysis - Spatial models tested by a cross-validation technique. *Geomorphology* 94, 438–452.

Malamud B.D., Turcotte D.L., Guzetti F, Reichernbach P., 2004. Landslide inventories and their statistical properties. Earth Surf. Process. *Landforms* 29, 687–711.

Lévy, S., Jaboyedoff, M., Locat, J., Demers, D., Erosion and channel change as factors of landslides and valley formation in Champlain Sea Clays: The Chacoura River, Quebec, Canada. *Geomorphology* 145–146, 12–18.

Varnes D.J., 1984. Landslide Hazard Zonation: A Review of Principles and Practice. UNESCO Press, Paris.