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Classification of potential landslides using the Shuttle Radar Topography Mission imagery in the Tulis Watershed, Indonesia

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ABSTRACT

Tulis is one of the watersheds in the Mrica Reservoir Catchment Area in Indonesia. The Tulis Watershed has an area of 12,750 ha, which is dominated by hilly areas with areas below alluvial-colluvial. This study aimed to map the potential distribution of the landslides in the Tulis Watershed. As the Tulis Watershed has the potential for landslides, this study was conducted by using Shuttle Radar Topography Mission (SRTM) imagery year 2016. This study considered five aspects that affect landslides, namely: geological type, soil regolith depth, fault, slope, and soil texture. Areas in the Tulis Watershed were classified into five levels of landslide potential The following landslide classes and the area they cover were predicted after applying the formula: very low (0%), low (48%, 6,126 ha), moderate (51%, 6,548 ha), high (0.5%, 63 ha), and very high (0.1%, 13 ha). From the results of the level of potential landslides, several prevention and mitigation measures are recommended according to the level. For shallow landslide levels, it is recommended that relocation centers should be set up. In contrast, for those areas with very high landslide potential, it is necessary to mitigate and install Early Warning System (EWS) tools and prepare the community for adaptation.

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1. INTRODUCTION

A landslide is a disaster that often takes lives and materials, and happens suddenly. In order to manage landslides, areas with the potential for landslides should be identified. Many landslide types require specific management intervention as each of them is different (Tofani et al., 2014). Research in the field of slip surfaces that sloped on landslides was conducted in Salaman Sub Village, in the Karanganyar area, which is part of the Pablengan Village, Matesih Subdistrict (Darsono et al., 2012). Landslides cause a decline in soil biophysical conditions and also cause a decline in the social economy by reducing land prices (Sugianti et al., 2014). Owing to high rainfall, tropical areas often experience landslides causing quick land degradation (Bhermana & Susilawati, 2019). Apart from mitigation, the local community should be able to adapt to an area prone to landslides by through observing landslide signs in the field and developing local wisdom. A community needs to be prepared how to deal with a landslide disaster and recognize the signs before the disaster happens (Putranto & Susanto, 2017).

The Tulis Watershed, covering an area of about 13,648.52 ha, is one of the sediment contributors to the Mrica Reservoir in Banjarnegara. Identifying areas with landslide potential in the watershed not only saves lives and materials but will also save the reservoir from silting due to sedimentation. Sedimentation in a reservoir results not only from landslides but also from bad land-use practices. If there are many open areas in the watershed, slight to severe erosion can occur (Supangat et al., 2018). Some of the biophysical properties of soil such as texture, soil structure, and permeability also affect the potential for land degradation (Widiatiningsih et al., 2018). The use of land cover data on a more detailed scale will increase the accuracy of predictions of landslides that occur in the watershed (Wahyuningrum & Supangat, 2016).

Sedimentation from the Tulis Watershed will lower the water quality in the Mrica Reservoir, which is one of the sources of water for drinking and irrigation for the community in Banjarnegara. The sedimentation of the reservoir will also reduce its life span and function (Cahyono et al., 2015). The analysis of qualitative erosion in the Tulis Watershed can be done using the Soil Erosion Status formula (Harjadi & Susanti, 2019).

Considering its landslide susceptibility, which leads to reservoir silting, this study aimed to map the potential distribution of landslides of different classes in the Tulis Watershed using satellite imagery from SRTM (Shuttle Radar Topography Mission). Previous observations of ground movements or landslides using landslide pendulums or ews (Early Warning System) were only able to pick one landslide location. The landslide pendulum was conducted from 2005 to 2013 in three locations, namely, Banjarnegara, Purworejo, and Karanganyar (Harjadi & Paimin, 2013). Unlike landslide pendulums, landslide research with radar imagery is able to analyze the potential for landslides in watershed units, identifying areas of low to very high potential of landslide classes.

2. MATERIALS AND METHODS

This research was conducted in the Tulis Watershed in Banjarnegara Regency for one year in 2019. The Tulis Watershed is located at the latitude and longitude coordinates 109°40'–109°60 'E and 7°10'–7°26' S. Banjarnegara, Central Java Province, is an area prone to landslides of various types every year. The Tulis Watershed is part of the catchment area of the Mrica Reservoir, which is bounded by the Pekalongan Regency on the northwest,, the Kendal Regency on the northeast, and the Purbalingga Regency on the southwest, and the Temanggung Regency on the east (Figure 1).

