Landslide Susceptibility Analysis using Geographic Information System

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ABSTRACT

Landslide is a natural phenomenon that potentially causes damage and loss related to either properties or casualities. Although the damage is just temporary, the damaged land infrastructures affect people's lives, especially in economic activities. Therefore, to anticipate the landslide on the roads, it is necessary to conduct a study to determine which areas that are potentially prone landslide. The model which applied to determine the landslide areas is Storie Index approach by implementing Geographic Information System (GIS). Based on analysis at National roads in Bener Meriah Regency, the insecurity landslide is very low to moderate, despite the fact that there are 6 landslides spot in this location.

KEYWORDS: GIS, landslide, national roads, storie index, Bener Meriah, Indonesia

INTRODUCTION

Landslide is a transfer or a shift in the soil mass naturally, landslides occurred in a relatively short time. Mass transport of soil is happening at once so that it can cause great damage. An area or location otherwise has the potential for landslides if it meets three requirements, namely: 1) steep incline, 2) it has a layer below ground level which is semi-permeable and soft, and 3) there is enough water to make the soil saturated (Indrasmoro, 2013).

According to Government Regulation No. 34 of 2006 on the roads:

The roads is the infrastructure of land transport covering all parts of the roads, including complementary buildings and equipment intended for traffic, which is at ground level, above ground, below ground and / or water, as well as on the surface of the water, excluding railroads, roads lorries, and the cable path.

Bener Meriah district is a region that consists of hills and mountains that were encountered slopes or bumpy. Potential landslides in Bener Meriah happens around the mountains or hills area, which is affected by the steep slope on the wet soil and weathered rock, heavy rainfall, earthquakes or volcanic eruptions. Topography consists of hills and mountains traversed by many national roads that connect Bener Meriah districts with its neighbors, so that landslides often occur along the roads.

Geographically, Bener Meriah district is located on 4˚33'50"- 4˚ 54'50" N and 96˚40'75 "- 97˚ 17'50" BT and has an area of 1941.61 km2. It is located in the remote areas of Aceh, precisely in the Gayo highlands, with rainfall of 1000-2800 mm, ranging from 143 up to 178 days per year (Bener Meriah in number, 2014). National roads through Bener Meriah is the national roads that stretches from the border district of Bireuen until Border Central Aceh district, specifically from KM 35 to KM 90 is along 55 KM. National roads link passing through the Bener Meriah Regency, Pintu Rime Gayo, Gajah Putih, Timang Gajah, and Pesam.

Geographic Information Systems (GIS) is a tool for storing, analyzing and manipulating the data, in order to produce products that are useful in a variety of studies and land resource management activities and mapping of landslide hazard. The advantages of GIS is its ability to combine a variety of different data structures, formats and levels of precision that allows integration with a wide range of fields of scientific disciplines *beranfaat* in landslide hazard analysis and can also be done with a relatively short time (Barus 1999; Mehrdad et al. 2010; Saleh et al. 2005)

The objective of this study is to determine areas that are prone to landslides along the national roads Bener Meriah. Finally, it will be implemented into the map of landslide prone areas on the national roads Bener Meriah.

METHODOLOGY

Landslide Hazard Analysis

In analyzing the landslide hazard in this study, several parameters are required to determine areas that are prone to landslide. By using the Storie Index model, predictions of landslide hazard at a particular location can be determined. Storie Index is a function of several parameters comprising parameters cause landslides, namely: the climate (rainfall), topography (slope and slope length), vegetation (land use), soil (soil type) and the factor of conservation measures (land management), and other factors such as geomorphology / landform, lithology, soil texture, soil moisture and geology (Arifin and Ita, 2006).

The parameters can be identified as a result of landslides working interaction between climatic factors, topography, ground vegetation, and human, which form as the following equation:

L=f(I,r,v,t,m)

L   : landslide prone
I   : climate
r   : topography
v   : ground vegetation
t   : soil
m   : human

The equation contains two variables (Arifin at al, 2006):

1) Factors that can be changed by human beings like plants that grow on the ground (v), as the properties of the soil (t), the fertility of the soil and the infiltration capacity, an element of topography (r) is the length of the slope, and

2) Factors that cannot be altered by humans such as climate (i), the type of soil.

