Journal of Geology & Exploration
Vol. 2, No. 2, December 2023 : 53 – 62
E-ISSN 2963-2869

Landslide Susceptibility Mapping using Geographic Information System (GIS) and Remote Sensing Data in North Luwu, South Sulawesi Province, Indonesia

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ABSTRACTS

Climate, topography, and rock conditions in Indonesia are relatively diverse, both physical and chemical, these conditions can cause adverse consequences such as floods, landslides, forest fires, and droughts. The Information from Volcanology and Geological Disaster Mitigation on Monday, July 13, 2020, flash floods and flow of debris due to landslides have occurred in Masamba and Baebunta, North Luwu, South Sulawesi Province. The purpose of this paper is to map the distribution of landslide susceptibility area using remote sensing and GIS data. The Method used to analyze the landslide susceptibility estimation model refers to the Indonesian Center for Agricultural Land Resources Research and Development (ICALRD). The parameters used in this model are rainfall, soil type, rock type, slope, land use, and land movement. The ICALRD Landslide Susceptibility Estimation Model in study area shows that there are three classes of landslide susceptibility, such as low, medium, and high susceptibilities. There are six subdistricts which are in medium to high landslide susceptibility, and the others are low to medium landslide susceptibility. The locations of landslides and flash floods that occurred in Masamba and Baebunta indicate areas with medium to high landslide susceptibility.

ARTICLE INFO

Article History:
Received 23 Sep 2023
Revised 24 Sep 2023
Accepted 17 Dec 2023
Available 30 Dec 2023

Keyword:
Landslide, mapping, Geographic Information System, and remote sensing

https://doi.org/10.58227/jge.v2i2.115

INTRODUCTION

Landslide disaster is one of the natural disasters that often occur in Indonesia and generally occur in mountainous areas and during the rainy season. Landslide cause great damage for human lives and infrastructure (Nefeslioglu, Gokceoglu, and Sonmez 2008). Landslide hazard assessment and risk reduction can be reduced by providing risk managers with easily accessible, continuous, and accurate information about landslide occurrences (Dai, Lee, and Ngai 2002). As such, accurate vulnerability mapping can be critical information for human of users from both the private and public sectors, from government departments and the scientific community at the local and international levels (Fell et al. 2008). Remote sensing is a technology capable of monitoring and identifying the earth's surface quickly. Meanwhile, a geographic information system (GIS) can provide information that cannot be identified by remote sensing such as soil type, rainfall, or slope. Remote sensing information and GIS can be combined (overlay), so that it can be used to determine landslide prone areas (Yunianto 2011).

Recently, landslide susceptibility mapping has been likely due to the accessibility and diversity of remote sensing and GIS data (Gupta and Joshi 1990; Qiao et al. 2013; Scaioni 2013). Most of these landslides referred to as an important geomorphic process which is an important aspect of landscaping in a humid tropical mountainous environment (Thomas 2001). Records show that in Southeast Asia, the hill slopes, seasonally dry periods, rainfall intensities, and unstable soils are the main causes of landslides (Douglas 1999). Identifying the different types and processes of landslide is considered a major factor in preventing landslide damage. The preparation of a landslide susceptibility map is a major step in the management of the overall landslide hazard (Bednarik et al. 2010). Landslide susceptibility assessment in a GIS method is based on the selection of factors that play a dominant role in slope stability (Shahabi et al. 2014). There are many qualitative and quantitative techniques available for

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analyzing the relationship between landslides and conditioning parameters (Ayalew and Yamagishi 2005).

The Information from Volcanology and Geological Disaster Mitigation on Monday July 13, 2020, flash floods and flow of debris due to landslides were occurred in Masamba and Baebunta, North Luwu regency, South Sulawesi Province. The problem related to landslide and flood disasters in Masamba and Baebunta, North Luwu, which are the background for this study. The follow-up to this problem is to find solutions and appropriate steps to overcome and reduce the impact of landslides. It is necessary to map landslide-prone area, which is to recognize the characteristics of areas where landslides occur. One way to able to manage the risk of a disaster is to estimate the areas which are potentially affected by landslides. This analysis can be done by using parameters that cause landslide by using remote sensing and GIS data.

