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Landslide susceptibility mapping using sinmap method in a small hilly area: case study in Cibanteng Village, West Java

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Abstract. This paper presents the results of landslide susceptibility mapping in small hilly areas, Cibanteng village, Cianjur district, West Java. In this study, the physically-based model SINMAP (Stability Index Mapping) was applied in the GIS platform. The SINMAP model simulation requires data of physical properties of soil, such as cohesion value, internal friction angle, and soil hydrology to calculate the value of factor of safety (FS). The values of cohesion and fraction angel for the 10 sample points were obtained from the laboratory test results, while the value of soil hydrology, i.e hydraulic conductivity, transmissivity, effective rainfall and index wetness, referred to the literature source. The DEM (digital elevation model) was generated from the 1:25,000 digital topographic map, which produced the soil slopes and specific upstream contributing areas. The result of SINMAP model simulation shown that the regions with a high landslide susceptibility (FS <1, unstable) were spread unevenly with an area of 261ha (17,6% of the study area). The Landslide susceptibility map from the SINMAP model provided a satisfactory result with an accuracy of 62,5% against to the landslide events occurred during the period 2010-2017.

1. Introduction

From 2000 to 2017, more than 85 percent of natural disaster events in Indonesia were categorized as a hydro-meteorological disaster, such as of floods, landslides, droughts [1]. The National Disaster Management Agency (BNPB) reports that there were 2175 disasters in Indonesia in 2017, where landslides were 577 events. The events in 2017 caused 335 fatalities, 969 people were injured, and 3,22 million people displaced and suffered [1].

Mapping the landslides susceptibility in an area is important because its function as a tool for land use planning, infrastructure, and in the disaster-prone areas is the basis for disaster mitigation and preparedness plans. Landslide susceptibility is the probability of a landslide occurring in an area by local environmental conditions [2]. It is the degree to which a terrain can be affected by slope movements, i.e., an estimate of “where” landslides are likely to occur. In the last 30 years, many mapping techniques have been applied and

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used to present slope stability. Stability Index Mapping (SINMAP) is one method of landslide susceptibility mapping using the principles of soil/land stability [3].

The advantage of SINMAP model implemented in a geographic information system (GIS) environment is that it is possible to analyze quickly over large areas even with limited data [3,4]. SINMAP has been successfully applied by many researchers in mapping landslide hazards in many regions of the world, and the majority reported satisfying modeling results. [see 5,6,7,8,9,10]. SINMAP model needs some parameters related to the physical properties of soil and hydrology data such as soil cohesion (C), internal friction angle (ϕ), and a ratio of transmission to effective recharge (T/R) or degree of wetness (w). The value of these parameters can be determined from the soil type map (based on the literature) or direct through soil sampling and laboratory tests [6,7]. In order to get a rapid landslide susceptibility assessment in a large area, many researchers and practitioners used the available soil type map and literature sources [6,10].

This paper presents the outcome of a landslide susceptibility mapping using the SINMAP model in a GIS platform in small hilly areas based on the results of soil sampling and laboratory test. The study area was conducted in Cibanteng Village, Cianjur Regency, West Java. This area was chosen because the region is prone to landslide hazards [11,12,13].

2. Methods

2.1 Study Area

Cibanteng village located in the northern part of Cianjur district, West Java. The total area is 1332 hectar. The study area is a hilly areas with altitude between 350 and 950 m a.s.l. Regions with a slopes 15-25% dominate with a proportion of 60% of the total area (see Fig. 1). In 2017, most areas (about 84%) were agriculture cultivation areas, which were dominated by rice field, mixed garden and non-irrigated field. While the remaining areas (213 ha or 16%) are still covered by forests [13].

The lithology of Cibanteng hilly area is dominated by sedimentary rock [14]. Sandstone cover hilly areas with altitude above 600 m a.s.l. Furthermore, clystone spreads out on areas with altitude between 400-600m. Soil type of brown reddish latosol association and brown latosol cover mostly the study area. Rainfall in the study area is characterized by a monsoon type, where the rainy season takes place in December – March and dry season in June – September. The annual rainfall ranges between 2000 – 2800 mm.