Parameters of Landslide Prone Areas

Parameters of landslide prone areas are divided into several classes and given value to distinguish the level of vulnerability. The following parameters define areas prone to landslides (Arifin et al, 2006):

Table 1: Parameters of Landslide Prone Areas

No.	Variable	Criteria	Value
1.	Climate	- 3700-4000 mm rainfall per year	8
		- 3400-3700 mm rainfall per year	7
		- 3100-3400 mm rainfall per year	6
		- 2800-3100 mm rainfall per year	5
		- 2500-2800 mm rainfall per year	4
		- 2200-2500 mm rainfall per year	3
		- 1900-2200 mm rainfall per year	2
		- 1600-1900 mm rainfall per year	1
2.	Slope	- Steep to the extremely steep slopes> 75%	6
		- Very steep to the steep slope of 46-75%	5
		- Steep to very steep, slope of 31-45%	4
		- A bit steep, hilly, slope of 16-30%	3
		- Ramps, wavy, bumpy, the slope of 4-15%	2
		- Flat, slope of 0-3%	1
3.	Land use or vegetation	- Without vegetation	5
		- Grass, bushes, vegetation paddy (rice, maize)	4
		- Mixed garden, garden plants	3
		- Plantations (trees)	2
		- Dense forest	1
4.	Soil	- Oxisol	7
		- Ultisol	6
		- Alfisol	5
		- Mollisol	4
		- Enseptisol	3
		- Entisol	2
		- Histosol	1

(Source: Arifin et al, 2006)

The model used to identify areas prone to landslides is Storie index model. Storie index has the following formula (Arifin et al, 2006):

$$L = A \times \frac{B}{10} \times \frac{C}{10} \times \frac{D}{10}$$

L : landslide prone
A : slope
B : land use
C : soil
D : climate/rainfall

Determination of landslide-prone areas using this method has a value range of 0.001 to 1.68. Furthermore, the range of this value will be converted into 5 classes or levels (Arifin et al, 2006):

Table 2: Landslide Prone in Storie Index

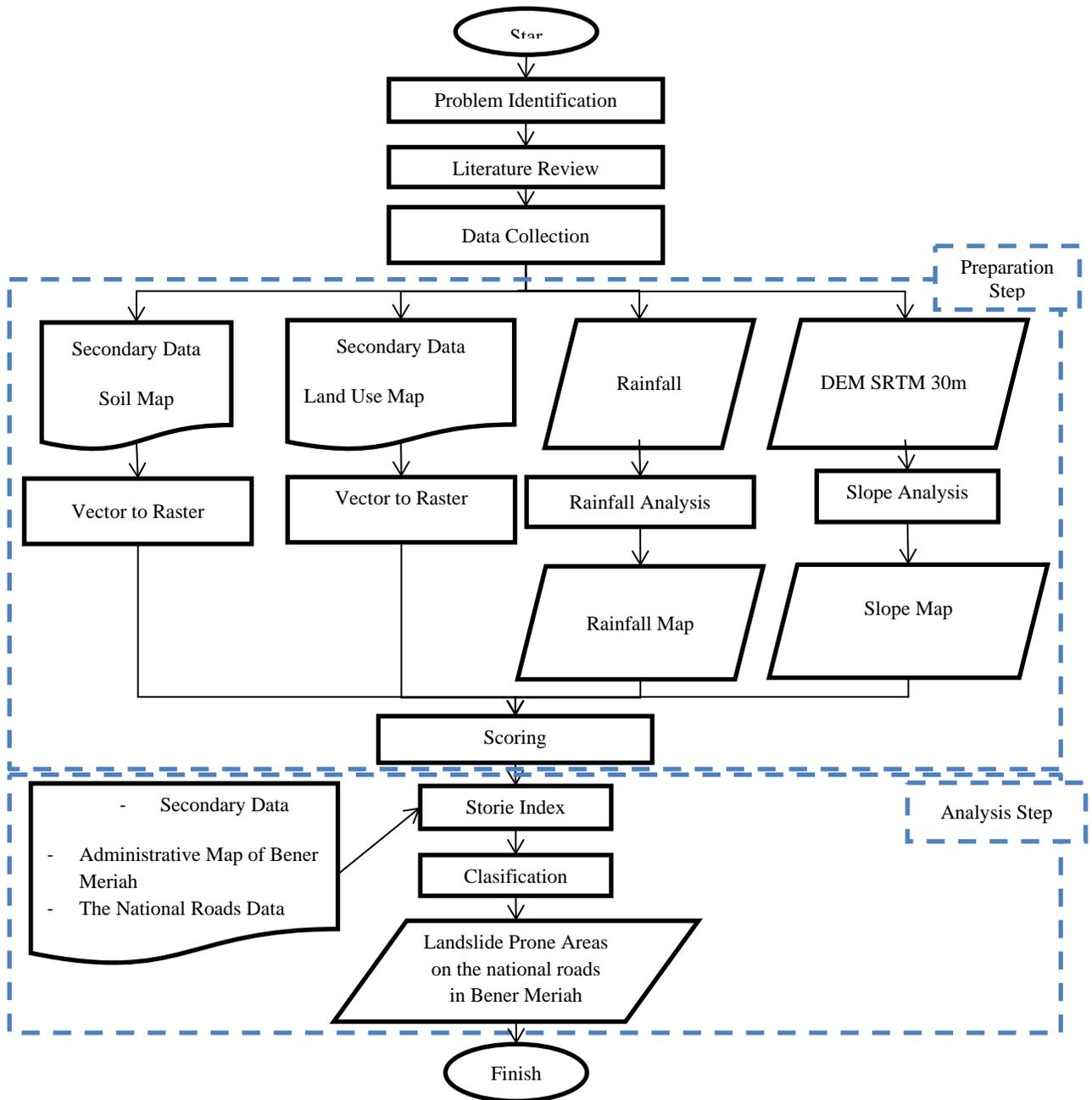| No.	Clasification	Values
1.	Very high	>1,5
2.	High	1,2 – 1,5
3.	Moderate	0,8 – 1,1
4.	Low	0,4 – 0,7
5.	Very low	0,001 – 0,3