The Tulis Watershed is an area that mainly functions as a water catchment zone. It is on the upper part of the Serayu River and has an area of 13,648.52 ha. The topographical area covers mountains ranging from 600 to 2000 m above sea level and various slopes from wavy to steep surfaces. Annual rainfall in the Tulis Watershed is >3,000 mm. The main types of soil in this area are andosol and latosol. Most of the area (49%) was under a potato and vegetable horticultural plantation (Nearing et al., 2017).

The topographic map of the area is derived from the shuttle radar topography mission (SRTM) data. This mission produced a fine-resolution (30 m) topographic map of the study area based on the imagery produced in the year 2016. The accuracy assessments based on GPS and other reference data showed that the SRTM DEM had 8.8-m accuracy at the 90% confidence level (Rodriguez et al., 2006).

Research materials with Landsat imagery in 2016 and also using SRTM (Shuttle Radar Topography Mapper) image of the same year 2016. Furthermore, geometric and radiometric corrections and analysis were carried out for each aspect affecting landslides with the software ILWIS 3.3. Several parameters that affect landslides were analyzed, including geology factor (G), soil regolith depth (R), slope (S), fault (F), and soil texture (T) (Harjadi, 2015).

Geology factors were analyzed by looking at the distribution of land forms from lowland with an altitude of < 500 m above sea level, alluvial-colluvial, foothill, hilltop, foot mountain, and top of the mountain with an altitude of > 3000 m above sea level. The depth of the regolith was analyzed by approaching the steep slope area with a depth of regolith < 1 m while on a flat slope with a depth of regolith > 5 m. Slope was calculated using the formula:

Slope (PCT) = 100 × HYP (Dx,Dy)/PIXEL SIZE DEM [1]

While the formula degree (Degree) is Slope DEG = RadDeg (ATAN) slope PCT/100)), (ILWIS, 2018). Furthermore, for fault analysis using geological maps, there was a fault or no fault. For the texture of the soil, there were 12 classes of texture analyzed based on the location of the land. The soil in areas that have steep slopes tend to have very course textures whereas that in flat areas has very fine texture, so that in general the texture can be divided into five classes: very course (S, LS), course (SL, SiL, L), medium (Si), fine (SCL, SiCL, CL), and very fine (SC, SiC, C).

The potential area for landslides was classified into five classes, namely (1) very low, (2) low, (3) medium, (4) high, and (5) very high. The magnitude of landslide potential is influenced by geology (SG), regolith depth of soil (SR), slope (SS), soil fault (SF), and soil texture (ST) (Susanti et al., 2017). Each factor was incorporated into a map. Five potential landslide maps representing geology (SG), regolith depth of soil (SR), slope (SS), soil fault (SF), and soil texture (ST) with five classes were constructed. Each factor was then multiplied by the coefficient factor resulting in landslide potential analysis of the Tulis Watershed. Figure 2 shows the flow diagram of the study processes. The potential landslide maps of the Tulis Watershed consist of five classes spreading from upstream to downstream. The formula for the calculation was as follows:

*Landslide = 0.16*SG + 0.12*SR + 0.42*SS + 0.17*SF + 0.14*ST* [2]

Recommendations for each landslide class were produced after the field survey. The findings of this study were socialized to the community in cooperation with Badan Penanggulangan Bencana Daerah (BPBD)/Regional Agency for Disaster Countermeasure in Banjarnegara. Starting from soil conservation demonstration plots on an area heavily affected by previous landslide disasters, the community was expected to establish the conservation effort on their lands according to the risk classes.