The purpose of this paper is to map the distribution of landslide susceptibility area using remote sensing and GIS data. The first step involves identifying the parameters of the factor responsible for the occurrence of landslides. The second step estimates the score from each parameter based on single model from annual report of Indonesian Center for Agricultural Land Resources Research and Development (ICALRD, 2009). Then overlay data to evaluate the map based on landslide susceptibility area.

METHODS

North Luwu Regency has an area of 7502 km^2 and geographically North Luwu Regency located in South Sulawesi Province at coordinates between 20 ° 30'45 "to 2 ° 37'30" South Latitude and 119 ° 41'15 "to 12 ° 43'11" East longitude (Figure 1).

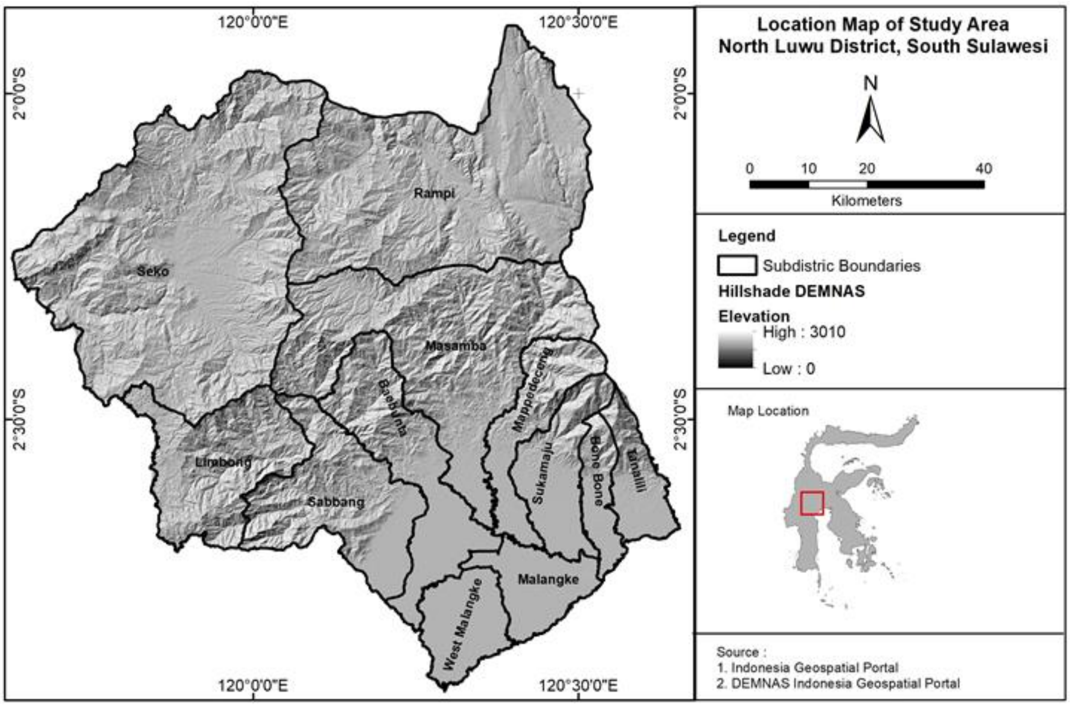

Figure 1. Location of the study area in North Luwu District, South Sulawesi Province.

Based on the Official Portal of North Luwu Regency, in the northern part of North Luwu is bordered by Central Sulawesi Province, the southern part is bordered by Bone Bay, the western part is bordered by Tanah Toraja Regency and West Sulawesi Province, and in the eastern part borders East Luwu Regency (Thamsi dkk, 2019). North Luwu District consists of 12 sub-districts, namely Seko, Rampi, Masamba, Baebunta, Sabbang, Limbong, Mappedeceng, Sukamaju, Bone-bone, Tanlili, Malangke, and West Malangke.

