VULNERABILITY ASSESSMENT AT MT. BROMO INDONESIA BY USING TIME-SERIES LAND SURFACE DEFORMATION AND GIS

Arliandy P. Arbad[1,2], W. Takeuchi[2], Y. Aoki[3], Achmad Ardy[4]

[1]Dept. of Geomatics Engineering,Sumatera Institute of Technology, Lampung, 35365, Indonesia

[2]Institute of Industrial Science, The University of Tokyo, Tokyo 153-8505, Japan

[3]Earthquake Research Institute, The University of Tokyo, Tokyo 113-0032, Japan

[4]dept. of grotechnology, Lampung University, Lampung, 35141, Indonesia

e-mail :arliandyarbad@gmail.com[1,2]

ABSTRACT

Among the 127 active volcanoes located in eastern Java, Indonesia. Mt. Bromo is the most famous active volcano, type of Mt. Bromo is a strombolian. Many aspects that make volcano an interesting, we conduct a critical and comprehensive study and analysis concerning of volcano eruption based on remote sensing and GIS approaches. Nowadays, remote sensing play an important role to observe volcanic activity and facilitate real-time information. The method used in this study is the determination level of risk in the Mt. Bromo by Pairwise Comparison method. Vulnerability parameters to be obtained from the potential of land deformation, population density, and distance from the volcano dome. In addition, we used SAR data to observe time-series land surface deformation which derived from PALSAR sensor and the images which L-band frequency characteristic on board from Advanced Land Observing Satellite (ALOS) with active microwave sensor to achieve cloud-free and day-and-night land observation. The dataset is composed of 24 SAR images, collected from 24 May 2007 to 5 July 2016 (Descending passes, HH polarization). Consequently, the information result has been created and processed at a municipal or city level including thematic maps, the database has been built, classified and analyzed by using GIS environment. The main idea is providing hazard mitigation map at Mt. Bromo to provide adequate guidance for disaster-prone areas to determine the level of disaster risk.

Keywords : Active Volcano; Deformation; Eruption; GIS; Vulnerability Assessment

INTRODUCTION

A large number of volcanoes are situated in the (so-called) ring of fire area. Analysis from geographic and topographic data suggests that Indonesia is the most volcanically active in the world, with numerous eruptions each year and millions of people living on the flanks of the volcanoes (Loughlin et al., 2015). About 13 % of the world's active volcanoes are located in Indonesia. Tectonically, the active volcanoes are the result of a collision between Indian-Australian, Eurasian, and Philippine Plates (Zaennudin, 2010). Volcanic eruptions produce disaster materials such as the lava, pyroclastic fall, pyroclastic flows, pyroclastic surges, lateral blast, debris avalanche, volcanic tsunamis, mud, flooding and harmful gases (Tilling, 1989).

Scheme of Bromo volcano disaster event is a social catastrophe to the people who are living around the affected area. Due to the potential devastating of volcanic influence to urban settlements, we should prepared method and system based on understanding of volcanoes

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today. The basic theory of volcano disaster assessment, related to size, style, frequency of eruptions and proximity of volcanoes, can impact on the local society with mortalities and poisoning caused by gases. On the other hand, people (choose to) live close to volcanoes because these areas usually contain some of the most mineral rich soils, which provide perfect conditions for farming. Lava and material from pyroclastic flows are weathered to form nutrient rich soils which can be cultivated to produce healthy crops and prosperous harvests. The objective of this study is to estimate disaster prone-areas based on time-series land deformation monitoring and volcanic materials, and number of population at Mt. Bromo.

METHODS

SAR Data

For analyzing the eruption events in 2010 we used SAR data derived from PALSAR sensor and Images which L-band frequency characteristic onboard from Advanced Land Observing Satellite (ALOS) with active microwave sensor to achieve cloud-free and day-and-night land observation. The dataset is composed of 22 SAR images, collected from 24 May 2007 to 4 Noovember 2011 (Descending passes, HH polarization, Track 91, Frame 3780).

Time-Series Analysis

For monitoring land deformation, we applied time-series analysis based on Small Baseline interferometric (SBI) modules which TimeFun algorithm by Hetland et al.,(2011). The TimeFun method is an implementation of the temporal inversion scheme established formerly for multiscale interferometric time- series techniques directly in the data domain. This method allows to explain each pixel's phase evolution using a dictionary of user defined functions (Agram et al., 2013). The key point of the SBI analysis is to mitigate the impact of decorrelation by properly selecting the interferometric pairs with short temporal (Bt) and geometry (perpendicular) baselines. The maximum allowed baseline value is defined and used to constrain the interferogram pair by selecting manual after differential InSAR processing in single face working The observation equation for each pixel is:

$$\Phi_{ij} = \sum_{k} \alpha_k \left(f^k(t_i) - f^k(t_j) \right) + eB_{perp}^{ij}$$

$f^k(t)$: k-th function

α_k: Coefficient associated with the k-th function.