3. RESULT

3.1 Production of landslide level from Geology (G)

Table 1 shows that the Tuli Watershed is very high in potential landslides because much rock is starting to weather, resulting in a deeper regolith. The Tulis Watershed is dominated by areas of low landslide potential (36%, 4,555.6 ha), whereas the smallest portion (1%, 170.9 ha) has a very low potential of landslides. The sequence of landslides from the most extensive to the narrowest occurs in the following landforms: alluvial-colluvial, foothill, hilltop, top of the mountain, and lowland, respectively. The geological formation

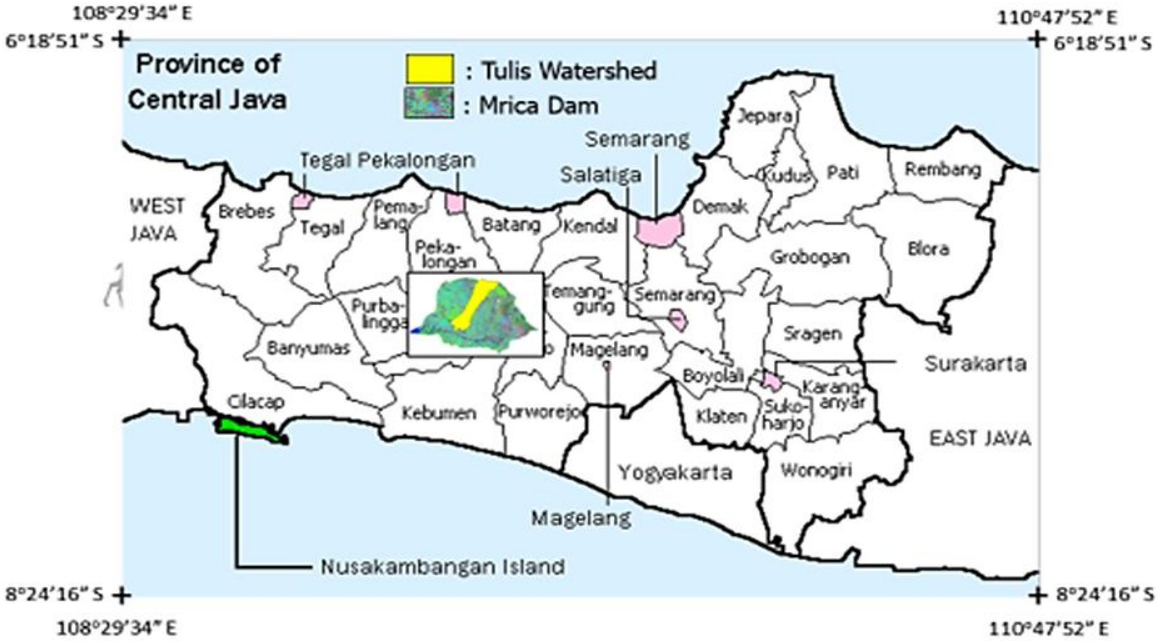

Figure 1. Location of the Tulis Watershed in relation to Mrica Dam

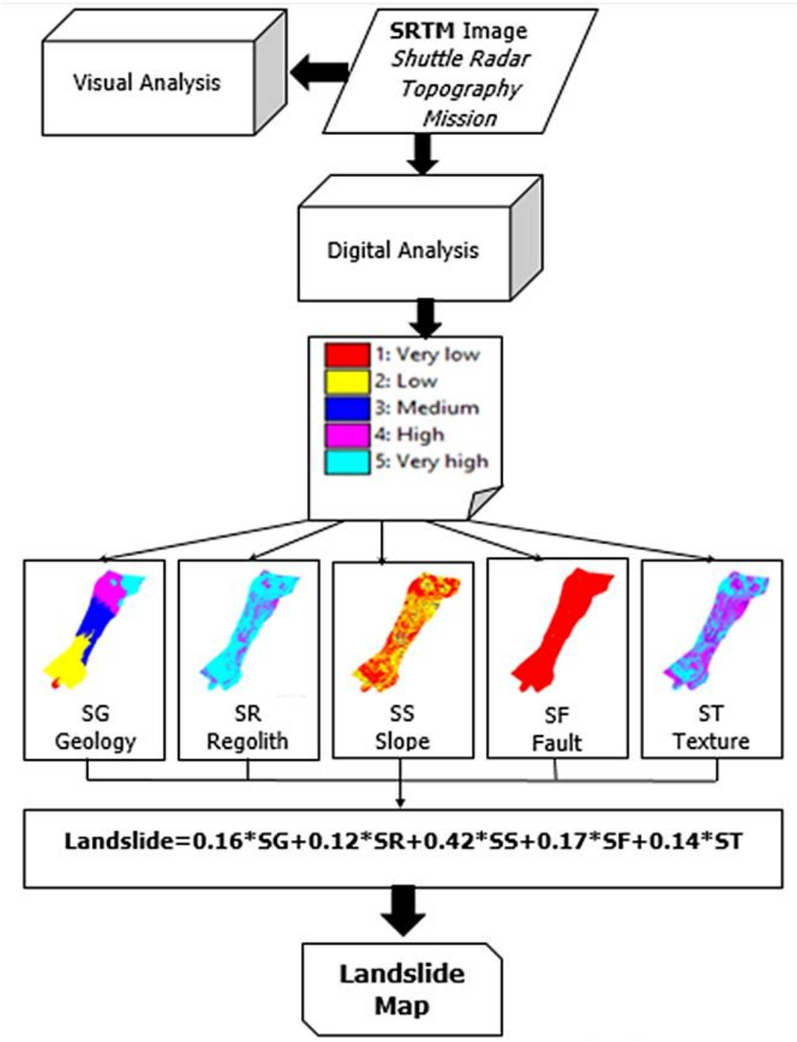

Figure 2. Flow chart of the potential landslide classification in the Tulis Watershed

Table 1. Potential landslide levels in each geology class in the Tulis Watershed

Geology Classes	Altitude (m asl)	Description Landform	Landslide Level	Area (ha)
1	<500	Lowland	1.Very low	170.9
2	500–1000	Alluvial-Colluvial	2.Low	4,555.6
3	1000–2000	Foothill	3.Medium	3,589.1
4	2000–2500	Hilltop	4.High	2,975.9
5	2500–3000	Foot Mountain	5.Very high	
6	>3000	Top of the mountain		1,458.6

in the Tulis Watershed is dominated by areas with a low potential for landslides (36%, 4,555.6 ha). In contrast, areas with very high landslide potential account for only 11% (1,458.6 ha) of the watershed.

3.2 Production of landslide level from Regolith (R)

The Tulis Watershed is dominated by a very deep regolith, which covers 10,573.6 ha followed by deep regolith (2,171 ha), and medium regolith (5.1 ha). This means that a lot of parent material has begun to weather (Table 2). The depth of regolith in the Tulis Watershed consists of only three categories: medium (3–4 m), deep (4–5 m), very deep (>5 m). The Tulis Watershed is dominated by deep and very deep regolith, meaning that the potential for landslides is high level in 17% (2,171.3 ha) and very high level in 83% (10,573.6 ha) of the area.

