Analysis of landslide vulnerability in Sibolangit area using Geographic Information System (GIS)

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Abstract. Natural disasters are a natural phenomenon that can occur at any time causing material and immaterial losses. Sibolangit is one of the subdistricts in the Deli Serdang Regency with relief of sloping hills between 60\textdegree{} – 90\textdegree{} with high rainfall so that the Sibolangit subdistrict has the potential for landslides. Geographic Information System can connect spatial and non-spatial data so that maps and information analysis can be made in a digital form. This study aimed to determine the level of landslide vulnerability in Sibolangit subdistrict, where the data used include types of rocks, types of soil, slope, rainfall, and land use. The analysis used in the study was the Geographic Information System with Puslittanak Modelling 2004. The study results obtained four criteria for landslide vulnerability in Sibolangit subdistrict, namely low landslide-prone areas which were 7 villages (32.65 km\textsuperscript{2} or 18.84%), moderate landslide-prone areas which were 13 villages (77.93 km\textsuperscript{2} or 44.96%), high landslide-prone areas which were 8 villages (46.43 km\textsuperscript{2} or 28.96%), and very high landslide-prone areas which were 2 villages (16.31 km\textsuperscript{2} or 10.17%).

1. Introduction

Landslides are categorized as one of the causes of natural disasters, in addition to earthquakes, floods, hurricanes, and others. The danger of landslides has a major impact on the survival of human life and always threatens human safety. In Indonesia, the occurrence of landslides has resulted in huge losses such as loss of human lives, damage to homes, roads, public facilities and disruption of natural ecosystems. Landslides are caused by two factors, namely natural and human factors. Landslides are one of the natural disasters which often hit hilly areas in the wet tropics. This mass movement does not only cause direct damage, such as damage to public facilities, agricultural land, or the existence of human casualties but also indirect damage that disturbs development and economic activities in the disaster area and surrounding areas. The natural disasters of the mass movement tend to increase along with the increase in human activities [1]. Based on the data of the National Disaster Management Agency from 2009 to mid-2019, there were 5,242 recorded landslide disasters in Indonesia, and 61 occurred in North Sumatra. Of the 61 landslide incidents, 17 people died and disappeared, 64 were injured, 11,804 were displaced, 130 houses were severely damaged, 1 house was moderately damaged, and 333 houses were slightly damaged. Furthermore, 2 units of health facilities, 3 units of worship facilities, 3 units of educational facilities were also damaged[2].

Sibolangit subdistrict is located at 3\textdegree{}24' - 3\textdegree{}37' LU and 9\textdegree{}856' - 9\textdegree{}860' BT with an area of 173.32
Sibolangit is a plateau area with an altitude of 350-700 m above the sea level and has a rough topography with corrugated hilly reliefs, in which the slopes ranging between 60°-90° [3]. As a result, the Sibolangit subdistrict is vulnerable to landslides. Topographic factor is one of the factors causing the magnitude of surface water flow velocity, which can increase erosion [4]. The climate in Sibolangit is classified as tropical with an average annual rainfall of 2448 mm [5]. This is also one of the causes of the Sibolangit area prone to landslides. Heavy rainfall causes the retained water to increase its discharge and volume. Consequently, the water in the slope presses the soil grains and pushes the sandy soil to move landslides [6].

2. Literature Review

2.1 Soil Condition

Soil conditions also determine the potential for erosion and landslides. Loose soil easily drains water into the cross-section of the soil so that it is more likely to cause landslides compared to massive soil, such as clay. This can be seen from the sensitivity of soil erosion. The soil erosion sensitivity (K) value indicates whether the soil erodes easily determined by various physical and chemical properties of the soil. The smaller the K value, the more insensitive a soil is to erosion [7]. The depth or solum, texture, and structure of the soil determine the size of the surface runoff water and the rate of land saturation by water. In deep soluble soil (> 90 cm), loose structures and tight land cover, most of the rainwater is infiltrated into the soil, and only a small portion becomes surface runoff water. Conversely, in shallow-soluble soil, the structures are dense, land cover is less dense, only a small portion of rainwater is infiltrated, and most of it becomes surface runoff [7].