In this study, the small baseline interferomtric (SBI) method developed in the StaMPS/MTI toolbox and three SBI approaches implemented in the GIAnT toolbox

Vulnerability Assessment

Regarding the Ministerial Regulation No. 11 year 2016 of Ministry of Energy and Mineral Resources Indonesia (Kementerian ESDM) about the determination of Disaster-Prone Areas of Geological Hazard paragraph 1 point (2) and (6). Volcano hazard mitigation is an event how to reduce the risk of volcano hazard through the physical infrastructure nor establishing the awareness and ability for facing the volcano risk. Disaster-prone area of volcano hazard is the area which has inundated or identified as a potential hazard of a volcanic eruption with a direct nor indirect circumstances.

In this paper we used vulnerability assessment to create disaster prone-

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areas. Vulnerability analysis of the elements at risk so as to assess their resistance to the impacts of the different anticipated physical effects. Vulnerability assessment in volcanic risk evalution (e.g. Aceves, Q., et al., 2007; and Dibben, C., et al., 1999) and the hazard event may influence the process of developing vulnerability for human assessment. From this, it is possible to assess the damage and determine the weak points in the regional system (Thierry, P., et al., 2008). The method of formulating the vulnerability assessment is Simple Additive Weight Method with the following equation:

$$V = a(A) + b(B) + c(C) + d(D) + \ldots$$

where,
V = Vulnerability Scale
a, b, c, d = Value each Criterion
A, B, C, D = Criterion Assessment

The criterions are used number of population, time-series land surface, distance from the summit of volcano, lava flow. Population density was selected as the main indicator for social vulnerability. Disaster management tools are available to help minimize the risk and thereby the impact of a hazardousProvide steps for problem solving clearly and concisely. It is recommended to explain with a flowchart, with no more than 15% words of the entire article.

RESULTS AND DISCUSSION

Combining the three risk elements (land surface deformation, volcanic materials, distance, and number of population) through a Geographic Information System (GIS) enabled us to produce several risk zoning maps related to the geological phenomena around Mount Bromo and corresponding to the major disaster.

Population Density

Mt. Bromo is located at East Java Province which number total of population reach 38.85 million people. Our study focus on four cities (Kabupaten/Kota) surrounding Mt. Bromo, there are Pasuruan, Lumajang, Probolinggo and Malang. According to Indonesia national statistical agency, the number of population dramatically increase since 2010 to 2015 in cities which affected of Mt. Bromo activities as shown in figure 1 below.

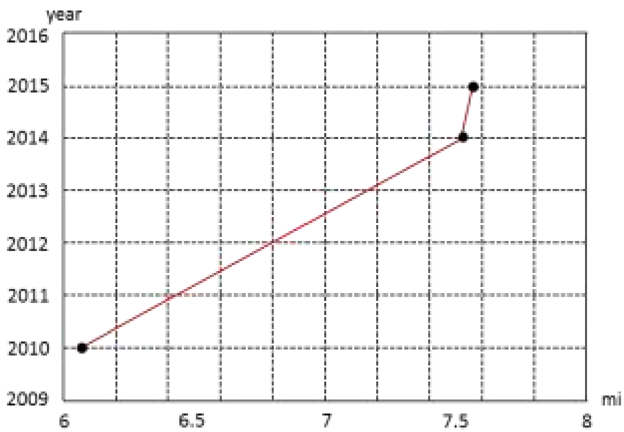

Figure 1. Number of Population in cities affected of Mt. Bromo hazard from 2010 to 2015 based on national census. (data source taken from Indonesia National Statistical Agency, 2016). (mi) mean Million.

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Hazard Zoning

We divided into three hazard zoning areas, high intensity, medium intensity and low intensity. We defined the intensity as the physical impact on the exposed elements and environments. The potential intensity should be expressed on a scale that is consistent between all the phenomena. We divided into three categories of hazard intensity, where:

a. The high hazard intensity will be named Disaster-Prone areas III,
b. The medium hazard intensity will be named Disaster-Prone areas II, and
c. The lower hazard intensity will be named Disaster-Prone areas I.

The first step is to establish a matrix pairwise of each criterion of the element of vulnerability (matrix pairwise comparison) to determine the level of interest among group criteria elements by providing an assessment based on assessment index that had been developed by Saaty (1990) as shown in Table 1. This method involves pairwise comparisons to create a matrix ratio in decision making (Malczewski, 1999).

