Mapping of Landslide Prone Areas in Regencies South Tapanuli Based on System Geographical Information

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Informasi artikel

Sejarah artikel
Diterima : 23 July 2019
Revisi : 15 Nov 2019
Dipublikasikan : 1 Des 2019

Kata kunci:
Tapanuli Selatan
Longsor
Kerawanan Longsor

A B S T R A K

Potensi gerakan tanah di Kabupaten Tapanuli Selatan termasuk kedalam potensi bahaya tinggi. Hal ini karena Kabupaten Tapanuli Selatan berada pada daerah dengan ketinggian elevasi yang cukup tinggi, wilayah berada di zona sesar besar Sumatera dan curah hujan yang tinggi. Tujuan penelitian ini adalah untuk mengetahui sebaran spasial kerawanan longsor di Kabupaten Tapanuli Selatan. Metode yang digunakan dalam penelitian ini adalah survey dan deskriptif kualitatif dengan menggunakan metode kerawanan longsor dengan parameter : faktor alami dan manajemen. Analisis yang digunakan dalam penelitian ini adalah overlay dari parameter yang telah ditentukan dan pembobotan. Hasil penelitian menunjukkan bahwa wilayah Kabupaten Tapanuli Selatan terbagi kedalam 4 (empat) kelas kerawanan longsor yaitu sedikit rawan, agak rawan, rawan dan sangat rawan dengan luasan secara berturut – turut 183 km² atau 4,20 %, 825,66 km² atau 18,95 %, 2.092,58 km² atau 48,04 % dan 1.254,253 km² atau 28,78 %. Dan yang paling mendominasi adalah kelas kerawanan rawan. Untuk kelas kerawanan sedikit rawan hanya terdapat di beberapa daerah saja yakni di Kecamatan Muara Batang Toru tepatnya di desa Lumut dan Janji Maria. Untuk kerawanan kelas agak rawan mendominasi hampir diseluruh Kecamatan Batang Angkola dan Kecamatan Muara Batang Toru dan Angkola Selatan di sekitar desa Tolang Jae. Untuk kelas kerawanan Rawan mendominasi di Kecamatan Batang Toru, Sayur Matinggi Sipirok, Aek Bilah, dan Saipar Dolok Hole. Dan untuk kelas kerawanan sangat rawan mendominasi di wilayah Kecamatan Marancar, Sipirok, Arse dan Angkola Selatan.

Keywords:
South Tapanuli
Landslides
Vulnerability of Landslides

A B S T R A C T

The potential for land movement in South Tapanuli Regency included in the high hazard potential. South Tapanuli Regency is in an area with a high elevation, and the region is in a large fault zone of Sumatra and high rainfall. The purpose of this study was to determine the spatial distribution of landslide vulnerability in the South Tapanuli Regency. The method used in this study is a qualitative descriptive survey and using the landslide vulnerability method with parameters: natural factors and management. The analysis used in this study is an overlay of predetermined parameters and weighting. The results showed that the area of South Tapanuli Regency divided into 4 (four) landslide hazard classes, which were slightly vulnerable, somewhat vulnerable, vulnerable and very vulnerable with an area of 183 km² or 4.20%, 825.66 km² or 18.95 %, 2,092.58 km² or 48.04% and 1,254,253 km² or 28.78%. And the most dominant is the vulnerable class. For the vulnerable class, there are only a few weak areas, namely in the District of Muara Batang Toru, precisely in the villages of Lumut and Janji Maria. For class vulnerability, it is somewhat vulnerable to dominate almost all of Batang Angkola and Muara Batang Toru and South Angkola Districts around Tolang Jae village. For the vulnerable class, Rawan dominates in the Districts of Batang Toru, Sayur Matinggi Sipirok, Aek Bilah, and Saipar Dolok Hole. And for the vulnerable class, it is very vulnerable to dominate in the Districts of Marancar, Sipirok, Ass, and South Angkola.

Introduction

A landslide or often referred to as a ground movement is a geological event that occurs due to the change of rock or soil with various types and types such as falling rocks or large lumps of clay (Paimin et al. 2009). In general, landslide events caused by two factors: trigger factors and push factors. Landslides are considered as third in the list of natural hazard in terms of degree of hazard a natural disaster may pose and its worldwide effects (Feizizadeh, 2011; Kanwal, Atif, & Shafiq, 2017; Zilman, 1999) . The driving factors are the factors that influence the material condition itself, while the trigger factors are the factors that cause the material to move (Badan Nasional Penanggulangan, 2015)(Badan Penanggulangan Bencana Daerah Sumut, 2018).

