Slope Stability Zonation Map of the Citanduy River Catchment Area, West Java, Indonesia

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Abstract

In Indonesia, West Java Province is well known for the most frequent landslide occurrence from time to time. Physically destructed land by geological hazard such as landslide could widely affect people and infrastructures. In the eastern part of West Java landslide frequently occurs on the Citanduy River catchment area. This phenomenon is approached through slope stability analysis.

Quantitative analysis of slope stability (SF) and plotting of previous landslides occurrences on Geological map are carried out to produce slope stability map. Conditions of geomorphology, hydrogeology, soil types and distribution and also current landuse are considered as supported data.

Result of analyses shows that there are 3 zones of slope stability on the study area. SF more than 1.25 is stable zone. SF 1.25 to 1.1 is critical to stable zone. SF 1.1 to 1.0 is critical zone. SF less than 1.0 means unstable slope where landslide occurs. Stable zone is characterized by plain area on thin soil, coarse grain soil. Critical to stable zone is of hilly to mountainous land, fine grain thick soil of sedimentary or volcanic rocks. Critical zone is of swelling-shrinking type of thick soil on high-angle slope, high density of geological structures, high run-off caused by drainage on the top of slope (ponds, paddy fields, etc).

Keywords: Landslide, Slope Stability, Citanduy River, Safety Factor

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Introduction

In Indonesia, West Java Province is well known for the most frequent landslide occurrence region from time to time, especially during the rainy season (Hirnawan, 1998). In the study area, earthquake also frequently occurs, which is potential to become the trigger for geological hazard such as landslide (Syarief *et al.*, 2001; Tobing *et al.*, 2002). Physically destructed land by geological hazard could widely affect people's life and infrastructures.

The Citanduy River catchment area lies on the eastern part of West Java. This river flows from mountainous area in the central part to the Indian Ocean in the south. On the surface, this catchment area is mainly covered by forest region, which has undergone intensive deforestation in many places due to urban development (Sugalang *et al*., 1995).

Landslide is one type of geoclimatic hazard, which occurs on a unique geological condition (Dearman, 1992). As a part of rock and/or soil mass movement, landslide occurrences in forested area are controlled by many factors such as conditions of geology, geomorphology, climate, hydrology, etc (CDMG, 1999). The aim of this paper is to elucidate the interaction of those factors producing landslide susceptibility area. This phenomenon is approached through slope stability analysis in the study area.

Geological Setting

Tectonics & Stratigraphy

The study area lies in the continental margin of Eurasian Plate and relatively close to the subduction zone, where Eurasian and Indo-Australian Plates subduct each other below the Indian Ocean. There are several major geological structures across the study area. Their azimuths in general are in-line with the azimuth of subduction zone, suggesting recent driving-force working on them.

In the Citanduy River catchment area, stratigraphical arrangement consists of lithologic units from Tertiary (Oligocene) to Quaternary and Recent deposits. The Tertiary units compose of limestone, sandstone, claystone, marl, mudstone, conglomerate and breccia. The Quaternary units compose of andesitic lava and intrusion, volcanic breccia, pyroclastic rocks, alluvium, terrace (beach & river) deposits. In general, lithologic units in the study area can be classified into sedimentary rocks (deep marine to terrigeneous environment) and igneous rocks with volcanic products (Budhitrisna, 1992; Djuri, 1995).

Geomorphology & Hydrogeology

The Citanduy River catchment area geomorphologically consists of mountainous to hilly land on the upstream and gentle hill to lowland on the downstream. On the upstream part, it is common to find high geomorphologic relief with steep slope indicating intensive vertical erosion

in “youth” stage, composing harder lithologic units. On the downstream, low relief is common with gentle slope to plain area indicating lateral erosion in “mature” stage, composing softer lithologic units. Phyisiographically the study area lies on Bogor Zone (Bemmelen, 1949)

According to Sutrisno (1983), groundwater resource in the study area varies hydrogeologically based on the aquifer productivity (very high to low). The Citanduy as main river is a perennial type with fluctuative volume between dry and rainy seasons. Its tributaries distribute over large area covering 6 regencies and 2 municipalities. The Citanduy River catchment area is composed of 6 sub-river catchment area (Table.1).