Table 1. Matrix Pairwise of vulnerability elements

Matrix pairwise	Population	Land Deformation	Distance From Lava	Criterion Weight
Population	1.0	0.333	0.25	0.124
Land Deformation	3.0	1.0	0.667	0.358
Disatance From Lava	4.0	1.5	1.0	0.517

The greater value of criterion weight, that mean more important to consider as hazard. The formula of the level of vulnerability of each component were calculated using a simple additive weight formula as shown table 2 below.

Table 2. Simple additive weight calculation

Disasterprone areas	I	II	III
Population	Low	Medium	High
Land Deformation	Small	Medium	Large
Disatance From Lava	30Km	20Km	10Km

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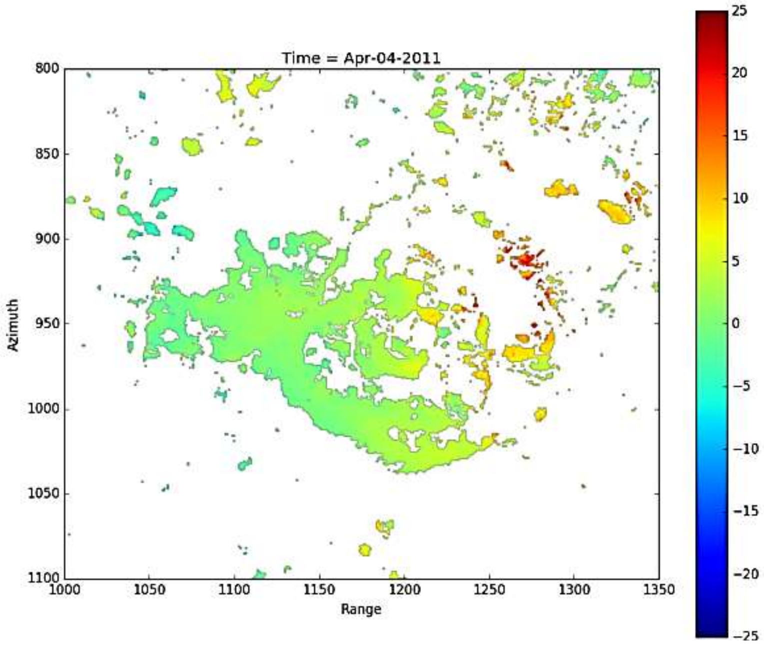

Figure 2. Time-series displacement results of Mt. Bromo for period 2007-2011 with the color range unit of centimeters based on TimeFun algorithm.

At the Mt. Bromo most of pixels were processed with 110 interferoframs, with a fully selected temporal and spatial network, the particularly coherent pixels that caused of sandy area at Mt. Bromo. We overlayed the result of time series map with another elements in simple additive method. We calculated the criterion weight -5 to 5 is lower intensity, -10 to 10 is medium more than 10 is high intensity.

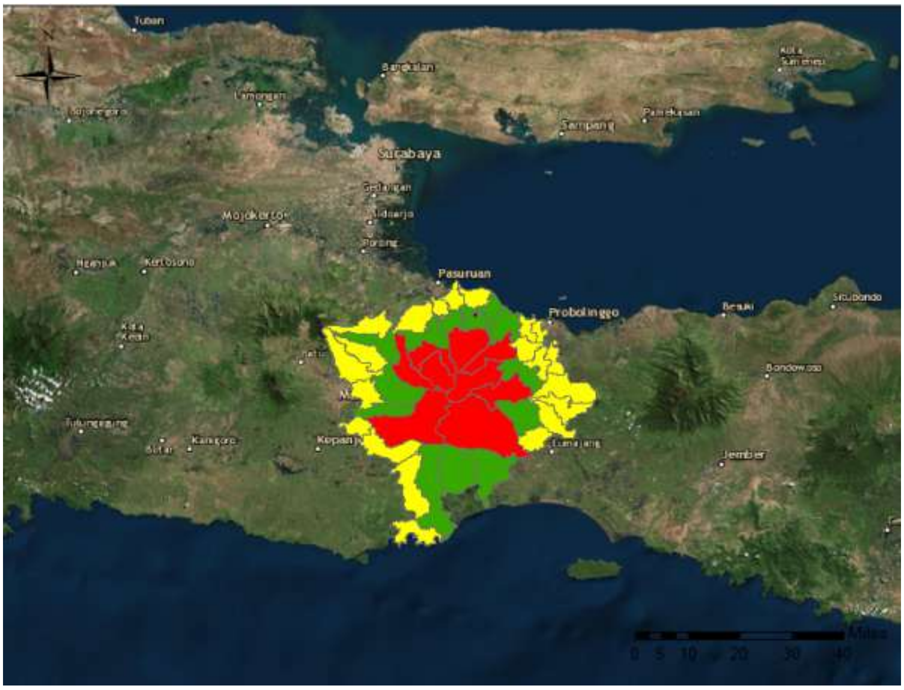

Figure 3. Disaster-prone areas caused of Mt. activities in East Java province. The Red color as representative of high intensity, the green color as representative of medium intensity and the yellow color as representative of lower intensity.