2.2. Human Activity

Human activity is one of the categories of active factors causing landslides in addition to rainfall, land-use, and earthquakes. Human activities that can cause landslides such as cliff cutting, landfill in slopes, land use changes such as deforestation into wetlands, standing water on slopes, agricultural systems that do not pay attention to safe irrigation, and regional development, which is not in accordance with regulations.

2.3. Land Use
The type of land use that determines the level of potential landslides (prone to highly vulnerable), namely shrubs, fields, settlements, rice fields, and fields. Based on the risks of landslides, settlements, buildings, and irrigated fields because it has the highest risk of material and non-material loss. Land use patterns for rice fields, especially in areas that have steep slopes can increase the potential for landslides. This is because the increase in the volume of water stored in paddy fields can increase the slope load. The rice fields are made by modifying and cutting slopes. This activity causes the slope angle to be higher, thereby increasing the potential for landslides. Besides, soils that lose vegetation cover will crack in the dry season. Then, in the rainy season, the water will easily seep into the soil layer through the cracks and cause the soil layer saturated with water so that it can increase the risk of landslides. Furthermore, the characteristic of rain in the research location which is classified as high can cause the rice paddy season to become a water reservoir, and if it continues, it is highly potential to become a landslide [6].

3. Research Method
The research location was the Sibolangit subdistrict using secondary data, namely rock type map, soil type map, slope, rainfall, and land use. Data was processed into spatial data such as analog and digital data. Analog data was in the form of land use maps and rainfall maps, whereas digital data was in the form of maps of soil types, rock types, and slopes. Furthermore, the earthquake data was processed and made so that it became a vector-format digital map. In the initial stages of data processing, each data must be made into a digital map. Analog data in the form of land use and rainfall maps were processed, and each of them was made into a digital vector format map. The process of entering data was done through a laptop with ArcGIS 10.5 software. The output data was then used as research reference data.

The score of each parameter class was determined based on the classification results of the Bogor Pusliittanak [8]. The higher the score, the higher the potential for landslides. The scoring of each parameter is as follows:

| Parameter | Scale | Percentage | Score |
|-----------|-------|------------|-------|
| Very wet  | >3000 | 30%        | 5     |
| Wet       | 2501-2300 | 30%  | 4     |
| Normal    | 2001-2500 | 30%  | 3     |
| Dry       | 1501-2000 | 30%  | 2     |
| Very dry  | <1500 | 30%        | 1     |

| Parameter | Weight | Score |
|-----------|--------|-------|
| >45       | 20%    | 5     |
| 30 – 45   | 20%    | 4     |
| 15 – 30   | 20%    | 3     |
| 8 - 15    | 20%    | 2     |
| <8        | 20%    | 1     |

| Parameter              | Percentage | Score |
|------------------------|------------|-------|
| Moor, rice fields      | 20%        | 5     |
| Shrubs                 | 20%        | 5     |
| Forest and Plantation  | 20%        | 4     |
| City/Settlement        | 20%        | 3     |
| Ponds, reservoirs, waters | 20%  | 2     |
Moor, rice fields 20% 1

Table 4. Classification of Rock Types [8]

| Parameter       | Percentage | Score |
|-----------------|------------|-------|
| Volcanic rocks  | 10%        | 3     |
| Sedimentary rocks | 10%   | 2     |
| Alluvial rocks  | 10%        | 1     |

Table 5. Classification of Soil Types [8]

| Parameter          | Percentage | Score |
|--------------------|------------|-------|
| Regosol            | 10%        | 5     |
| Andosol, podsolik  | 10%        | 4     |
| Brown latosol      | 10%        | 3     |
| Yellowish brown latosol association | 10% | 2 |
| Alluvial           | 10%        | 1     |

