

Weights of Evidence Method for Landslide Susceptibility Mapping in Takengon, Central Aceh, Indonesia

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Abstract. Takengon is an area prone to earthquake disaster and landslide. On July 2, 2013, Central Aceh earthquake induced large numbers of landslides in Takengon area, which resulted in casualties of 39 people. This location was chosen to assess the landslide susceptibility of Takengon, using a statistical method, referred to as the weight of evidence (WoE). This WoE model was applied to indicate the main factors influencing the landslide susceptible area and to derive landslide susceptibility map of Takengon. The 251 landslides randomly divided into two groups of modeling/training data (70%) and validation/test data sets (30%). Twelve thematic maps of evidence are slope degree, slope aspect, lithology, land cover, elevation, rainfall, lineament, peak ground acceleration, curvature, flow direction, distance to river and roads used as landslide causative factors. According to the AUC, the significant factor controlling the landslide is the slope, the slope aspect, peak ground acceleration, elevation, lithology, flow direction, lineament, and rainfall respectively. Analytical result verified by using test data of landslide shows AUC prediction rate is 0.819 and AUC success rate with all landslide data included is 0.879. This result showed the selective factors and WoE method as good models for assessing landslide susceptibility. The landslide susceptibility map of Takengon shows the probabilities, which represent relative degrees of susceptibility for landslide proneness in Takengon area.

1. Introduction

Landslides caused by the earthquake and its continuation caused by the rainfall are causing severe damages to both properties and lives, significantly in the populated area. This rainfall and earthquake-induced landslide occurred in Takengon, Central Aceh District of Aceh Province. Landslide susceptibility mapping produced in this area as a mitigation measurement. In this study, a bivariate statistical method called the Weights of Evidence (WoE) was applied to derive landslide susceptibility map to evaluate landslide-prone area in Takengon. Numerous research have applied the WoE Method in Landslide Susceptibility Mapping these recent years [1-7].

2. Study Area

Takengon is located in Sumatra Island, an active fault zone, the source of active earthquakes. Sumatra is also known as a region prone to landslides. The effects of ground movement of earthquakes in Sumatra are associated with numerous landslide disasters [8]. On Tuesday, July 2nd, 2013 at 2:37 PM, a catastrophic earthquake with a magnitude of 6.0 SR hit Central Aceh, estimated at least 43 deaths, 52.113 evacuees, and around 18.902 houses and building destroyed directly or indirectly by the catastrophe [9]. The study area occupied an area of $\pm 1.047 \text{ km}^2$ and is located in Central Aceh District



of Aceh Province. It lies between 4° 29' 53,09" to 4° 45' 51,76" S latitude and 96° 54' 21,69" to 96° 35' 18,23" W longitude.

The landslide sites were located along volcanic rocks, Enang-Enang and Lampahan unit, and Telong unit. Enang-Enang and Lampahan units were formed by extrusive igneous rock (pumiceous to massive andesitic flows and ashes) and reworked volcanic deposits (breccias, conglomerates, and sandstones) in the Pleistocene epoch. The Telong unit consists of extrusive igneous rock deposited by subaerial processes such as pyroclastic flows in the Holocene epoch [10]. The Enang-Enang, Lampahan, and Telong unit comprises a characteristic younger volcanic deposit, which consists of loose sediment and is vulnerable to sliding [11].

3. Materials and Weights of Evidence (WoE) Method

The following approved bivariate statistical method in this study is Weights of Evidence (WoE) model. The Theory of evidence (WoE) is a log-linear version on the theorem of Bayes used to calculate the probability based on the concept of prior (P) and posterior probability [6]. This approach is based on the information obtained from the interrelation between landslide causative factors and the landslide distribution [12]. The landslide causative factors are the input parameters for the WoE approach and to provide the information, which may control the occurrence of areas prone to landslides [7]. The WoE calculates the spatial relationship between the causative factors (VP) and the distribution of landslides (VM), in the form of positive (W^+) and negative weights (W^-) [7]. These positive and negative weights are calculated from the ratios of the natural logarithms [6, 13].

$$W^+ = \ln \frac{P\{VP/VM\}}{P\{\overline{VP}/\overline{VM}\}} \quad (1)$$

$$W^- = \ln \frac{P\{\overline{VP}/VM\}}{P\{\overline{VP}/\overline{VM}\}} \quad (2)$$

