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Earthquake induced landslide susceptibility mapping using an integrated ensemble frequency ratio and logistic regression models in West Sumatera Province, Indonesia

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ABSTRACT

An 8 Richter Scale (RS) earthquake struck West Sumatra on Wednesday, 30 September 2009, at 17.16 pm which led to huge number of landslides. Hence a comprehensive landslide susceptibility mapping (LSM) should be produced in order to reduce the damages to people and infrastructures. In the international landslide literature, various statistical methods such as frequency ratio (FR) and logistic regression (LR) have been widely used individually for LSM, but they have some weaknesses. FR which is able to perform bivariate statistical analysis (BSA) assesses the influence of classes of each conditioning factor on landslide occurrence. However, the correlation between the factors is mostly neglected. On the other hand, LR is able to analyze the relationship among the factors while it is not capable to evaluate the classes of each landslide conditioning factor. This paper aims to propose an ensemble method of FR and LR in order to overcome their weak points. For LSM, a landslide inventory map with a total of 87 landslide locations was extracted from various sources. Then the landslide inventory was randomly divided into two datasets 70% for training the models and the remaining 30% was used for validation purpose. The landslide conditioning factors consist of: altitude, curvature, river, SPI, rainfall, soil type, soil texture, land use/cover (LULC), peak ground acceleration (PGA), geology, slope, aspect, lineament and topographic wetness index (TWI). Four PGA of 7.5, 8, 8.6 and 9 were acquired and PGA 8 which was related to the 2009 earthquake was used to generate the model. Finally, the produced landslide susceptibility maps were validated using an area under the (ROC) curve method. For the model which was derived by PGA 8, the validation results showed 84% and 78% success and prediction rates respectively. Furthermore, the prediction rates for the models made by PGA 7.2, 8.6 and 9 are 79%, 78% and 81% respectively. The result proved the reasonable efficiency of the proposed method for earthquake induced landslide susceptibility mapping. Also the proposed ensemble method can be used in other hazard studies as it is capable to produce rapid and accurate assessment for disaster management and decision making.

1. Introduction

Landslide is one of the dangerous natural hazards and its frequency of occurrence is increasing worldwide (Jebur et al., 2013a; Pradhan and Lee, 2010b; Yin et al., 2010). Landslides can cause damages to transportation, people and properties (Mohammady et al., 2012). The Indonesian archipelago sits on the junction of the world's three great plates namely the Indo-Australian plate, the Eurasia plate, and the Pacific plate. The junction is situated in the subduction zone which resulted in the formation of a volcanic island arc with moderate to steep slopes (Karig, 1974). Volcanic eruption of the material has high porosity, less compact and scattered in an area with a steep slope. If this condition disturbs the hydrological balance, the area will be prone to landslides (Van Asch et al., 1999). The territory of Indonesia in general and the Province of West Sumatra in particular are mostly hills and mountains which are susceptible to landslides. Frequent and high intensity precipitation, and earthquakes are naturally triggering factors in landslide occurrence. Based on the review of the locations of landslides in Padang, the locations of landslides were estimated to be in the line of the fault. The hills are composed of tuft and pumice rides above andesitic rocks with 20 m thickness which made this area very prone to landslides (Leo et al., 1980).

An 8 Richter Scale (RS) earthquake struck West Sumatra and its surrounding areas on Wednesday, 30 September 2009, at 17.16 pm. The epicenter of this earthquake was located at latitude 0° 84′ South,

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and longitude 99° 65′ East, 57 miles South-West of the city of Pariaman, with a depth of 71 km (Indonesia Meteorologi and Geophysics Body (BMKG), 2009). The earthquake destroyed many districts/towns in this area and caused large number of deaths (Satkorlak Disaster of West Sumatra, 2009). In addition to the Semangko fault and the meeting point between the two tectonic plates, the land of West Sumatra is also composed of intermingling highlands; starting from the Province of Aceh in the north to the Province of Lampung in the south (Islam and Khan, 1986). Some of the volcanic mountains on this highland are still active. The main rock types in this highland are also truncated by fissures, and cracks. They are destroyed by earthquakes and this led to the occurrence of many landslides in the region (Wilkinson et al., 2012). For this reason, it is important to detect the susceptible areas in order to predict future landslides. Landslide susceptible areas can be assessed and predicted through scientific analysis and thus landslide damages can be decreased through the proper prevention actions (Ozdemir and Altural, 2012; Pradhan, 2013). Over the last decades, numerous efforts have been devoted by many researchers to develop landslide susceptibility maps worldwide using GIS (Lee and Pradhan, 2007; Pourghasemi et al., 2013; Pradhan and Lee, 2010a; Pradhan, 2013; Bui et al., 2013; Pradhan et al., 2010c, 2011).