3.3 Production of landslide level from the slope

There are nine classes of slope that are very influential on the potential for landslides that occur, namely: A (0%–4%), B (4%–8%), C (8%–15%), D (15%–25%), E (25%–35%), F (35%–45%), G (45%–65%), H (65%–85%), and I (>85%).

The steeper the slope of the area that experienced landslides the narrower the area that has the potential to landslide, the flater the area the wider the area that has the potential to landslide. For example, on land with a slope of 50 % (slope class G), the potential for landslides is in grade 4 or high covering only 3.8 ha. Conversely, on land with a moderate slope the area that has the potential to landslide will be wider (6,287 ha).

The land with slope class A has the potential to cause landslides at a very slow rate, covering an area of 6,145.5 ha (Table 3). Very low landslide potential conditions are resistant to landslides and can be allocated as a relocation place if landslides occur elsewhere. Likewise, slope class B also has a low potential for landslides, so there are almost no landslides in the area, covering 6,287.5 ha. Considering slope classes, the larger area in the Tulis Watershed is resistant to landslides. Also, as there are no areas with more than 85% slopes, there is no potential for very high levels of landslides.

3.4 Production of landslide level from fault (F)

Table 4 shows that areas with geological faults have a potential for landslides at very high levels. The Tulis Watershed has only a few areas that are crossed by a fault, meaning that the area with a potential for landslides is small (only 25.5 ha). Specifically, for the Tulis Watershed, most areas, 12,724.5 ha (99.8%), are not crossed by fault lines making them relatively resistant to landslides.