The remote sensing and GIS data may be used in detecting landslide features. The data which used in this study shown in Table 1. Six data used as parameters to estimate landslide susceptibility such as rainfall, rock type, land use, soil type, land movement, and slope.

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Table 1. Data used in this study area

No	Data	Source	Type
1	Rainfall (January-December 2019)	TRMM Rainfall Estimate L3 (https://disc.gsfc.nasa.gov/)	Raster Image
2	Rock Type	Geological Map of Malili Quadrangle Sulawesi	Vector Data
3	Land Use	Land Use Map of South Sulawesi from Ministry of Environment & Forestry, Scale 1: 250.000	Vector Data
4	Soil Type	Soil Type Map of Luwu Utara from Development of Agricultural Land Resources, Scale 1:50.000	Vector Data
5	Land Movement	Land Movement Map of South Sulawesi from Vulcanology and Geological Disaster Mitigation, ESDM.	Vector Data
6	Slope	DEM Nasional (DEMNAS) from Indonesia Geospatial Portal. Resolution 8 meter	Raster Image
7	North Luwu Administration Area	RBI Map of North Luwu From Indonesia Geospatial Portal, Scale 1:50.000	Vector Data

There are three techniques were employed to identify landslide features in the study area. The first technique was to overlay landslide parameters into digital maps. The second technique was to classify the images using ArcGIS software. The last technique was to overlay all parameters into one image. The spatial data used in this study consists of two types, namely raster data and vector data. The initial stage of processing is that each data must be made into a digital map. All data processing is carried out through the ArGIS 10.3 tool. The digital map is then used as a reference for this research data. The processing data for landslide susceptibility in this area shown on Figure 2.

Landslide susceptibility analysis is done after thematic maps are finished. The thematic maps are rainfall map, soil type map, rock type map, slope map, land movement map, and land use map. The Method used to analyze the landslide susceptibility estimation model refers to the Indonesian Center for Agricultural Land Resources Research and Development (ICALRD, 2009).

The parameters used in this model are rainfall, soil type, rock type, slope, land use, and land movement. Each parameter is classified according to the level of landslide sensitivity and given a score for each level. A score of 5 (five) shows a high sensitivity to susceptibility areas, and a score of 1 (one) shows a low sensitivity to susceptibility areas.

Based on Table 2, the parameters of rainfall have a weight of 20%, 25% weight for rock type, 10% weight for soil type, 20% weight for slope, 10 % weight for land use, and 15% weight for soil movement susceptibility. The total score calculation use ICALRD (Balai Besar Litbang Sumberdaya Lahan Pertanian (BBSDLP) 2009):

$$Total\ Score = 0.2\ RLF + 0.25\ RTF + 0.2\ SLF + 0.1\ LUF + 0.1\ STF + 0.15\ LMF \qquad (1)$$

Explanation:
RLF: Rainfall Score
RTF: Rock Type Score
SLF: Slope Score
LUF: Land Use Score
STF: Soil Type Score
LMF: Land Movement Score

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Table 2. Landslide scoring parameters by BBSDLLP 2009

Parameter	Class	Score	Factor Weight
Rainfall	Very Wet (>4000)	5	20 %
	Wet (3001-4000)	4	
	Medium Wet (2001-3000)	3	
	Dry (1001-2000)	2	
	Very Dry (<1000)	1	
Slope	> 45 %	5	20 %
	25 – 45 %	4	
	15 – 25 %	3	
	8 – 15 %	2	
	< 8 %	1	
Rock Type	Vulcanic	5	25 %
	Sediment	3	
	Alluvium	1	
Land Use	Tegalan, Rice Field	5	10 %
	Shrubs	4	
	Forest and Plantations	3	
	Settlement	2	
	Ponds, Body Water	1	
Soil Type Sensitive to Landslide	Highly Sensitive	5	10 %
	Sensitive	4	
	Medium Sensitive	3	
	Low Sensitive	2	
	Not Sensitive	1	
Land Movement Sensitive to Landslide	Highly Sensitive	5	15 %
	Sensitive	4	
	Medium Sensitive	3	
	Low Sensitive	2	
	River	1	

