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Generating landslide inventory by participatory mapping: an example in Purwosari Area, Yogyakarta, Java

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ABSTRACT

This paper proposes an approach for landslide inventory mapping considering actual conditions in Indonesia. No satisfactory landslide database exists. What exists is inadequate, focusing, on data response, rather than on pre-disaster preparedness and planning. The humid tropical climate also leads a rapid vegetation growth so past landslides signatures are covered by vegetation or dismantled by erosion process. Generating landslide inventory using standard techniques still seems difficult. A catalog of disasters from local government (village level) was used as a basis of participatory landslide inventory mapping. Eyewitnesses or landslide disaster victims were asked to participate in the reconstruction of past landslides. Field investigation focusing on active participation from communities with the use of an innovative technology was used to verify the landslide events recorded in the disaster catalog. Statistical analysis was also used to obtain the necessary relationships between geometric measurements, including the height of the slope and length of run out, area and volume of displaced materials, the probability distributions of landslide area and volume, and mobilization rate. The result shows that run out distance is proportional to the height of the slope. The frequency distribution calculated by using non-cumulative distribution empirically exhibits a power law (fractal statistic) even though rollover can also be found in the dataset. This cannot be the result of the censoring effect or incompleteness of the data because the landslide inventory dataset can be classified as having complete data or nearly complete data. The so-called participatory landslide inventory mapping method is expected to solve the difficulties of landslide inventory mapping and can be applied to support pre-disaster planning and preparedness action to reduce the landslide disaster risk in Indonesia. It may also supplement the usually incomplete data in a typical landslide inventory.

1. Introduction

One example of the recent progress of Indonesia's disaster management after the enactment of Undang–Undang (Law) 24/2007 is the availability of the online Indonesian Disaster Data and Information Database (DIBI) which can be accessed online at: http://dibi.bnpb.go.id. DIBI was launched on 29 July 2008 and is housed within the newly established National Disaster Management Agency (BNPB). It is expected that, by utilizing DIBI, all relevant stakeholders can successfully implement disaster management planning at every stage of the disaster management cycle and support disaster reporting and monitoring at national and sub-national levels.

The landslide database provided by DIBI includes date of occurrence, location, and impact. The impact information is more detailed than others, including the number of deaths, missing, injured, affected, evacuated and elements at risk damaged/destroyed. Even though DIBI is developed to enhance disaster management planning at every stage of the management cycle, it still contains inadequate especially for landslide disaster risk reduction. Landslide database in DIBI is still focusing on disaster response rather than preparing database for pre-disaster planning and preparedness. A disaster report recorded in DIBI is also limited to a disaster with one or more people reported killed, 100 people reported affected, a call for international assistance or declaration of a state of emergency. Upgrading the landslide database in DIBI is needed to support pre-disaster planning and preparedness, including disaster risk reduction, mitigation, risk assessment and contingency planning.

The upgrading of landslide database should include the information about exact location (coordinates), type of landslide, landslide volume, state of activity, date of occurrence and other characteristic of landslides as well as information on triggering factors for all landslides. A collection of this information is called a landslide inventory (Guzzetti et al., 2000; Fell et al., 2008). Landslide inventory is a pre-requisite for landslide susceptibility, hazard, and risk zoning. The spatial relationship between landslide area and the environmental causative factors are key elements in the investigation of landslide susceptibility, which then can be used to investigate landslide hazard by incorporating recurrence or frequency of landslides. Landslide inventory can also be utilized to investigate

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the statistics of landslides and the evolution of the landscape. The statistics of landslides include their slope, area, shape, location, volume, length of run-out, etc. (Malamud et al., 2004). There are several methods to prepare a landslide inventory such as geomorphological field mapping, visual interpretation of aerial photographs, interpretation of satellite imagery, and analysis of surface morphology (Guzzetti et al., 2012). However, these methods are sometimes not possible for application in Indonesia.

Landslide is an important geomorphological feature and must be included in geomorphological maps. Geomorphological field mapping is a basic method of landslide inventory and the most applicable in Indonesia. Old landslides are often partially or totally covered by vegetation, or have been dismantled by erosion process and human actions including agricultural and construction practices. The humid tropical climate leads to rapid vegetation growth so landslide signatures will quickly disappear. Landslide signatures are difficult to be detected by remote sensing techniques. However, geomorphological field mapping is sometimes costly and time consuming to find landslide locations, especially for old landslides without initial data, such as previous reports, internal database or tentative landslide map obtained from the interpretation of ancillary data. Identifying the boundary of landslides through field investigation is also difficult where landslides are covered by vegetation or changed by erosion and human activities (Guzzetti et al., 2012).

Aerial photograph interpretation is the most widely-used method to investigate landslides. The investigation is usually based on visual interpretation of sets of photographs, viewed with a stereoscope. Simultaneous consideration and synthesis of multiple different criteria such as shape, pattern of objects, color/tone, shadow, texture and association/site of landslides are used to recognize landslides in the aerial photograph. The interpretation may vary among individual interpreters because of the lack of standard criteria. Generating a temporal landslide inventory in Indonesia by aerial photograph interpretation seems also difficult due to unavailability of multi-temporal aerial photographs especially in hilly and mountainous areas. The aerial photograph is often only available in a single year and is not regularly updated.