The work presented here addresses the sites investigation problem to identify the areas having potential to experience landslides. Assessment of spatial problem may involve taking into consideration of numerous criteria (Guzzeti, 2000; Lan, 2008; P, 2007; Pachauri A, Gupta P, 1998; Pourghasemi HR, Pradhan B, 2012; Ray R, 2009). Landslide susceptibility, according to (Paimin et al. 2009), occurs in conditions: 1) steep / steep slope, 2) the presence of sliding (waterproof) in the subsurface layer, and 3) there is groundwater above the watertight waterproof layer. Besides, (Paimin et al. 2009) also added that there are two determinants of landslide susceptibility, namely: natural factors and management factors. Natural factors include: 1) annual rainfall, 2) geology/rock 3) slope of the land, 4) the presence of faults/faults/ claws, 5) depth of soil regolith to impermeable layers; while management factors include: 1) settlement density, 2) land use, and infrastructure.

Based on BNPB on Disaster Risk Assessment (KRB) of North Sumatra Province 2016 - 2020, there are in several Regencies / Cities in North Sumatra Province prone and very prone to landslides. The percentage and vulnerability of high-class landslides, there are 20 in North Sumatra Province, and South Tapanuli Regency ranked third. The very potential areas include Batang Angkola District, Saipar Dolok Hole District, Sipirok District, and Sayur Matinggi District.

Based on data from the North Sumatra BPBD there were 37 landslides in 2018, including North Tapanuli happened nine times, Mandailing Christmas happened five times; Sibolga and Toba Samosir happened three times; Karo, Langkat, Labuhan, South Nias, Simalungun, and South Tapanuli happened twice; Dairi Deli Serdang, Lawas, Padang Lawas, Padang Sidimpuan, and Central Tapanuli happened once.

Landslides, one of the main types of natural disasters, gravely threaten and harm people's lives, property and environments (He, Hu, Sun, Zhu, & Liu, 2019). The landslide caused various impacts, including 39 fatalities, 512 housing units, 16 serious/minor injuries, three units of damage to places of worship, 60 hectares of plants, 4,258 families, and three missing people (Badan Penanggulangan Bencana Daerah Sumut, 2018).

South Tapanuli Regency is a regency in North Sumatra Province, Indonesia, which is the result of the division of South Tapanuli Regency. South Tapanuli Regency before the division consisted of the Mandailing Natal area, Padang Sidimpuan, Padang Lawas Utara, Padang Lawas. The capital of the South Tapanuli Regency in Sipirok.

Based on data on the occurrence of disasters in the South Tapanuli Regency in 2018, that disaster occurred 35 times, and landslide events were the most frequent disasters that happened 12 times.

Based on the previous description shows that this area has an area that is prone to landslides, and this landslide also caused a lot of losses, both material and immaterial losses, even though the impact caused by landslides has not claimed lives, especially in areas where avalanches occur. To be able to monitor and observe the phenomenon of landslides in this area there needs to be an identification of

landslide areas that are able to provide an overview of the area condition, because spatial data on landslide-prone in detail up to the district level is still not available, so there needs to be a response and efforts to minimize the risks inflicted. The landslide hazard mapping is essential for delineating hazard-prone areas (Dangol, n.d.). One application of technological advances associated with landslides is the overlay spatial analysis techniques using geographical information systems (GIS) to produce vulnerable and not-vulnerable zones (Souisa, Hendrajaya, & Handayani, 2016).

Method

Based on BNPB on Disaster Risk Assessment (KRB) of North Sumatra Province 2016 - 2020, there are in several Regencies / Cities in North Sumatra Province prone and very prone to landslides. The percentage and vulnerability of high-class landslides, there are 20 in North Sumatra Province, and South Tapanuli Regency ranked third. The very potential areas include Batang Angkola District, Saipar Dolok Hole District, Sipirok District, and Sayur Matinggi District.

1. Research Location

This research conducted in South Tapanuli Regency, South Tapanuli Regency, located at 0º 58'35 "- 2º 07'33" LU and 98º42'50 "- 99º34'16" East BT. And geographically, South Tapanuli has boundaries:

- Northside: North Tapanuli Regency and Central Tapanuli Regency.
- Southern side: Mandailing Natal Regency.
- Eastside: Padang Lawas Regency, North Padang Lawas Regency, and Labuhan Batu Utara Regency.
- West: Indonesian Ocean and Mandailing Natal Regency.