Source: (Balai Besar Litbang Sumberdaya Lahan Pertanian (BBSDLP) 2009)

The stages of landslide susceptibility mapping can be seen in the following figure (Figure 2).

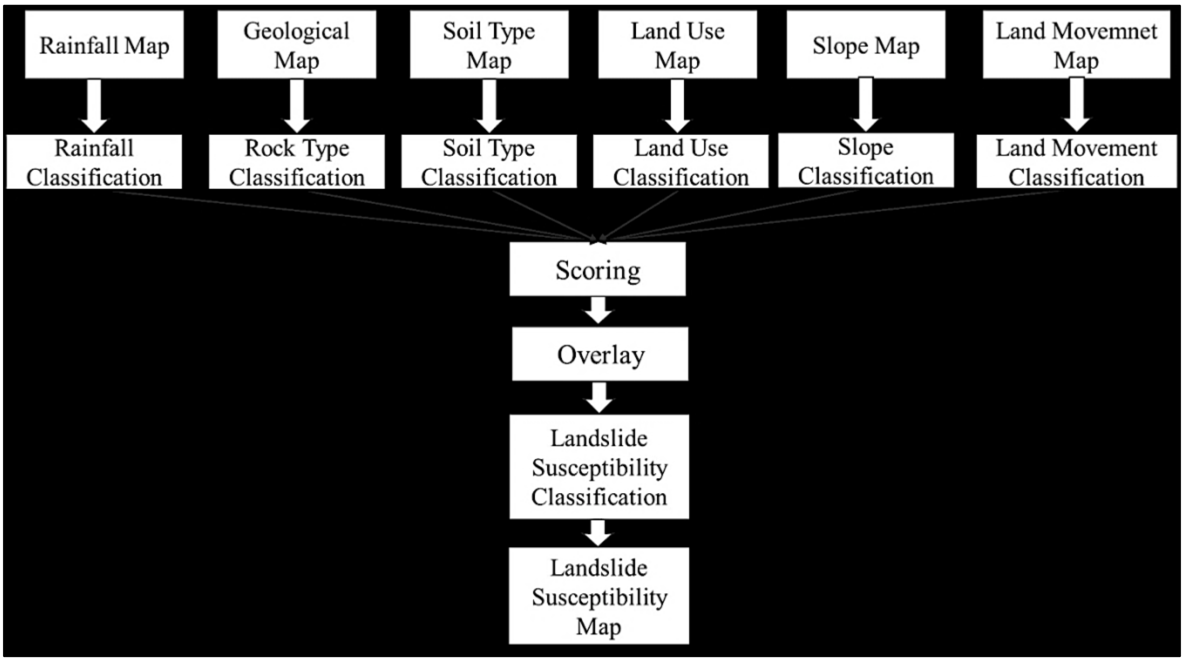

Figure 2. Steps of preparing the map for landslide susceptibility mapping

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RESULTS AND DISCUSSION

Rainfall

Rainfall data in the study area comes from TRMM (Tropical Rainfall Measuring Mission) Rainfall Estimate L3 satellite data. Rainfall data is focused on North Luwu district and then classified to produce a rainfall map in the study area. Based on the rainfall map in Figure 3, TRMM Rainfall Estimate data of North Luwu Regency has rainfall ranging from 985-3938 mm / year. Rainfall is divided into three classes, namely wet (3000-4000 mm/year), wet medium (2000-3000 mm/year), and dry (1000-2000 mm/year). Area has 3453.3 Ha or 0.4% belongs to the dry rain class, 579067.6 Ha or 80% area is the wet medium rain class, and 141291.3 Ha or 19.5% area is the wet rain class. Areas that have high rain intensity or wet class are Masamba, Baebunta, West Malengke, Malengke, Mappedeceng, Sukamaju, Bone-Bone, and Tanalili Districts. Then the areas that have low rain intensitiy or dry class are Seko, Rampi, Limbong, and Sabbang.