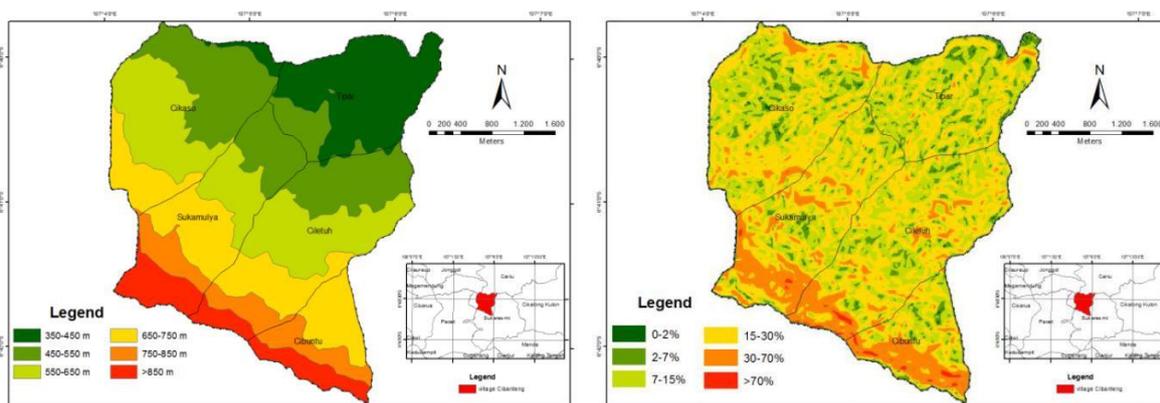


Figure 1. Elevation and slope maps of Cibanteng village, Cianjur, West Java

2.2 Methods and Data

SINMAP is the mapping method of landslide susceptibility which use the slope stability principle. The slope stability of an area is calculated by the equation (1)

$$SI = FS = \frac{c + \cos\theta \left[1 - \min\left(\frac{Ra}{T \sin\theta}, 1\right) r \right] \tan\phi}{\sin\theta} \quad (1)$$

$$w = \text{Min}\left(\frac{Ra}{T \sin\theta}, 1\right) \quad (2)$$

where SI is stability index or FS is the factor of safety, θ is the slope angle; C is the dimensionless cohesion value integrating both soil and root cohesion, as well as soil density and thickness w is the relative wetness as the relation of water-table height to soil thickness; r is the ratio of the density of water to the density of soil, ϕ is the internal friction angle, and equation (2) is an estimate of the relative wetness, which is the effective water recharge I for a is the internal friction angle [4]. Relative wetness (w) is modeled as induced by topographic conditions and depends on the specific catchment (a) area of a given point.

The equation reflects a dimensionless quantity derived from infinite-slope modeling. The model works against the slope and wetness of each grid (DEM pixel), assuming that other parameters are constant or have a constant distribution probability over a large area. In operating SINMAP in GIS Platform, some data related to the DEM topography of the study area (specific catchment area and slope angle), the physical property of soil (soil cohesion, friction angle), and hydrology (ratio of transmissivity to effective recharge or degree of wetness) are needed (Table 1).

Table 1. Type of data used and the method of acquisition

Type	Comment	Resolution	Source
1 DEM	Processed from 1:25,000 digital topographic map	12.5 x 12.5 m	Geospatial Information Agency, Republic of Indonesia
2 Land use map		1 : 25,000	Geospatial Information Agency, Republic of Indonesia
3 Soil map		1 : 250,000	Indonesian Soil Research Institute, Ministry of Agriculture.
4 Physical property of the soil parameters	Soil test in laboratory		Undisturbed soil samples were taken from 10 points in five hamlets in Cibanten village.
5 Rainfall data	Data for the periode 2000-2016	nearest rainfall station	Meteorology, Climatology and Geophysical Agency
6 Landslide inventory		Polygons	[11,12 & 13] & the Regional Disaster Management Agency

Based on the equation 1, the factor of safety (FS) can be calculated and slope stability classes can be defined [4]. Furthermore, the landslide susceptibly classification in this mapping was simplified into 4 classes, very low (no potential), low, moderate and high classes (see Table 2)

3. Result and Discussion

3.1 Physical Properties of Soil in The Study Area

Soil sampling in this study was taken from 10 points in 5 hamlets (2 sample points for each hamlet). Determination of sample points is determined by a stratified random method based on factors of soil type, altitude, slope, and land use. Undisturbed soil samples were tested in the civil engineering laboratories,

Universities of Indonesia. Laboratory test results from 10 soil samples include cohesion and friction angle parameters, are shown in Table 3.