2. Tool and Materials

1) Tool

- Computer hardware (hardware) with core i3 specifications with 4.00 GB RAM.
- Software (GIS software) for obtaining spatial data: ArcMap 10.1, Envi 4.7, and Google Earth Pro.
- Cameras used for field documentation.
- A meter used to measure the depth of the regolith.

2) Material

- Map of research location administration (BAPPEDA Tapanuli Selatan)
- DEM BIG data.
- Rainfall data from BMKG stations that processed into rainfall maps.
- Slope map processed from BIG DEM data.
- Map of soil types (BAPPEDA Tapanuli Selatan).
- Geological map (BAPPEDA Tapanuli Selatan) by looking at landforms and faults.
- Map of land use and cover (BAPPEDA South Tapanuli).
- Infrastructure map by looking at the presence or absence of roads that cut across the slope.
- The plan of settlement density processed from the population obtained from the South Tapanuli BPS office.

3. Data Collection and Analysis

The survey method was carried out to determine the physical conditions in the field, while to identify areas prone to landslides, the landslide formula used according to Paimin et al. (2009). The potential of remote sensing–GIS technology to devise an automatic and intelligent approach for route planning in hilly regions that are prone to landslides (Saha, Arora, Gupta, Virdi, & Csaplovics, 2005). The data used include natural parameters (rainfall, slope, geology, fault/fault, and depth of soil regolith) and management factors, including: (settlement density, infrastructure, and land use). The method used is overlapping (overlaying) of the eight parameters previously scoring and weighting. Data collection is the main step in landslide susceptibility mapping whereby the relevant

landslide conditioning factors are extracted to construct a spatial database (Shahabi & Hashim, 2015).

Scoring and weighting tables presented in the following table 1:

Table 1. Score Points and Landslide Parameters

No.	Parameters	Classification	Category	Score
A. Nature (60%)				
a.	Rainfall (mm/year) (25%)	<1000 1000 – 1500 1500 – 2000 2000 – 2500 >2500	Low Rather Low Moderate Rather High High	1 2 3 4 5
b.	Land Slope (%) (15%)	<25 25 – 44 45 – 64 65 – 85 >85	Low Rather Low Moderate Rather High High	1 2 3 4 5
c.	Geology (bedrock) (10%)	Sedimentary Material – 2 and Vulcanic -2 Sedimentary Material Vulcanic Material Alluvial Material	Low Moderate Rather High High	1 2 3 4
d.	The Presence of Fault (5%)	None All	Low High	1 5
e.	Regolite soil depth up to an impermeable layer (m) (5%)	<1 1 - 2 2 – 3 3 – 5 >5	Low Rather Low Moderate Rather High High	1 2 3 4 5
B. Management (40%)				
a.	Land Use	Forest	Low	1

	(20%)	Scrub Plantation Moor/Backyard Field/Settlement	Rather Low Moderate Rather High High	2 3 4 5
b.	Infrastructure (If the slope <25 % = score 1) (15 %)	No way Cut the road Slope/Slope cut through	Low High	1 5
c.	Settlement Desnsity (person/km²) (If the slope < 25 % = score 1) (5 %)	<2000 2000 – 5000 5000 – 10000 10000 – 15000 >15000	Low Rather Low Moderate Rather High High	1 2 3 4 5

Source: Paimin et al. 2009 with modification

The results of the parameter stacking, are then grouped into five classes of landslide hazard levels, as presented in table 2 below:

Table 2. Score Points and Category Prone Landslide

No.	Weighted Score	Category
1	>4,3	High Vulnarable
2	3,5 – 4,3	Vulnarable
3	2,6 – 3,4	Rather Vulnarable
4	1,7 – 2,5	Low Vulnarable
5	<1,7	Np Vulnarable

Source: Paimin et al. (2009)

Result and Discussion

Result

1. Factors that cause Landslides

1) Slope

The percentage of the hill in South Tapanuli Regency will present in the following figure 1:

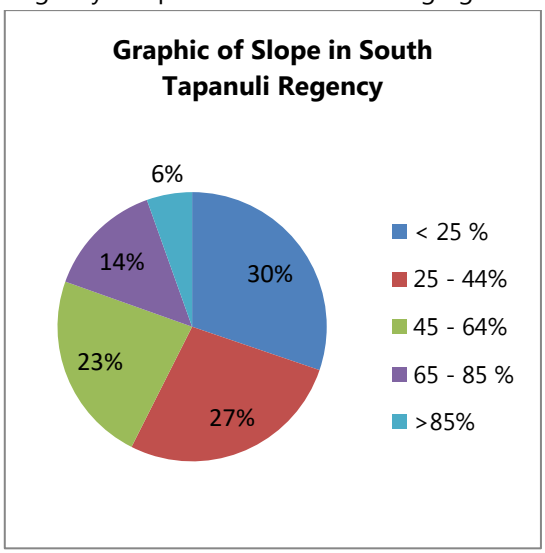

Figure 1. Precentage of Slope

Based on Figure 1 above, it can see that the slope of the slope is more dominant at a slope < 25 with an area of 1,309.71, while the slope of> 85 is the lowest slope of 236.63.

2) Rainfall

The percentage of rain in South Tapanuli Regency presented in the following figure 2:

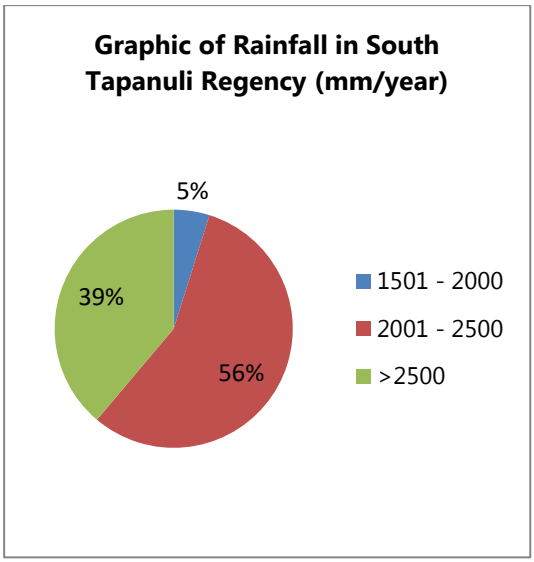

Figure 2. Precentage of Rainfall

Based on Figure 2 above, it can explain that the study area divided into 3 regions of average annual rainfall, namely rainfall with a range of 1501 - 2000 mm / year with an area of 215.67 km² (4.85%), range 2001 - 2500 mm / year with an area of 2,449.76 km² (56.24%), range> 2500 mm / year with an area of 1,689.92 km² (38.80%). Rainfall in the most dominant research location is 2000 - 2500 mm / year, this means that the study area is in an area that has a relatively high average annual rainfall.

3) Land Use

Based on processed data obtained from the Bappeda South Tapanuli Regency office, land use in South Tapanuli Regency can be seen in Figure 3 below.

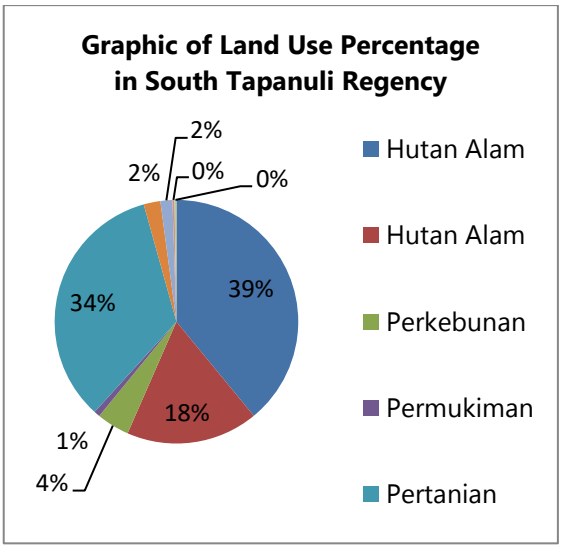

Figure 3. Presentage of Land Use

Based on Figure 3 that the use of natural forest land is the most extensive land cover with an area of 1,699.9 km² or 39.03% of the region of South Tapanuli Regency. While the highest land use to trigger landslides is the use of settlements, rice fields, and agriculture with settlement area of 34.91 km² (0.80%) and agricultural region of 1,478.09 km² (33.93%) and rice fields of 96.99 km² or 2.22% of the total area of South Tapanuli Regency.