The contrast of the weight (C) is added to define how significant the overall spatial association between the landslide causative factors and the landslide distribution [1]. The contrast value is calculated as the difference of positive and negative weights [4].

$$C = W^+ - W^- \quad (3)$$

The WoE model processing steps can be summarized [2]: (I) compilation of a landslide inventory randomly subdivided into a training set (70%) and test set (30%) [5, 14, 15]; (II) derivation of each causative factor and calculation of its weights by using the training set of the landslides; (III) multiclass generalisation of the continuous evidence based on the cumulative weighting; (IV) calculation of the posterior probability map (i.e., combination of the causative factors to predict potential landslide occurrences).

The next step is a model verified by comparing the susceptibility maps to both the training sets that were used for building the models and the test set that were not used during the model building process. The rate curves can be created for both techniques. The area under curve (AUC) of the success rate represents the quality of landslide models to reliably classify the occurrence of existing landslides, whereas the AUC of the prediction rate explains the capacity of the proposed landslide model for predicting landslide susceptibility [1, 4, 5, 7, 16, 17]. The results from the weighting were used for the interpretation of classes of causative factors on landslide proneness. All of this process was supported and derived through digital processing and the interpretation of remote sensing data on the Geographic Information Systems (GIS) based environment.

A total of 251 landslides in Takengon area were recorded into the landslide inventory map, and out of which 176 points (70%) as a training set selected for building landslide susceptibility model, and the other 75 points (30%) as a test set used for validating the model.

In this study, 12 thematic maps of evidence were used and defined as landslide causative factors. These causative factors are slope degree, slope aspect, lithology, land cover, elevation, rainfall, lineament, peak ground acceleration (PGA), curvature, flow direction, distance to river, and distance to roads. These maps were converted to raster maps with a grid size of 7,5 x 7,5 m with a spatial resolution of 7,5 x 7,5 m.

4. Results and Discussions

The twelve landslide causative factors were calculated using WoE model and then validated by comparing each to the landslide validation set. The validity of each factor was tested by calculating the prediction rate curve (Fig. 1). The areas under the curve (AUC) were estimated from the rate curves. The AUC values of each factor showed the highest prediction accuracy respectively (Table 1).

Eight factors with the highest prediction accuracy: slope degree, slope aspect, PGA, elevation, lithology, flow direction, lineament, and rainfall were used to generate the landslide susceptibility map. The WoE method applied to the training data set produced a landslide susceptibility zone map (LSZ) (Fig. 2). The calculated success rate for WoE model is 87.9% and the prediction rate of 81.9% accuracy. The curve provides a basis to distinguish different susceptibility levels which were classified into five susceptibility zones. There are five levels of relative landslide occurrence defined on a landslide susceptibility map: (1) very low; (2) low; (3) moderate; (4) high and (5) very high susceptible to landslide.