Engineering Geology

In this research, the engineering properties of material (rocks and soil) are approached through analysis of engineering formation according to Anon (1976) and Dearman (1992). The Engineering Formation map is produced by combining 4 aspects, namely ; surface morphology (steep-gentle-plain), mass movement (active, less active, passive), deformation (strong-medium-weak), erosion (high-middle-low).

Methodology

To obtain the engineering properties of material for this research, rock and soil sampling were carried out in the field. Disturbed (DS) and Undisturbed (US) soil sampling were obtained around the area where

landslides previously occur. It is followed by soil testing in the laboratory according to ASTM methods to get physical and mechanical properties of soil. Data of physical and mechanical properties of soil from several terrains were used to calculate (quantitatively) the stability factor (SF) of each slope. Basically, the SF is a value representing the resultant ratio of resisting force with driving force acting in the body of slope.

Engineering formation map was produced from geological map by putting the material characteristics (physical and engineering properties) onto the map and considering the conditions of geomorphology, tectonics (minor and major geological weaknesses), hydrogeology and current landuse. Results of quantitative analysis of slope stability were mapped (SF mapping) and locations of previous landslides occurrences were plotted on the engineering formation map to produce slope stability map of the study area.

Units on the engineering formation map, which have high similarities in terms of material properties and slope stability factor (SF), were then grouped into 3 zonations based on the SF values of the slope to produce slope stability zonation map of the Citanduy River catchment area.

Geo-spatial analysis for this research is carried out through Geographical Information System (GIS) analysis using software MapInfo ver.7.

Result and Discussion

Burbank and Anderson (2002) explained that landslides result from interactions between rock strength (c), angle of internal friction (ϕ), slope gradients (β) and geometry, relief, pore pressure and seismic accelerations. This complex interaction produces SF values of hillslope, which dynamically degraded from stable to critical and finally unstable when landslide occurs. This phenomenon in an area is manifested into susceptibility zones, which can be classified into several ranks to produce slope stability zonation map.

From the slope stability zonation map, result of analyses shows that there are 3 zones of slope stability on the study area. Zone with the value of SF more than 1.25 is stable zone. SF 1.25 to 1.1 is critical to stable zone. SF 1.1 to 1.0 is critical zone. SF less than 1.0 means unstable slope where landslide occurs.

Explanation of each zone is as follows (Figure. 3):

- Stable Zone is characterized by lowland to plain area, slope < 5% and partly 15 %, consist of volcanic material (breccia, conglomerate, etc), alluvium and terrace deposits. On the surface, it is composed of thin, coarse grain, mainly transported soil. Mature stage of weathering. It is mainly urban development area, which covers about 30.2% of the study area.
- Critical to stable zone is characterized by gentle slope of hilly to

mountainous land (10 – 30%), fine grain thick soil of sedimentary or volcanic rocks origin (tuff, breccia, sandstone and mudstone). It is medium stage of weathering with medium annual rainfall and run off. It consist of agriculture and urban development area, covering about 62,6% of the study area.

- Critical zone is characterized by swelling-shrinking type of thick soil on high-angle slope (30 - 50 % & partly > 50 %), fine grain residual soil with monmorilonitic contents about 14-43 % (Hirnawan, 1998). It has high density of geological structures and high run-off caused by drainage on the top of slope (ponds, paddy fields, etc). It consists of agriculture and rural area, covering about 17.2% of the study area.

Due to the intensive and frequent landslide in the study area, special attention was paid to the occurrence of expansive soils and active structures in the critical zone. The expansive soil is characterized by high mud content (finer grain fraction) and certain clay mineral composition. Decomposed fine-medium marine sedimentary rocks will produce montmorilonite and illite minerals, which can significantly swell when water content is high (in the rainy season) and shrink when dry (swelling and shrinking clay minerals). While decomposed Quaternary volcanic material will produce halloysite and metahalloysite minerals, which are also belong to expansive soil type.

The occurrence of several major structures in the study area (fault, folds and joints) mainly characterize the critical zone. The high density of (active) fault in this zone suggests that the area is undergoing active deformation. It is understandable since the study area lies in active Eurasian continental margin and relatively close to the subduction zone in the Indian Ocean.

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* In Indonesian with English abstract