4) Settlement Density

Settlement density is the number of inhabitants per unit of the residential area in an area that usually expressed as the number of inhabitants per km². The frequency of settlements in South Tapanuli Regency can be seen in the following figure 4:

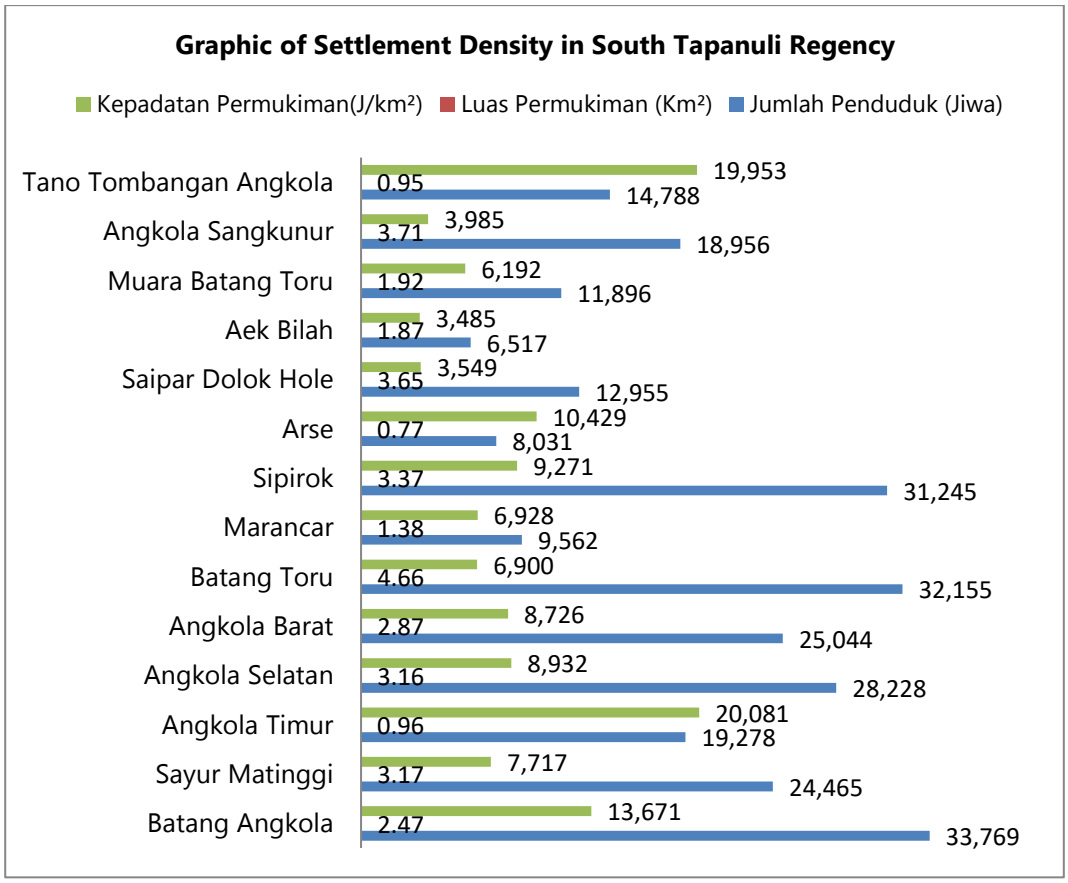

Figure 4. Resedential Density Chart

Based on Figure 4 above, it can explain that the highest settlement density in South Tapanuli Regency is in the East Angkola District with a settlement density of 20,081 per km². In Tano Tombangan Angkola District, that is 19,953 per km², and Batang Angkola District is 13,671 per km². And the lowest settlement density in South Tapanuli Regency is in Saipar Dolok Hole Subdistrict, which is 3,549 per km². Based on the population in the Saipar Dolok Hole Subdistrict classified as very low among the community in other Subdistricts. And Aek Bilah Subdistrict is also a Subdistrict with low settlement density.

5) Infrastructure

Infrastructure is a form of support in the form of space and networks. In this research, the foundation discussed is about the existing road network in South Tapanuli Regency. Infrastructure map obtained by overlaying between slope maps and the road map in South Tapanuli Regency. To see the presence or absence of roads and the existence of ways that cut slopes manually analyzed after an overlay result obtained between the road and the slope in the South Tapanuli Regency. And the score is obtained by seeing the presence and absence of ways and the path that cuts slopes. The lowest score (1) received if there is no road, while the highest score (5) obtained by looking at the way reducing the slope/slope of the road.