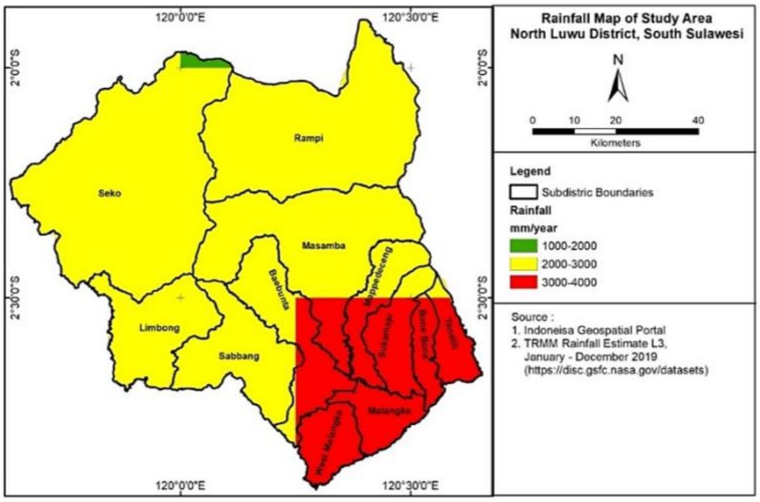

Figure 3. Rainfall map of study area

Rock Type

The rock types in the study area consist of alluvium, sediment, and Vulcanic. On the rock type map (Figure 4), The areas that have volcanic rock is 375 517.9 Ha or 52.3% of study area, sedimentary rock is 212001.7 Ha or 29.5% of study area, and alluvium rock is 129418.8 Ha, or 18% sedimentary rock is 212001.7 Ha or 29.5% of study area. The volcanic rock class is dominated by granite intrusion, and for the sedimentary rock class is dominated by limestone, clay, sandstone, and altered sedimentary rock, while the alluvium rock class is dominated by alluvium deposits.

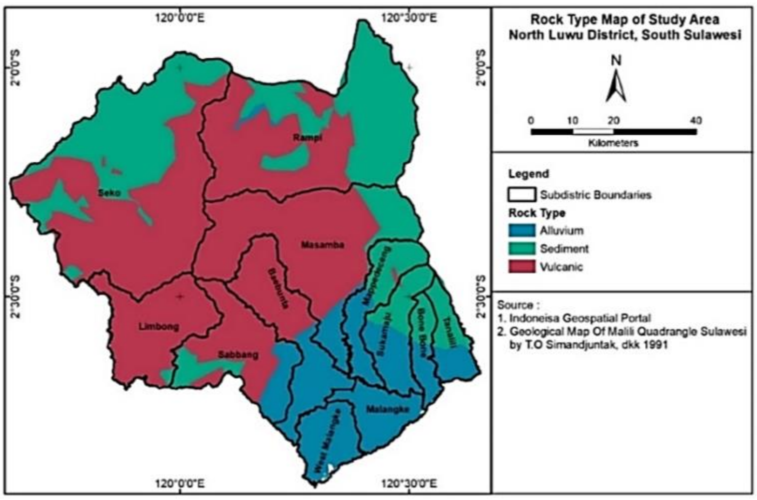

Figure 4. Rock type map of study area

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Soil Map

The soil type map shown in Figure 5 that the North Luwu area is composed of several types of soil such as alluvial, gleisoil, cambisol, oxisol, podzolic, and regosol. Based on the soil type map, the soil type that has the widest distribution area is cambisol which includes 528957 Ha (73% of study area), while the soil type that has the smallest distribution is Regosol 155 Ha (0.02% of study area) and Podzolic 11150 Ha (1.5% of study area).