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Prone areas were obtained adding the weights of the three variables and classifying them in the following way municipalities with a very high vulnerability. A reconstruction of the lava and other volcanic hazard materials at Bromo volcano's eruptive history has been carried out by comparing the reference of Mt. Bromo eruption history and Lahar-Z application, some report based on detailed fieldwork, using information derived from interview and visiting post observation of Mt. Bromo in Ngadisari village, Sukapura District, Probolinggo.

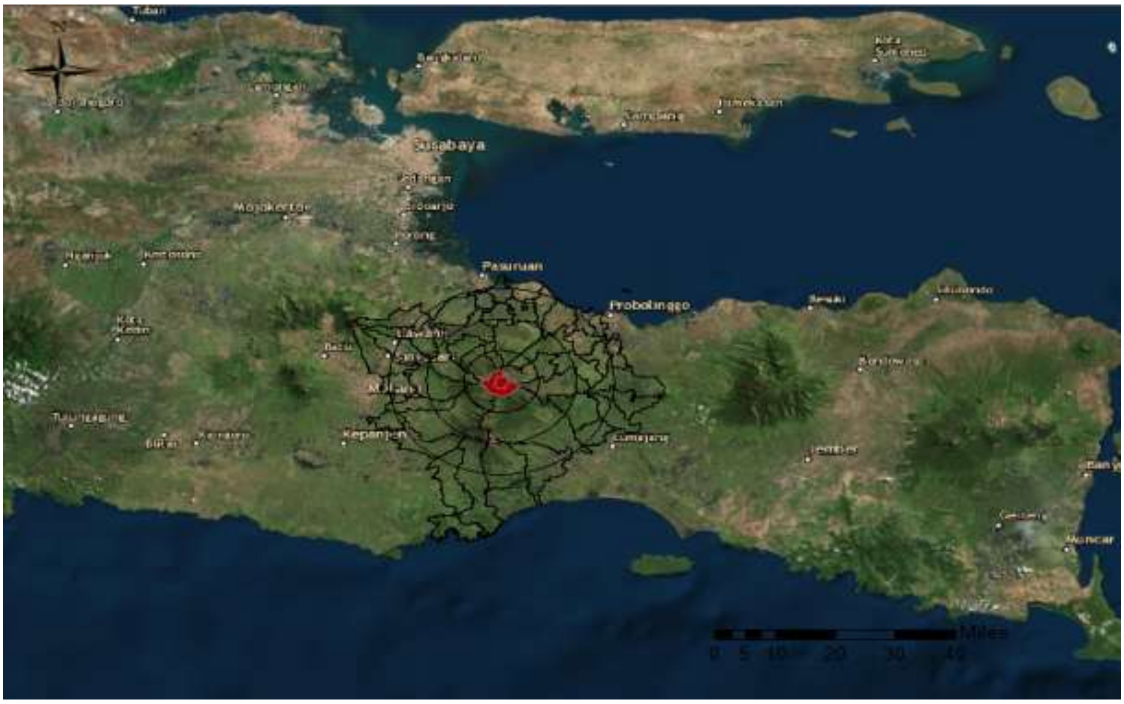

Figure 4. The estimation area which affected by lava flow based on interpretation of Mt. Bromo in the past eruption and simulation by using Lahar-Z application.

Existing methods either use data with limited suitability and availability (census data). By this study, We deals with the assessment of social vulnerability involves the time series land surface changes which can be evoke the landside. Risk assessment to support management requires knowledge about present and future hazards, elements at risk and different types of vulnerability. Moreover, we can add another secondary datasets such as precipitation, and also housing assessment index.

CONCLUSION

By this study, we found three sub-cities with larger percentage of risk area based on the analytical hierarchy process model are Sukapura, Sumber and Tosari. The most important principle of application of the GIS tools in that they constitute a distinctive information integration and management system that allows interpretation of spatial and attribute information in a far more effective, rapid and integrated way. Additionally, it makes good use of the enormous capacity of spatial technology in a single work environment for making the decision in various information layers, extraction of relevant data and ongoing information updating.

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