(Sources: Arifin et al, 2006)

Figure 1: Work scheme

RESULTS AND DISCUSSION

Slope

Greatest element of topographic effect on the landslide is slope. In general, the steeper the slope, the greater the possibility of landslides will occur. Region with slope between 0% - 15% will be stable against the possibility landslides, while over 15% of the potential for landslides in areas prone to earthquakes will be even greater. Slope in Bener Meriah is dominated by 4-45% and prone to earthquakes. Therefore, there are many areas that have the potential for the occurrence of landslides.

Land Use, Soil Type and Rainfall

Based on secondary data obtained from the Regional Development Planning Board (BAPPEDA) Bener Meriah, land use in the study area consists of 11 types, which are as follows:

Table 3: Land Use Classification.

No	Land Use Type	area(hectares)
1	Body of water	1.75
2	Paddy field	1598.00
3	Secondary forests	109553.00
4	Shrubs	26300.47
5	Primary forest	1661.04
6	Plantation	341.31
7	Mixed dry land agriculture bush	40496.91
8	Dryland farming	1926.09
9	Existing settlements	2271.05
10	Clearing	2597.85
11	Swamp	31.89

Types of soil in Bener Meriah are very diverse. Most of the soil types Kambisol mixed with other soil types, such as Gleisol, Regosol, Andosol, Alluvial and Podsolic.

Rainfall in the district of Bener Meriah ranging from 528 mm to 2896 mm and occurred 143 to 178 times a day each year.

Landslide Hazard Analysis

In the analysis of areas prone to landslides Bener Meriah, it can be seen that the values obtained after using Storie Index ranged from 0.029 to 0.837 with the highest value of 0.837. Then, along the national roads in Bener Meriah have classification of very low to moderate. Although it was classified into classification very low to moderate, it is not likely to happening landslide, considering there are still other factors that can trigger landslides.

Each parameter causes of landslides have different characteristics. Where rainfall dominating factor along the national roads is classified moderate, has the value of 2500 – 2896 mm / year. The average level of the slope along the national roads is above 15%. It can be seen from the street that

has a slope below 15% only 22 KM and 33 KM above 15%. The land use around the roads is dominated by residential, agricultural, and shrubs. Factor in the type of land in the roads is dominated by soil types of oxisol and enseptisol.

A wide variety of the landslide hazard classification shows that there are others factors which do not fit into the parameters of the Storie Index, but have the possibility to cause the landslides. Thus, the landslide which occurred on the national roads in Bener Meriah can be caused by several factors as follows:

1. Rain

Heavy rains early in the season can lead to landslides because of water coming in through the cracked ground and assembled on a slope causing the movement on the ground. With the presence of the trees on the slope surface, the landslides can be prevented. Also, the trees can absorb water and roots will bind the soil. In the vicinity of the national roads Bener Meriah, it can be seen that there is lack of trees at ground level and there is not even a tree on the land cover, consequently there is no roots bind the soil and absorb water when it rains, causing landslides on the roads.

2. Steep Slope

Slope between 00-150 will be stable against the possibility of the landslides, while over 150 potential for landslides in areas prone to earthquakes will be even greater. Bener Meriah is an earthquake-prone area, so it is possible there will be landslides in areas that have a slope of over 150. It is also supported by the six-point landslide on the national roads, which is located on the slope of more than 150.

3. Remnants of past landslides

Remnants of past landslides can also cause landslides continuously if not handled properly. It also happened on the national of Bener Meriah, given that often landslides occur in the same place and in adjacent time.