Table 2. Slope stability classes and classification in landslide susceptibility mapping

<i>Factor of safety</i>	Slope Stability class	Classification in Landslide susceptibility mapping
FS > 1,5	Stable	No potential (very low)
1,5 > FS > 1,25	Moderately stable zone	Low
1,25 > FS > 1,0	Quasi stable slope zone	Moderate/medium
1,0 > FS > 0,5	Lower threshold slope zone	High
0,5 > FS > 0,0	Upper threshold slope zone	

Table 3. Characteristic of sampling location and physical properties of soil in the study area

No.	Sampling location (hamlet)	High (m.asl)	Slope (%)	Soil type	Land use	Physical properties	
						Cohesion	Fraction Angle
1	Cikaso	600	7-15	Latosol	Bush	0,11	8,4
2	Ciletuh	800	7-15	Latosol	Settlement	0,25	19,3
3	Sukamulya	775	30-70	Latosol	Bush	0,36	23,1
4	Cibuntu	700	15-30	Latosol	non-irrigated field	0,11	14,0
5	Tipar	375	7-15	Podszolik	Settlement	0,27	10,5
6	Tipar	460	7-15	Latosol	Bush	0,16	26,0
7	Cibuntu	785	15-30	Latosol	Bush	0,09	13,4
8	Ciletuh	650	15-30	Latosol	Bush	0,15	13,6
9	Cikaso	550	7-15	Latosol	Bush	0,11	26,1
10	Sukamulya	875	30-70	Gray Regosol	non-irrigated field	0,20	26,1

The soil structure in the study area is mostly silty clay. Based on the literature [15], the characteristics of soil hydrology can be classified as follows, the value of hydraulic conductivity (k) ranges from 0,02 – 0,04 m/h, the solum depth of 1,5 – 3,5 m, transmissivity (T) value of 0,03 – 1,05 m²/h, soil infiltration rate of 0,2 mm/h, and effective rainfall of 1,5 m/h. Finally, the wetness index value or the ratio of transmissivity to effective recharge ranges from 0,02 – 0,07 m²/h.

3.2 landslide Susceptibility

Figure 2 shows a landslide susceptibility map for Cibanteng village, Cianjur regency, West Java. The degrees of landslide susceptibility are grouped in four classes as established in Table 2. The region with a high landslide susceptibility can be found mainly in the southern region and partly in the western part of the study area with a total area of 261 ha (17,6%) (see Table 4). This region is physically located in an area with altitudes above 600 m above sea level and slopes above 30%. Land use in this area, mostly is in the form of shrubs and mixed gardens, with annual crops, such as fruit trees (mangosteen (*Garcinia mangostana*), durian (*Durio Zibethinus*) and other annual crops. But at the foot of a steep slope, people cultivate land with seasonal plants, such as cassava, corn, vegetables, and land close to water sources, they grow rice. So that this area becomes vulnerable to landslide hazard.

The region with a moderate landslides susceptibility with an area of 585 ha (39,4%) spread throughout the area with altitudes of less than 600 m a.s.l. and slopes of 15-30%. Most types of land use in this area are

rice fields and non-irrigated fields ('Tegalan' in Bahasa). Furthermore, regions with a low and very low landslide susceptibility dominate the study area with an area of 639 ha (44,1%). This region can be found in areas with an altitude of 350 - 800 m a.s.l. and slope of less than 15%. Most of the land in this area is used for rice fields and non-irrigated fields.