6) Geological state

South Tapanuli Regency predominantly composed from pyroclastic rocks or volcanic igneous, metamorphic, and sedimentary. The rock structure in South Tapanuli Regency is dominated by volcanic rocks in the form of Sibual Volcano - except with an area of 885.49 km² or 20.33%, and Gunung Api Lubuk Raya, with an area of 892.54 or 20.49%, sedimentary rocks in the form of Tapanuli Group, Diorite, and alluvial rocks. The geology/rocks condition of South Tapanuli Regency can be seen in the following table 3:

Table 3. The Geology Condition of South Tapanuli Regency

No.	Geology Condition	Wide (km²)	Precentage (%)
1	Vulcanic : Toba Tuffs	460.03	10.56
2	Vulcanic : Sibual Volcano – buali	885.49	20.33
3	Vulcanic : Lubuk Raya Volcano	892.54	20.49
4	Sub – Vulcanic	17.45	0.40
5	Sub – Vulcanic	115.67	2.65
6	Sub-Vulcanic : Diorite	51.07	1.17
7	Sub – Vulcanic : Tinjoan Diorite	11.68	0.26
8	Tapanuli Grup: Limestone	22.08	0.50
9	Sediment : Limestone	28.68	0.65
10	Metamorf – Vulcanic Meta	1.18	0.02
11	Metamorf : Kuantan Formation	69.47	1.59
12	Old Alluvium	132.52	3.04
13	Sediment : Tapanuli Grup	141.38	3.24
14	Young Alluvium	91.31	2.09
15	Fluvial	692.10	15.89
16	Fluvial: Barus Formation	12.45	0.28
17	Sediment : Barus Formation	358.02	8.22
18	Alluvial : Barus Formation	22.68	0.52
19	Alluvial : Huraba	351.32	8.06
Wide		4,355.35	100

Source: Bappeda Tapanuli Selatan dan Hasil Olahan GIS

7) Regolith Land

How to measure the depth of soil regolith in the area of the study site is done by looking for cliffs that are exposed to facilitate the measurement. Where researchers estimate from the upper layer (horizon above) soil to the main rock layer (waterproof layer) in taking a sample point of soil depth based on the type of land in the study site. For more details, the extent of soil regolith in the study area can see in Figure 5 below.

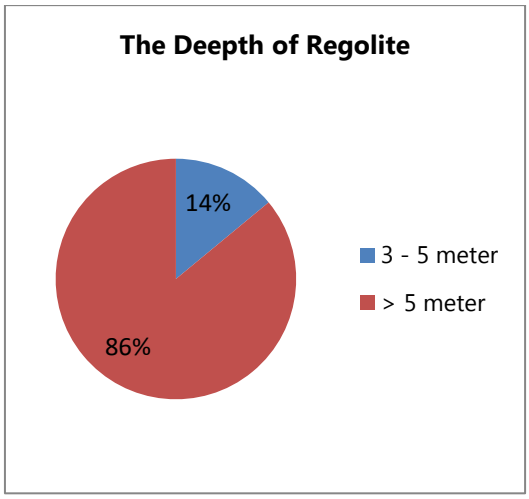

Figure 5. Regolite Depth of The Land

2. The spread of Landslide

Prone Areas Determination of the level of landslide vulnerability obtained by giving scores and weights of each of the landslide parameters. So that it will produce a new weight value, which is a potential value of a landslide-prone after these parameters overlapped. Based on (Paimin et al. 2009) the results of landslide hazard overlay classes are grouped into 5 categories of landslide vulnerability classes, in contrast to the effects of spatial analysis on each parameter causing landslides in the study area resulting in a map of landslide area distribution with 4 categories of landslide vulnerabilities, namely: slight vulnerability, somewhat vulnerable, vulnerable and very vulnerable. Full details of the extent of each landslide vulnerabilty class are presented in Figure 6 below:

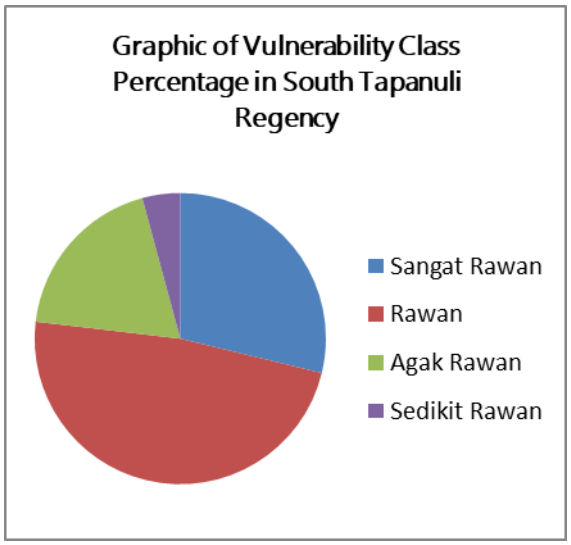

Figure 6. Landslide Vulnerabilty Class

Based on Figure 6 above, it shows that the most vulnerable vulnerability level is 2,239.53 km² or 51.4% of the total area of South Tapanuli Regency, while for the extent of the weak vulnerability level, it is somewhat vulnerable, and the least vulnerability respectively is 1,701.81 km² (39.06%), 402.81 (9.24%) and 11.16 km² (0.25%) of the total area of the study area.