4. Former pieces of land

The area which is where the roads were built was originally a sloping land, so there are many pieces of roads construction on the land. Many areas in the national roads are former pieces of land.

5. Poor drainage and lack of plaster.

On the national roads, it is found that there are many of poor drainage. Most drainage filled by the ground or other objects that impede the flow of water which can affect the movement of soil when it rains. It can only get worse in the absence of plaster that holds the soil in the surrounding streets.

The fifth parameters are considered as other factors that are not included in the Storie Index and can affect landslide along the national roads in Bener Meriah. Here are several photos of those location and the disaster prone maps of landslides on the national roads in Bener Meriah.
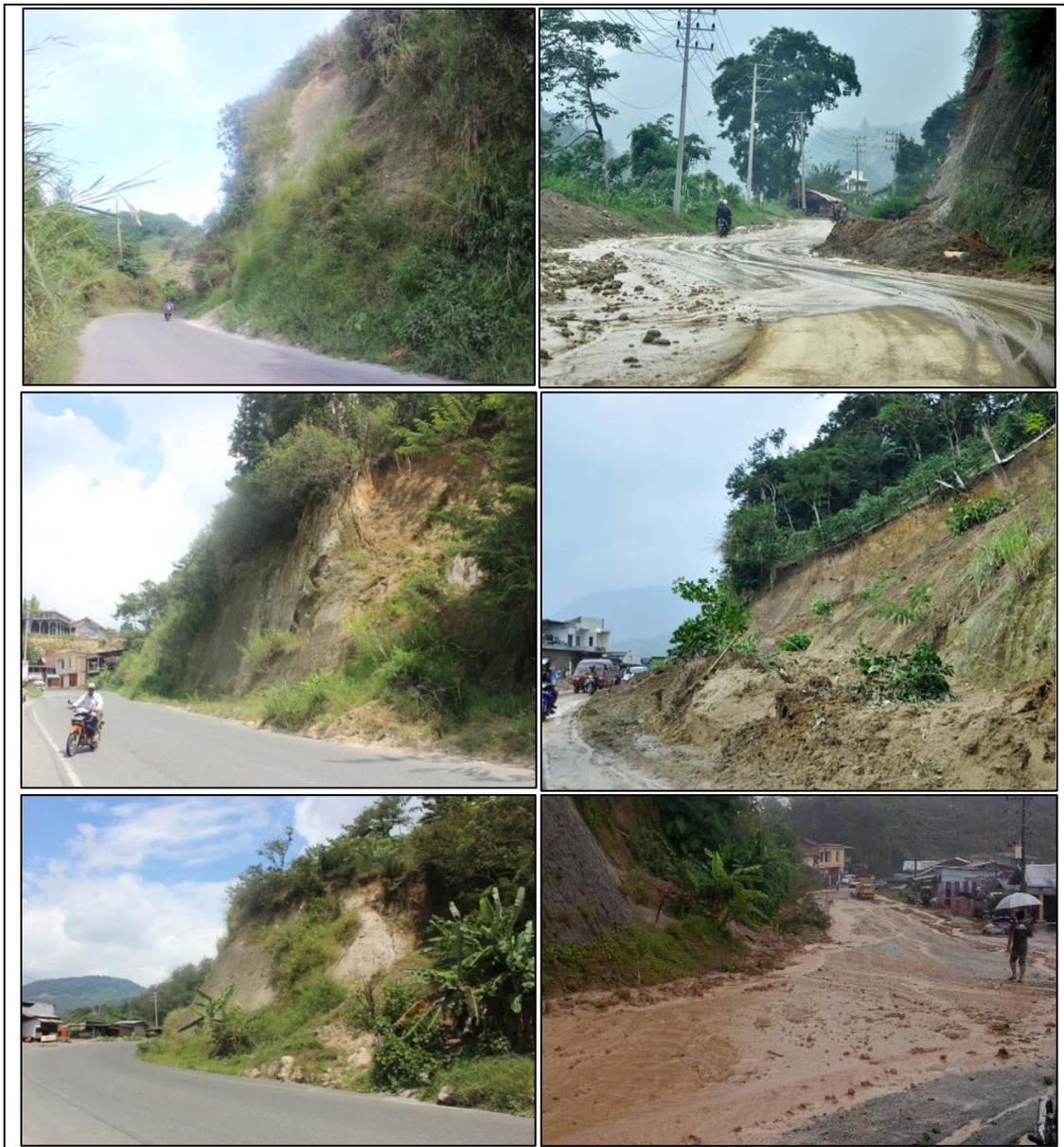
Figure 3: Field photographs of several locations at the national roads in Bener Meriah showing landslide-prone areas
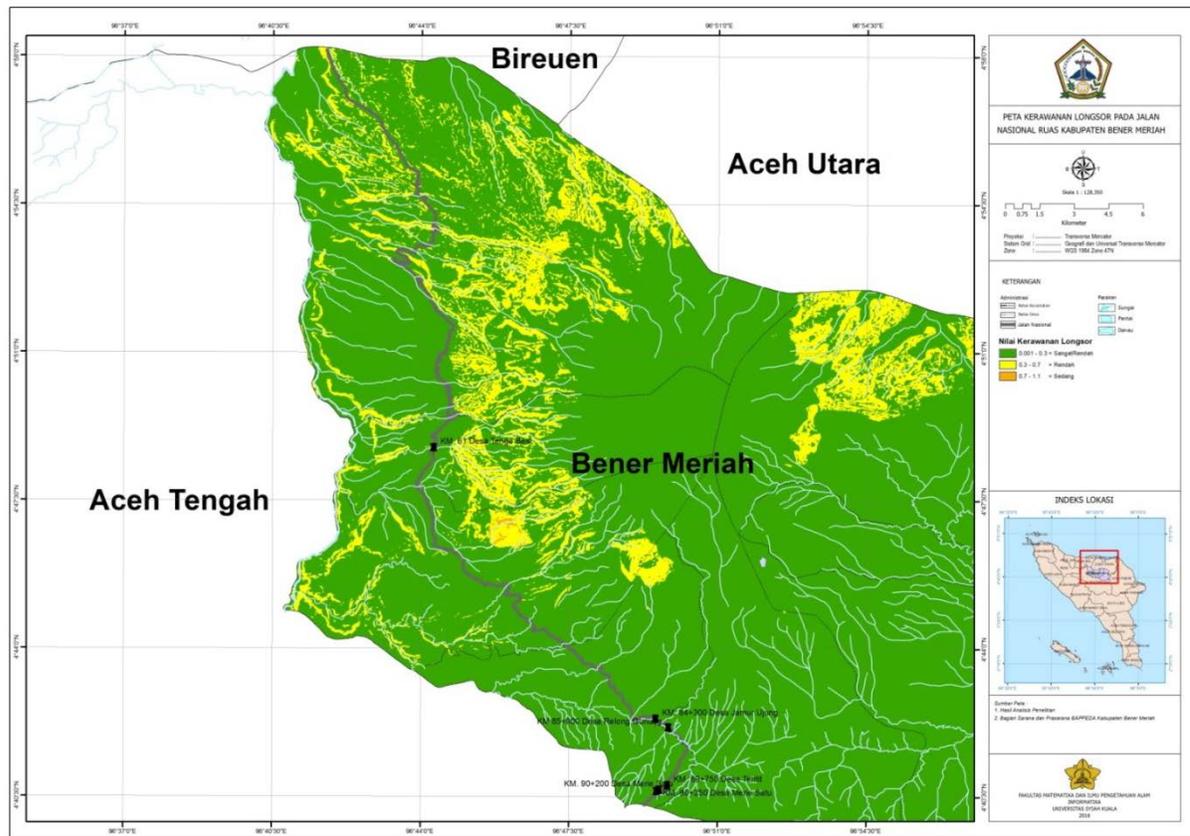
Figure 4: The map of landslide prone areas

CONCLUSIONS

The landslide susceptibility map of the area was prepared in GIS. The landslide susceptibility map divided the area into several classes of susceptibility, viz. very high, high, moderate, low and very low. The map was checked in the field and it was observed that the areas of high susceptible zones showed significant indications of slope instability marked by landslides, erosion and subsidence. The landslide susceptibility map was then used to assess the landslide risk.

Based on analysis of the landslide-prone areas at the national Bener Meriah, it can be concluded that all national roads belonging to the area that has a value of vulnerability to landslides is very low to moderate. However, there are other factors that do not fit into the parameters in the Storie Index which can cause landslides, namely:

a. Heavy rains early in the season can cause landslides due to soil broke through the water will enter and accumulate in the bottom of the slope, causing lateral movement and landslide.

b. Bener Meriah is an earthquake-prone area it is possible there will be landslides in areas that have a slope of over 15%.

c. Absence of proper drainage system along the roads so that when it rains the water will be stagnant and triggered landslides.

d. In the vicinity of the national roads, there are former Remnants of past landslides that have not been addressed properly, so it is possible to cause a landslide in the same place.

ACKNOWLEDGEMENTS

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