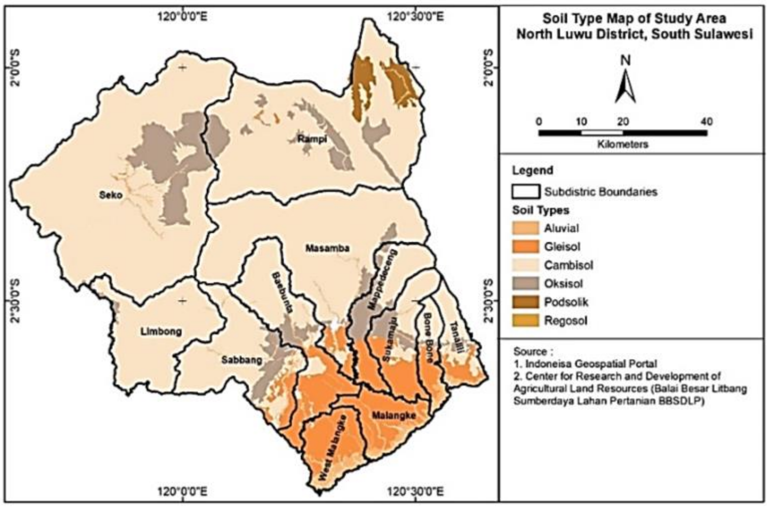

Figure 4. Soil type map of study area

Slope

The slope in the study area consists of 5 classes, such as flat (0-8% slope), gentle (8-15% slope), moderately steep (15-25% slope), steep (25-45% slope), and very steep (> 45% slope). The distribution of each slope class can be seen on the slope map (Figure 5). The slope in the study area is influenced by the varying altitude. In the northern of study area, which is yellow to red color of slope map, the altitude reaches more than 2500 meters above sea level which is in the top of the mountains in the southeast of the northern area, and in the central and southern of study area ranges from 2400-2600 meters above sea level which is shown in green color on the slope map. In general, the North Luwu region has a slope direction to the south so the rivers flow from mountainous areas in the north to the south.

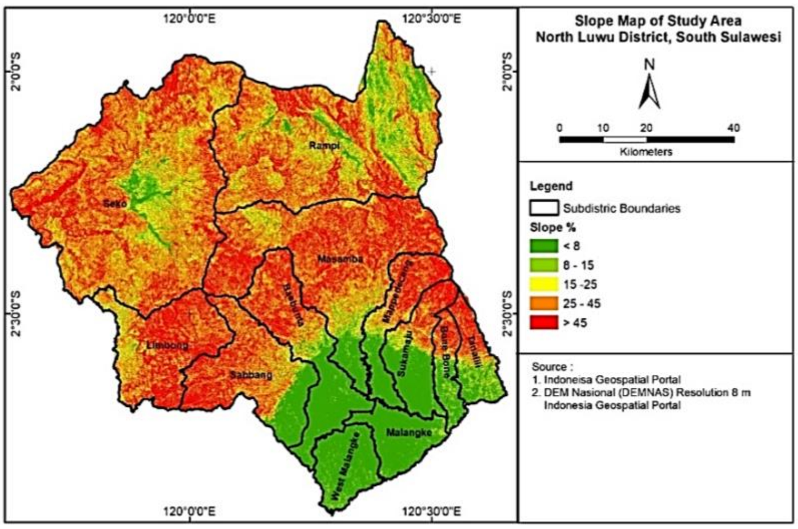

Figure 5. Slope map of study area

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Land Use

Land use in North Luwu is divided into twelve types, such as grove, swamp, primary dryland forest, secondary dryland forest, mangrove, settlement, farming, dryland farming, savanna, rife field, fishpond, and open area.