During the period of 2010-2017 eight landslides occurred in Cibanteng village. Types of landslides could be categorized as shallow landslides and rotational types. Landslides did not cause casualties, but it caused economic losses for the Cibanteng village community, directly or indirectly. The overlay result between the landslide susceptibility map generated from the SINMAP model simulation and landslide location map is shown in table 4. The highest number of landslide events occurred in the region with high susceptibility class and followed in the region with a moderate susceptibility class.

Table 4. Calculation results of the area of susceptibility from the SINMAP model simulation and landslide events during the period 2010-2017 in Cibanteng Village

No	Landslide susceptibility	Area in ha	Area in %	Number of events	%
1	High	261	17,6	5	62,5
2	Moderate / medium	584	39,4	3	37,5
3	Low	433	29,2	0	0
4	No potential	206	13,9	0	0

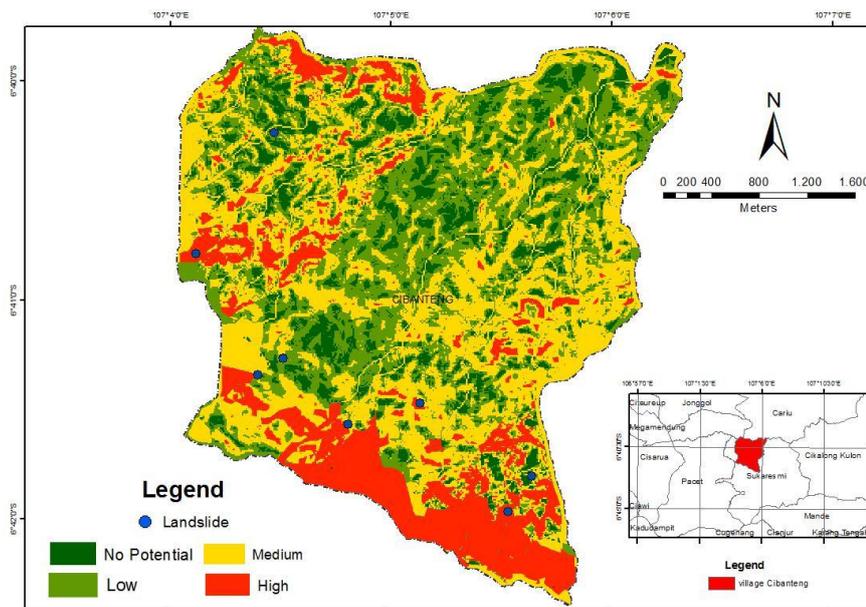


Figure 2. Landslide susceptibility map for the Cibanteng village, Cianjur, West Java.

In this study, we also tested the accuracy of landslide susceptibility maps generated from the SINMAP model simulation with landslide vulnerability maps from other models, namely the SMCE model (spatial multi-criteria evaluation). Landslide susceptibility maps generated from the SMCE modeling [12] developed from landslide trigger factors, namely factor of the slope, land use, lithology, and rainfall. Table 5 shows that the landslide susceptibility map generated from the SINMAP model simulation for small hilly areas is relatively more accurate with an accuracy of 62,5% than the SMCE model.

Table 5. Accuracy test of landslide susceptibility maps generated from the SINMAP and SMCE model against landslide events occurred during the periods 2010-2017.

No	Susceptibility SINMAP model	Landslide events		Susceptibility SMCE model	Landslide events	
		Number	%		Number	%
1	High	5	62,5	High	3	37,5
2	Moderate / medium	3	37,5	Moderate / medium	5	62,5
3	Low	0	0	Low	0	0
4	No potential	0	0			

4. Conclusion

A landslide vulnerability map for small hilly areas, Cibanteng village, can be compiled using the SINMAP model in the GIS platform. The model simulation results delivered region with a high landslide susceptibility (factor of safety (FS) <1 or unstable) with an area of 261 ha (17.6%) of the total area). The results of the accuracy test for landslide events during the period 2010-2017 showed very satisfactory results. Even when we compare to other models, such as the SMCE model. The landslides that ever happened before were mostly (62,5%) located in the region with a high landslide susceptibility.

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