Map of the level of landslide vulnerability in South Tapanuli Regency can be seen in Figure 7 below:

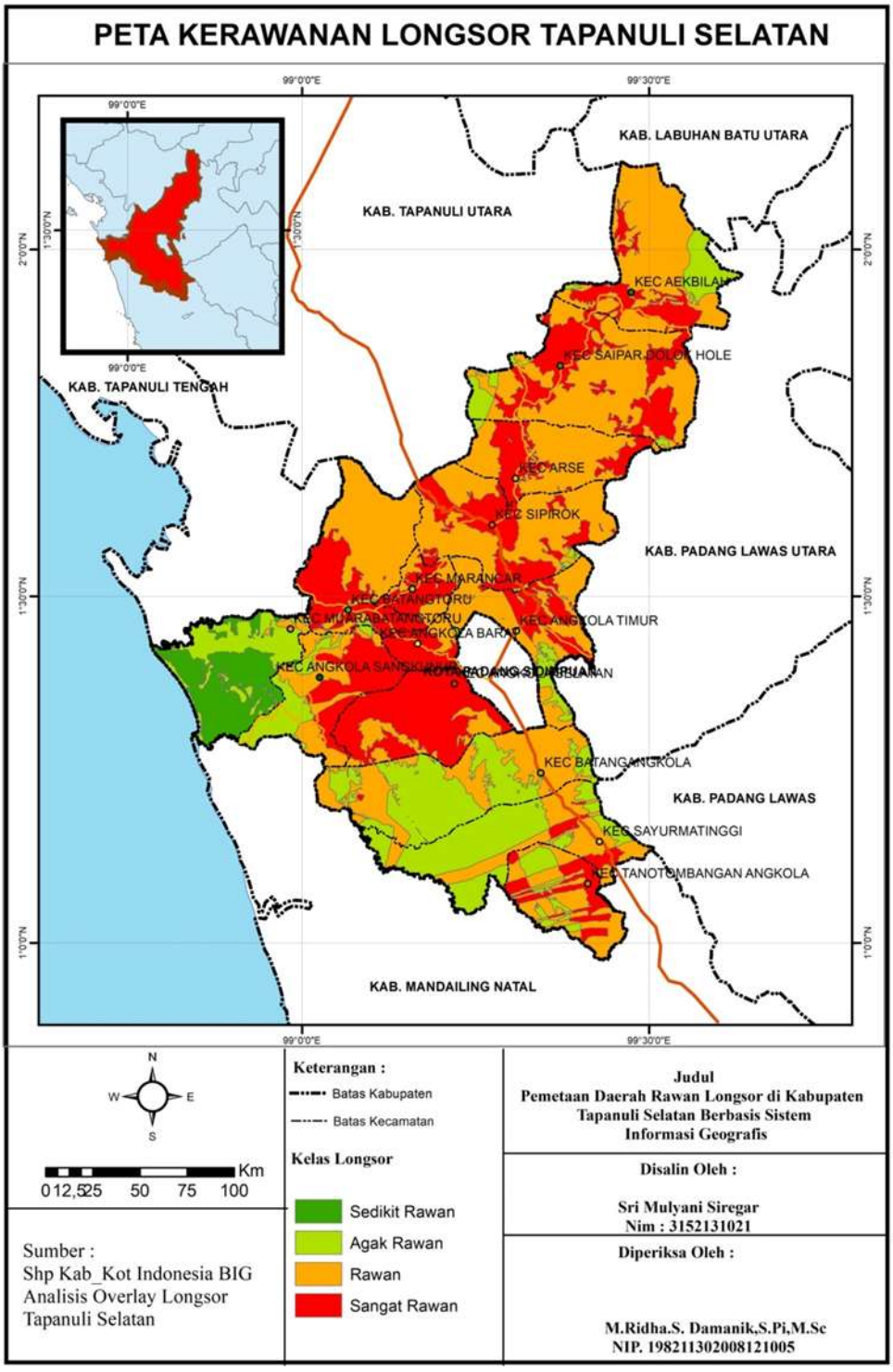

Figure 7. Map of South Tapanuli Landslide Vulnerability

Discussion

The results of the spatial analysis on each of the causes of landslides generated based on the value of the range of benefits, there are four types of landslide hazard levels, namely a little vulnerable, somewhat vulnerable, vulnerable, and very vulnerable. Various factors influence the distribution of landslides for each level. Landslide information extracted from satellite images with high spatial resolution is successful in mapping the existing landslides (Sarkar & Kanungo, n.d.).