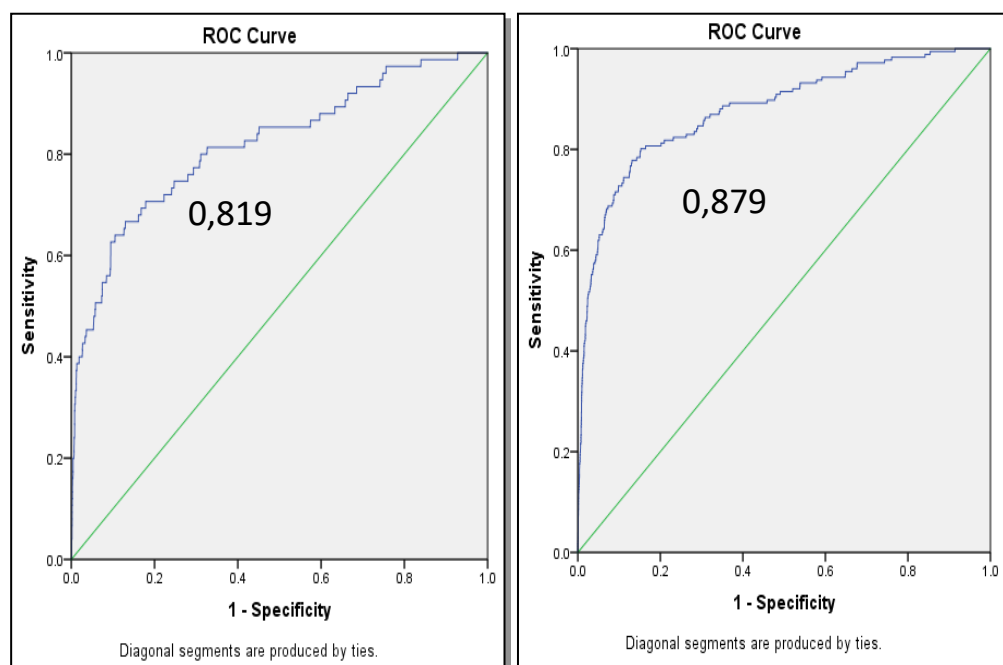
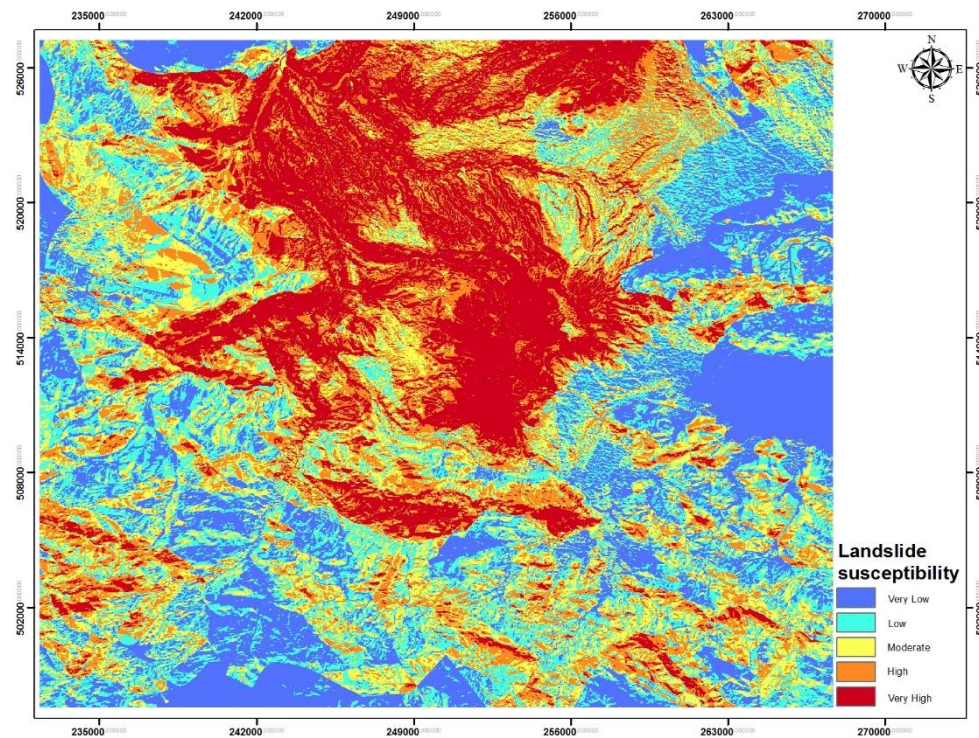


Figure 1. The success rate and prediction rate AUC graph.

Table 1. AUC for the twelve models after WoE modelling.

Factors	AUC
slope degree	0.792
slope aspect	0.745
PGA	0.693
elevation	0.685
lithology	0.669
flow direction	0.659
lineament	0.652
rainfall	0.649
distance to river	0.612
land cover	0.606
distance to roads	0.538
curvature	0.526

**Figure 2.** Landslide susceptibility zone map.

5. Conclusions

The dominant factors that influence the occurrence of landslides in the study area are the slope, followed by the slope aspect, peak ground acceleration, elevation, lithology, flow direction, lineament, and rainfall respectively. According to the validation results, the final landslide susceptibility zone map produced by WoE model exhibits a satisfactory result between the susceptibility map and landslides location data. Likewise, with the prediction value rate shows that the model was very good in predicting new events. The selection of landslide causative factors and landslides data is good and acceptable because of its AUC value (validity) exceeds the recommended limit. The WoE model is a data-driven statistical method, which is important to provide multiple landslides causative factors by taking into account the inventory of large numbers of landslides as an indispensable input. This model can be used

as an initial study for landslide risk and hazard assessment. Both are pivotal points for local/regional land use decision-making and planning.

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