Satellite imagery can, in many cases, be used instead of temporal aerial photographs. Very high resolution (VHR) panchromatic imagery may be an alternative to conventional aerial photographs (Weirich and Blesius, 2007). Combining higher resolution panchromatic image with the lower resolution multispectral image to obtain a single high resolution color image is also possible in order to improve the visual interpretation capacity of satellite imagery. However, tropical clouds can obscure some areas. It is possible to remove clouds by digital techniques with another scene of satellite imagery, but unfortunately this process can also remove landslide features. Another problem is that if satellite imagery is not recorded just after a landslide occurrence, the old landslides eventually become partially or totally covered by vegetation. Mixed landuse can also affect misinterpretation of landslides feature when using satellite imagery.

Analysis of surface morphology is the most recent trend in landslide inventory mapping due to the availability of very high resolution of DEMs (Digital Elevation Models) derived from airborne laser profiler or Light Detection and Ranging (LiDAR). After a landslide occurs, the surface topography changes and leaves a distinct signature (Pike, 1988). Digital representations of the topographic surface were employed to characterize and differentiate landslide morphology and to investigate the location and distribution of landslide activity (Schulz, 2004, 2007; Chen et al., 2006; Booth et al., 2009; Kasai et al., 2009; Derron and Jaboyedoff, 2010; Razak et al., 2011). Landslide detection can be achieved by visual interpretation of remote sensing images (Haugerud et al., 2003; Chigira et al., 2004; Schulz, 2004; Chen et al., 2006) or automatic/semi-automatic recognition using several approaches (Sato et al., 2007; Booth et al., 2009; Kasai et al., 2009). Also, some authors integrated DEM with satellite imagery to obtain a 3D view of the terrain, which can be visually interpreted to identify landslides (e.g. Nichol et al., 2006). However, analysis of surface morphology by using very high resolution DEMs is still very expensive and not common in Indonesia.

In this paper, the authors adopt several methods of landslide inventory and propose landslide inventory method, called participatory landslide inventory mapping, with the goal of providing a nearly complete landslide inventory data over a 33 year period (1978 to 2011) in the Purwosari Area, Java, Indonesia. The nearly complete landslide database is also used to generate of landslide statistics such as the relationships between geometrical measurements, including the height of the slope and length of run out, area and volume of displaced materials, the probability distributions of landslide area and volume, and mobilization rate.

2. Regional setting

The Purwosari area is located in the southern part of Central Java and covers an area of 13.7 km^2 (Fig. 1). It is dominated by a hilly area with a large open valley striking mostly NW–SE. The lithology consists of Tertiary Oligocene–Miocene Old Andesite Formation of van Bemmelen breccia originating from the Gadjah Volcano. The volcano's magma is composed of basaltic pyroxene andesites. It consists of andesitic breccia, tuff, lapilli tuff, agglomerate and intercalated andesite lava flows (Rahardjo et al., 1995). The thickness is approximately 660 m. There is also calcareous sandstone, limestone and coralline limestone in the small western part of the Purwosari area. Old Andesite Formation is a dominant lithology in Purwosari Area. It can be differentiated in the field by the degree of weathering. Most of landslides can be found in the Old Andesite Formation which is affected by the very intense weathering process.

The denudational landforms in Purwosari were influenced by strong gravitational movement after the geanticline of Java in the south was uplifted. The area is dominated by steep topography with a strongly dissected and V-shaped valley caused by past and ongoing valley deepening. Rill and gully erosion are dominant features identified in this area. The average annual rainfall in Purwosari Area is 2478 mm and the highest rainfall intensity usually occurs in February or March. The average monthly rainfall in February and March is 402 mm and 426 mm, respectively. The high intensity of precipitation induces very intense erosional processes and landslides. A settlement built by excavating the slope without adequate engineering applications may lead to a reduction in the stability of natural slopes and can cause landslides. Settlement in the hilly area is located mostly alongside the road network.

3. Participatory landslide inventory mapping

A landslide inventory map is the simplest landslide map and shows the location and the type of landslide occurrences. It can be used as information to construct hazard maps (Galli et al., 2008). The landslide inventory map can also indicate landslide occurrences for several years by combining with historical landslide data. Conventional approaches to obtain landslide inventory maps are usually conducted by someone who interprets remote sensing data without adequate knowledge of local resource conditions. Limited field experience can result in inaccurate delineation and misinterpretation of landslide boundaries. The objective of participatory landslide inventory mapping is to enable villagers/local people to carry out the interpretation of aspects of their experience with local landslides. In this process local people are the most likely to have knowledge of the exact boundary of past landslide events. The information will later be digitized and geo-referenced. Involving local people as eyewitnesses is expected to improve the accuracy and precision of data measurement.

3.1. Data sources

An official landslide database provided by DIBI is adopted from DesInventar (http://www.desinventar.org/) which is designed to collect