The area that is least prone to landslides is zthe least area for the occurrence of landslides because the results of data processing from

existing parameters show the numbers 1.7 - 2.5. The score given to the factors affecting landslides in the hazard class saw that each element gets a low score. Administratively, the dominant area in this slightly vulnerable zone is from the villages around Lumut and Janji Maria village in Muara Batang Toru District. The area which is somewhat prone to landslides is only around 183 km² or about 4.20% of the total area of South Tapanuli Regency. For land-use types, this vulnerability class dominated by shrubs/shrubs, swamps, plantations. The slope of this hazard class governed by a hill of <25%, rainfall in this hazard class is around> 2,500 mm / year, and the type of rock constituent is alluvial. The total area of this hazard class is 183 km² or 4.20% of the total area of the South Tapanuli Regency.

Slightly prone areas are areas that have a higher tendency for landslides compared to areas that are less prone to landslides. This area almost dominates in the Muara Batang Toru sub-district area, and a little is in the South Angkola sub-district, precisely in Tolang Jae village. This area also has the lowest slope of the South Tapanuli Regency, which is a slope of> 40%. For the type of land use in this hazard class are forests and bushes/shrubs, rainfall ranges from> 2,500 mm / year, the type of constituent rock is alluvial, and road infrastructure is an area where the road does not cut slopes. The total area of this hazard class is 825.66 km² or 18.95 of the total area of the South Tapanuli Regency.

Landslide-prone areas are areas that tend landslides. The calculation of environmental parameters that fall into this category are regions that have a parameter calculation score of 3.5 - 4.3. In this class, the dominant areas are Angkola Selatan District, Sayur Matinggi, Batang Toru, Aek Bilah, and Saipar Dolok Hole District. In this vulnerable class area, many landslides occur even though not all the factors that influence it to get a high score, this is affected by the disruption of the body of a very steep/steep slope. The type of land use in this hazard class dominated by forests and settlements, the type of constituent rock is volcanic in the form of Sibual Volcano - build and rainfall in this hazard class range from 2,000 - 2500 mm / year. The total area of this vulnerability class is 2,092.58 km² or 48.04 of the total area of South Tapanuli Regency, and this vulnerability class is the most dominant in this study area.

Very vulnerable areas are areas that generally have a high level of vulnerability to landslides because of the results of calculations on the parameter values described above are above average costs with a total score reaching> 4.3. In this class, the most dominant areas are Marancar, Sipirok, Ass, Subdistricts of South Angkola, Tano Tombangan Angkola, and West Angkola Districts. The total area of these classes is the highest in the South Tapanuli Regency, which is around 2,239.53 km² or about 51.4% of the total area of South Tapanuli Regency. The total area of this hazard class is 1,254.25 km² or 28.79 of the whole area in the South Tapanuli Regency, and this vulnerability class is the most dominant class after the hazardous landslide hazard class in this study area.

Conclusion

Based on the results of research and discussion that has described, the following conclusions drawn: South Tapanuli Regency divided into 4 (four) landslide hazard classes, which are slightly vulnerable, somewhat vulnerable, vulnerable and very vulnerable with an area of 183 km² or 4.20 respectively %, 825.66 km² or 18.95%, 2,092.58 km² or 48.04% and 1,254.25 km² or 28.79%. And the most dominant is the vulnerable class. For the vulnerable category, there are only a few sensitive areas, namely in the District of Muara Batang Toru, precisely in the villages of Lumut and Janji Maria. For class vulnerability, it is somewhat vulnerable to dominate almost all of Batang Angkola and Muara Batang Toru and South Angkola Districts around Tolang Jae village. For the vulnerable class, Rawan dominates in the Districts of Batang Toru, Sayur Matinggi Sipirok, Aek Bilah, and

Saipar Dolok Hole. And for the vulnerable class, it is very susceptible to dominate in the Districts of Marancar, Sipirok, Ass, and South Angkola.

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