Total Score: (0, 3 x Rainfall Factor) + (0, 2 x Slope Factor) + (0, 2 x Land Use Factor) + (0, 1 x Soil Type Factor) + (0, 2 x Rock Type Factor)

The final score is divided into four landslide hazard classes, namely low, medium, high, and very high. Landslide hazard class intervals are made based on the highest score and the lowest score with the score
determination: \( \frac{\text{highest score} - \text{lowest score}}{\text{number of class classification}} \)

4. Analysis and Results

The situation in the Sibolangit subdistrict is hilly, and there are several large rivers between the hills such as Belawan River, Petani River, Betimus River, all of which lead to Pancur Batu and Namorambe subdistrict. This can make the soil in this area fertile.

4.1 Map of Rainfall

The climate in this subdistrict generally has moderate air and consists of two seasons, which are the rainy and dry season [3]. The following map is a map of the annual rainfall in Sibolangit subdistrict based on the Spatial Plan Map of North Sumatra Provinces in the year of 2017 to 2037 made with ArcGIS 10.5 using the WGS 1984 UTM zone 47 N coordinate system, presented in Figure 2. Based on the classification of the Puslittanak Bogor[8], 28 villages had a score of 3 with rainfall ranging from 2001-2500 mm/year, and two villages had a score of 5. This happens because the village has two rainfall parameters, namely 1501-2000 mm/year and 2001-2500 mm/year [3].
Figure 2. Annual rainfall map of Sibolangit subdistrict

4.2 Map of Slopes
According to the classification of the [8], slopes in the Sibolangit subdistrict has flat to highly steep slopes. This was influenced by the various height of places in Sibolangit subdistrict in the range of 300-700 m above sea level. In general, the Sibolangit subdistrict has slopes relative to the north. The rivers flow from the mountains in the south to the north side. The scoring results showed that there were 5 villages with a slope of <8% to 30%, 6 villages with a slope of 15-40%, and 17 villages with a slope of <8% to >45%[8].

Figure 3. Classification of Slopes in Sibolangit subdistrict
4.3 Map of Land Use
Based on the map of the Deli Serdang Regency Spatial Planning (RTRW), Sibolangit subdistrict has various usages of land. It includes dense forests, community plantations, rice fields, dry fields, and settlements. Based on the classification of Puslittanak Bogor [8], the scoring results showed that 5 villages had a score of 3, 8 villages had a score of 5, 7 villages had a score of 8, and 10 villages had a score of 10 (Figure 4).

4.4 Map of Rock Types
Forming rocks found in the research site consisted of two types of rocks, namely volcanic rocks, and alluvial rocks. Volcanic rocks consist of rock formations of Barus Volcano (Q_{vbr}), Menden Microdiorite (Q_{tim}), Binjai unit (Q_{vbj}), Mentar unit (Q_{vmb}), Sibayak unit (Q_{vba}) and Singkut unit (Q_{vbs}). Alluvial rocks found in the research site were the Young Alluvium (Q_{ha}). Volcanic rock formations were irreducible volcanic rocks. This rock has a high sensitivity to landslides, whereas alluvial rocks have low landslide sensitivity. Almost all areas in the Sibolangit subdistrict have volcanic rock types with around 172 km², while the Alluvial rocks are only 1 km².

On the map, 29 villages had a score of 3 with volcanic rock types, and 1 village had a score of 4 with volcanic and alluvial rock types (Figure 5).

Figure 4. Map of land use in Sibolangit Subdistrict
4.5 Map of Soil Types

The scoring results for soil types showed that 10 villages had a score of 2, 2 villages had a score 4, 9
villages had a score 6, 2 villages had a score of 7, 2 villages had a score of 9, 1 village had a score of 10, 2 villages had a score of 12, 1 village had a score of 13, and 1 village had a score of 18 (Figure 6).