3.5. Production of landslide level from the texture (t)

Table 5 shows the distribution of landslide levels due to different texture classes. In the Tulis Watershed, high, and very high landslide levels due to most of the texture classes are fine and very fine. The Tulis Watershed contains 49% (6,287 ha) of fine texture and 48% (6,146 ha) of very fine texture.

4. DISCUSSION

The Tulis Watershed in the mountainous area shows the potential for landslides that are not too wide compared to those of the Alluvial-Colluvial area. Results indicate that the landslide rate that occurred in the Tulis Watershed was at low and moderate levels. Landslides at low levels occur in areas below or close to the outlet, whereas landslides at moderate levels occur in the high areas. Indeed, in high areas such as hills and mountains are very dangerous areas because they have a very potential for landslides (Hua-xi & Kun-long, 2014). Analysis of landslide-prone areas will be easier if one uses topographic maps that have high resolution (Booth et al., 2009). Areas with a low-risk of landslides should be used for relocation of landslide victims, whereas areas that have a very potential for landslides should be installed with Early Warning System (EWS), landslide monitoring devices to reduce fatalities. Data from EWS is useful for the community to reduce fatalities. The community must also be equipped with climate and weather data to improve the accuracy of predictions of landslide disasters (Balogun et al., 2020). The Tulis Watershed has a low landslide rate because it is supported by the conditions of the area below with a very shallow regolith depth, flat slopes, very rough texture, and no faults. Conversely, areas that have a high potential for landslides occur in over hills or mountains with very deep regolith depth, extreme steep slopes, very fine texture, and there are faults. Some of the parameters of the landslide can be analyzed using satellite imagery and the help of high resolution aerial photography (Pradhan et al., 2010).

Rock formations or geological factors are influenced by the location of the area in a landform. Areas with mountainous landforms are prone to landslides at very high levels, whereas lowland areas have a very low potential for landslides. Forensic identification of potential landslides depends on the geological rock formations (Ruffell, 2010). The strength of rocks close to the ground level largely determines whether landslides can occur easily or not (Gallen et al., 2015). Weathered rocks are easier to become parent material with a high potential for landslides.

The Tulis Watershed has geological formations consisting mostly of volcanic rocks, both those that have not been

Table 1. Level of landslides in each regolith class in the Tulis Watershed

Regolith Classes	Regolith (m)	Description	Landslide Level	Area (ha)
1	<2	Very shallow	1.Very low	0.0
2	2–3	Shallow	2.Low	0.0
3	3–4	Medium	3.Medium	5.1
4	4–5	Deep	4.High	2,171.3
5	>5	Very deep	5.Very high	10,573.6

Table 2. Level of landslides in each slope class in the Tulis Watershed

Slope Classes	Range Slope (%)	Description	Landslide Level	Area (ha)
A	0–4	Flat to slightly sloping	1.Very low	6,145.5
B	4–8	Gently sloping		
C	8–15	Moderately sloping	2.Low	6,287.0
D	15–25	Strongly sloping		
E	25–35	Moderately steep	3.Medium	313.7
F	35–45	Steep		
G	45–65	Very steep	4.High	3.8
H	65–85	Extremely steep		
I	>85	Precipitous	5.Very high	0.0

Table 3. Level of landslides in each fault class

Fault Classes	Description	Landslide Level	Area (ha)
1	No fault	1.Very low	12,724.5
5	there is a fault	5.Very high	25.5

Table 4. Level of landslides in each texture class

Texture Classes	Texture Type	Description	Landslide Level	Area (ha)
1	S, LS	Very course	1.Very low	0
2	SL, SiL, L	Course	2.Low	3.8
3	Si	Medium	3.Medium	313.7
4	SCL, SiCL, CL	Fine	4.High	6,287.0
5	SC, SiC, C	Very fine	5.Very high	6,145.5

Table 5. Area and recommendations at each level of landslides in the Tulis Watershed