The impact of earthquake on landslide occurrence has been reported by many studies (Bai et al., 2012; Sidle and Ochiai, 2006; Zhou et al., 2013). Yin et al. (2009) analyzed the distribution of landslides triggered by the earthquake in Wenchuan County, Sichuan Province, China on 12 May 2008. About 20,000 fatalities have been reported due to the impact of 15,000 landslides which was made by the Wenchuan earthquake. In a recent paper, Oh et al. (2010) evaluated the impact of earthquakes which is often aggravated by the triggering of landslides. They could discover that the areas affected by landslides are similar to other parts of the world and the size of the earthquakes has a direct effect on the size of landslides. Probabilistic approaches are based on the observed relationships between each conditioning factor and the distribution of landslides. Remote sensing (RS) and geographic information system (GIS) are efficient techniques for LSM and they are capable to identify the suitable and non-suitable areas for development activities (Gupta et al., 2008; Jebur et al., 2013b; Saha et al., 2005; Sarkar and Kanungo, 2004; Van Westen et al., 2003, 2008). Many methods and techniques have been proposed to evaluate landslide prone area using these two techniques (Konadu and Fosu, 2009; Lee and Pradhan, 2007; Pradhan, 2010; Pradhan and Lee, 2010a,b).

The most popular methods for landslide hazard mapping are deterministic approach (or safety factor) (Westen and Terlien, 1996), heuristic approach (Barredo et al., 2000; Van Westen, 2000), statistical approach (Luzi et al., 2000), support vector machine (SVM) (Pourghasemi et al., 2013; Wan and Lei, 2009), neuro-fuzzy based study (Akgun et al., 2012; Oh and Pradhan, 2011), fuzzy logic (Pradhan, 2011), and artificial neural network (ANN) (Chi et al., 2002). Although these methods are capable to recognize the susceptible areas and produce the landslide susceptibility map, they have some disadvantages that reduce the efficiency of the predictive models when applied individually (Tien bu et al., 2012c,d). Some comparative studies have been done in order to compare these methods and analyze their performance such as Pradhan (2010) and Pradhan and Lee (2010a). In a recent paper, Pradhan (2013) used decision tree (DT), SVM and adaptive neuro-fuzzy inference system (ANFIS) for LSM of Penang Hill, Malaysia in order to compare their efficiency. Defining the rules for DT and selecting the SVM parameters are hard task and it is very time consuming. Although ANFIS performs better than the others, it entails a large number of parameters. All three methods require a very high speed computer which can handle heavy analysis (Chau et al., 2005).

The ANN model is one the most popular methods in many fields and especially in landslide analysis (Wan et al., 2010b). However, the ANN model is considered as a black box which has complex process and its performance is not easy to understand (Pradhan and Buchroithner, 2010). Also this method cannot produce accurate predictions in the case that the validation dataset contains values outside the range of those used for training. Also in the case that the large number of variables is used, it makes the entire modeling process time consuming (Ghalkhani et al., 2012). On the other hand, in the qualitative

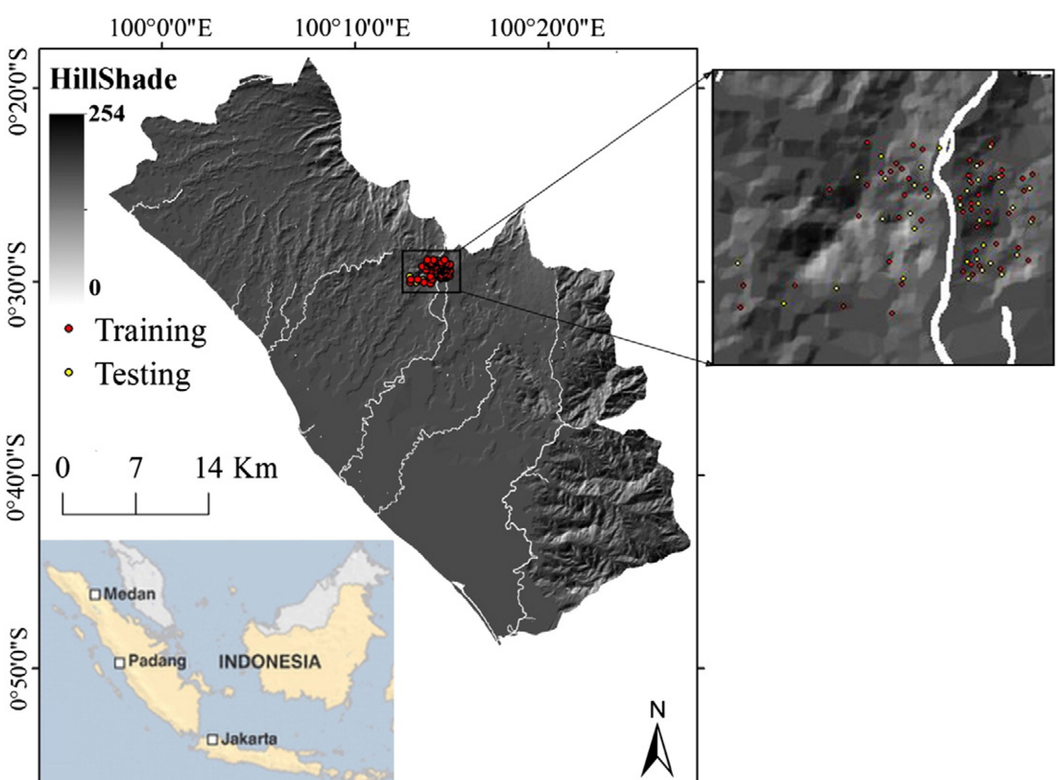

Fig. 1. Study area map.