4.6 Analysis of the Collapse

The analysis results of all parameters were landslide vulnerability areas in the Sibolangit subdistrict divided into four landslide vulnerability classes, namely low, medium, high, and very high vulnerability levels. Low landslide vulnerability level is an area that has slopes ranging from <8% to 45% and has a dry climate with the rainfall of 1501-2000 mm/year. There were 7 villages classified as low level of landslide vulnerability with an area of 32.65 km$^2$ or 18.84% of the Sibolangit subdistrict area, namely the Houses of Sumbul, Kuala, Batu Mbelin, Buah Nabar, Bingkawan, Sanyum Sabah, and Rambung Baru.

The moderate level of vulnerability is in the region with a slope range of <8% to 45%, has a dry climate with a rainfall of 1501-2000 mm/year, the dominant land use is community plantations except in Banda Baru Village which is dense forest, the dominant soil type is Yellow Latosol, and there were several rock formations such as the Mentar unit, Binjai unit, Sibayak unit, and Singkut unit. This vulnerability class is a vulnerability with the largest area of distribution compared to other classes. There were 13 villages classified as moderate landslide vulnerability class with an area of 77.93 km$^2$ or 44.96% from the Sibolangit Subdistrict area, namely Bandar Baru, Sikeben, Buluh Awar, Rumah Pilpil, Suka Makmur, Ujung Deleng, Tanjung Beringin, Tambunen, Puang aja, Betimus Mbaru, Sala Bulan, Bengkurung and Sembal Village.

The high landslide vulnerability class is an area that generally has a high level of vulnerability to landslides. Large to small landslides have occurred and will tend to occur frequently. This region has slopes ranging <8% to >45%, has a rainfall of 1501-2500 mm/year, the dominant land use is community plantations except in Negeri Gunung Village which is dense forest, the dominant soil type is Podsolik soil, and there are several rock formations such as the Mentar unit, Binjai unit, Barus volcano rocks, Mikrodiorit Menden and Singkut unit. There were 8 villages classified as high landslide vulnerability with an area of 46.43 km$^2$ or 28.96% of the Sibolangit Subdistrict area, namely Martelu, Negeri Gunung, Cinta Rakyat, Suka Maju, Batu Laying, Durin Serungun, Rumah Kinangkung, and Sibolangit Villages.

The very high class of landslide vulnerability is an area that generally has a very high level of vulnerability for landslides; the range of <8% to >45% where the slope >45% is more dominant, has a rainfall of 1501-2500 mm/year, heavy rainfall, community plantations, rice fields, and settlements. Areas in this class must always be on the alert because landslides can occur at any time, especially when entering the rainy season. Furthermore, the dominant soil types are Regosol and Podsolic Soils, and there are several rock formations such as the Mentar unit, Binjai unit, Sibayak unit, Singkut unit, Barus volcano rocks, and Young Alluvium. There were 2 villages classified as having a very high landslide vulnerability class, except Ketangkuhen dan Bukum Villages. This class is a vulnerability class with the smallest area of distribution compared to other.
5. Conclusion

Sibolangit subdistrict has a dry and moderate climate with rainfall of 1501-2500 mm/year and a slope of <8% to >45%. The types of land use in the Sibolangit subdistrict were dense forests, community plantations, rice fields, dry fields, and settlements. The soil types were Alluvial, Podsolic, Andosol, Latosol dan Regosol and a combination of these soil types. Moreover, the rock types were volcanic rocks, alluvial rocks, and formation of these rock types. Based on the Puslitpanak, the landslide vulnerability in the Sibolangit subdistrict, namely low landslide vulnerability area with 7 villages (32.65 km² or 18.84 %), moderate landslide vulnerability area with 13 villages (77.93 km² or 44.96%), high landslide vulnerability area with 8 villages (46.43 km² or 28.96%) and very high landslide vulnerability area with 2 villages (16.31 km² or 10.17%).

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