Classes	Description	Area		Recommendations
		ha	%	
1	Very low	0	0	Relocation area
2	Low	6,126.4	48.05	Soil conservation
3	Medium	6,548.4	51.36	Land rehabilitation and soil conservation
4	High	62.5	0.49	Mitigation and adaptation
5	Very high	12.8	0.1	the Early Warning System of the danger of landslides to the community.
Total		12,750.0	100	

weathered and those that have weathered. In soils that have started to weather, the soil will get deeper regolith because the parent material is getting thicker. From continuous weathering, a new layer of soil will be formed (Demattê & da Silva Terra, 2014). The dominant landslides in the Tulis Watershed occurs in areas that have a very deep regolith depth (Table 2), so many areas experience landslides. Regolith is soil depth measured from the ground surface to the boundary of the parent rock, which includes layers A, B, and C (parent material). The deeper the soil regolith is, the higher the level of landslides, the shallower the ground regolith is, the lower the level of landslides. The strength of aggregate stones in the regolith layer determines the easiness with which landslides occur (Gallen et al., 2015). The weaker the soil aggregate and the softer the soil, the easier it will be for landslides. Likewise, the parent material which has begun to decompose the soil becomes weak in aggregate and vice versa (Demattê & da Silva Terra, 2014). Deep regolith are associated with a high frequency of landslides marked by soil cracks (Pradhan, 2010). The Tulis Watershed is dominated by moderate slopes, so that landslides occur at slopes of 35%–65%. The slope is the ratio of vertical distances with horizontal distances in units of percent or degrees. The greater the slope values, the steeper the slope, conversely the smaller the

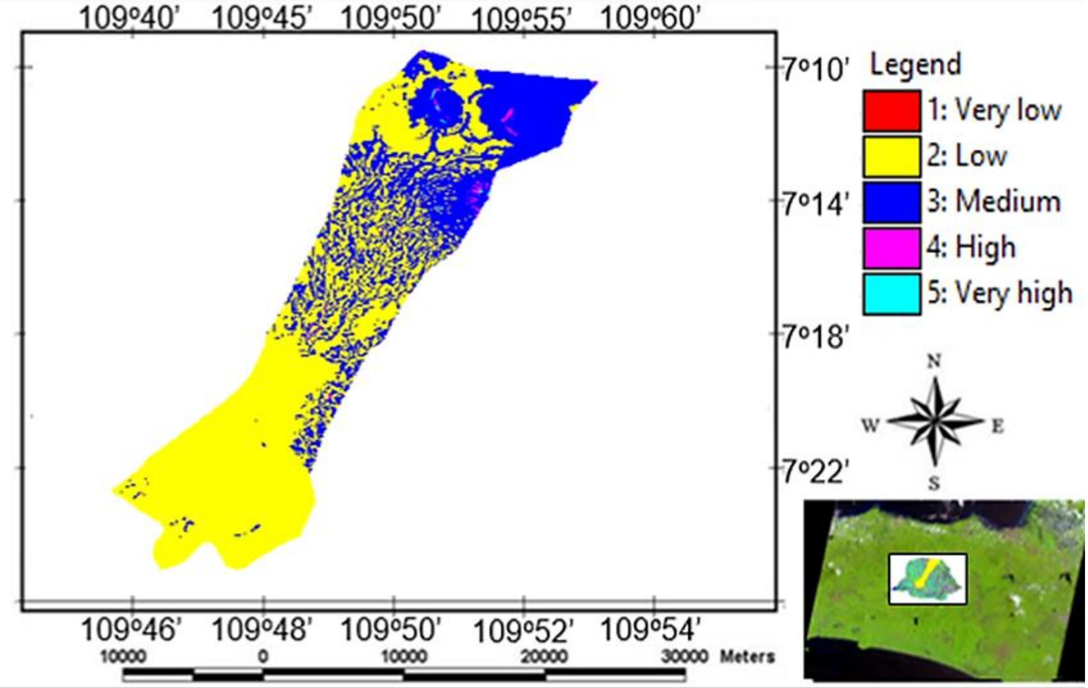

Figure 3. Map of the potential of the five classes of landslides in the Tulis Watershed

percent, the flatter the land. According to Putra (2014), the more sloping the land, the more potential for landslides. On dry agricultural land, land degradation can be monitored by analysis of temporal imagery of different times (Yan et al., 2016). The Tulis Watershed contributes very little to soil surface erosion, and the level of sedimentation in the Mrica Reservoir conforms this (Hatmoko et al., 2013).

Most of the Tulis Watershed is not traversed by fault lines, so this factor is not a cause of landslides. Fault lines in the soil layer indicate the potential for cracks and will become landslides if an earthquake occurs (Harp et al., 2011). Landslide vulnerability mapping models like this need field verification by looking for the presence of fault lines (Pradhan et al., 2010). With respect to fault lines, the category is only divided into two landslide levels: very low for areas that are not crossed by fault lines and very high in areas with fault lines.

The Tulis Watershed is dominated by very fine soil textures such as silty clay to clay, meaning that texture influences the occurrence of landslides in the area. Soil texture, which is a relative comparison of three soil fractions of sand, dust, and clay, also affects the landslide levels. The coarser the texture class, the lower the landslide level. Conversely, the finer the texture class, the higher the landslide levels. Fine textures include sandy clay loam (SCL), silty clay loam (SiCL), and clay loam (CL), and very fine texture classes, namely, sandy clay (SC), silty clay (Piñeiro et al.), and clay (C). Very fine texture conditions on land have the potential for very high landslides, and this can be analyzed by remote sensing and geographical information systems (Hartono & Nasikh, 2017).

Landslide is a downward movement of soil due to gravity in the form of lumps, a collection of rocks, or liquid in large quantities. Landslides have several types including sliding on a flat slope, creeping on a convex slope, and rotation on a concave slope. Besides that, there are other types of landslides such as rock collapse, subsidence in flat areas, earth flow in very soft and liquid soils. With the help of GIS, the distribution of all types of landslides in the field can be displayed in the form of maps (Hartono & Nasikh, 2017).

Table 6 summarizes recommendations according to potential landslide levels. Firstly, very low-risk areas are to be relocated when a landslide is occurring. Secondly, low-risk areas require soil conservation. Thirdly, areas with medium risk can have both soil conservation and land rehabilitation. In areas with a high risk of landslides mitigation measures and adaptation to their environment should be implemented. In the areas with a very high risk of landslide needs to be installed with an Early Warning System (EWS).

The Tulis Watershed is dominated by areas with landslide potential at low and medium levels (48% and 51%, respectively). In areas with low landslide potential (6,126 ha), low potential can be maintained through soil conservation. For areas with medium landslide potential (6,548 ha), it is suggested that land rehabilitation and soil conservation should be conducted by involving landowners and according to the rules and conditions of the land (Sallata, 2016). In areas with high landslide potential, many tools such as Early Warning System must be installed to monitor soil movements (Hua-xi & Kun-long, 2014).

From the analysis with Shuttle Radar Topography Mapper (SRTM), radar images of several aspects that affect the occurrence of landslides were mapped as shown in Figure 3. These radar images, in addition to the analysis of potential landslides, can also be used to help in planning an area (Maulana et al., 2017). Some aspects that affect landslides include slope, soil texture, fault lines, regolith depth, and geological aspects. The map color is dominated by blue, which indicates a moderate level of landslide potential. Furthermore, the potential for low-level landslides is in yellow.

The potential for landslides in the Tulis Watershed is dominated by low and medium levels, each of which covers6,126.4 ha and 6,548.4 ha, respectively. In areas of medium potential landslides, soil conservation, and land rehabilitation actions are recommended (Tingsanchali, 2012).

5. CONCLUSION

The map of the distribution of landslide-prone areas is very useful for local governments to identify areas that can be used as landslide disaster relocation areas. In general, the results show that the SRTM radar imagery can be used to analyze potential landslide areas. The results indicate that, in the Tulis Watershed, the dominant factors influencing potential of landslides were the slope, the depth of the regolith, and the texture of soil. The type of landform and fault line did not affect the potential of an area for landslides. The Tulis Watershed which, has an area of 12,750 ha, can be divided into five levels of potential landslides, namely, from the lowest: very low 0%, low 48% (6,126.4 ha), medium 51% (6,548.4 ha), high 0.5%, and very high 0.1%. In light of the findings of this study, the following recommendations are made: that areas that have a very low landslide potential should be used as relocation areas, that areas with very high landslide potential must have adequate Early Warning System (EWS) tools installed, and that socialization to the community should be done so that they adapt to their environment. EWS will help to minimize casualties and also material casualties, so the installation of EWS equipment must be carried out in areas that are very prone to landslides.

Declaration of Competing Interest

The authors declare that no competing financial or personal interests that may appear and influence the work reported in this paper.

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