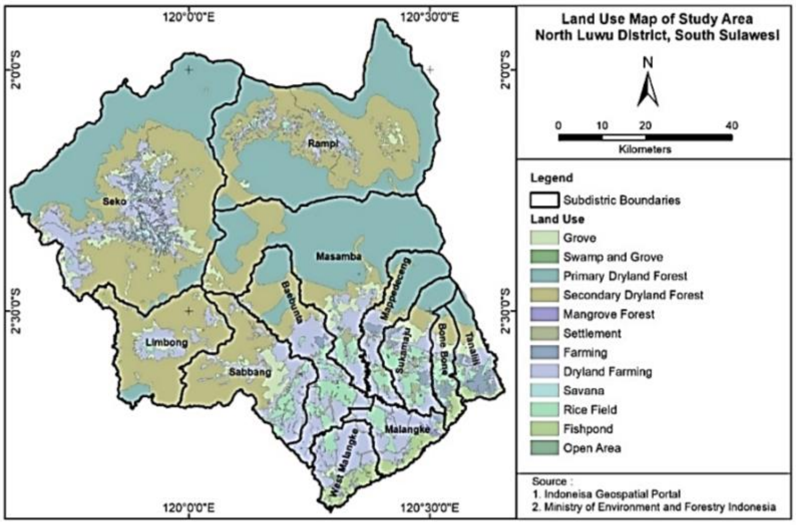

Figure 6. Land use map of study area

The land use type of primary dryland forest has an area of 246235 Ha (34% of the area of North Luwu) and the dryland forest has an area of 234286 Ha (32% of the area of North Luwu). The land use type of dryland farming has an area of 129080 Ha (17.8% of the total area of North Luwu) and other minor land use types have an area of 212 - 38154 Ha (0 - 5% of the area of North Luwu). The distribution of land use of study area shown in Figure 6.

Land Movement

Susceptibility of soil movement in the study area consists of four classes, such as very low susceptibility, low susceptibility, medium susceptibility, and high susceptibility. The medium susceptibility is the category with the widest area which is 473292 Ha (65% of the area of study area), the very low soil movement susceptibility zone has an area of 122881 Ha (16.9% of the area of study area), the high ground movement susceptibility is 103696 Ha (14% of the total area of study area), and the low ground movement susceptibility covers an area of 26161 Ha (3.6% of the area of study area).

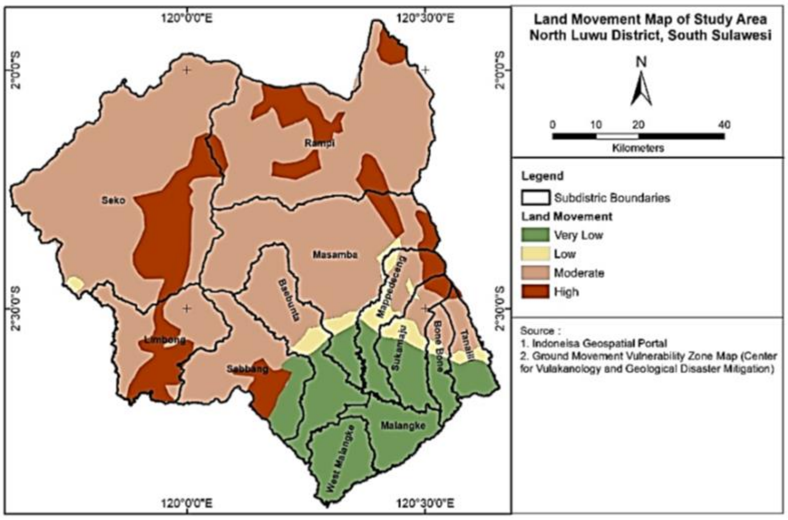

Figure 7. Land movement map of study area

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Landslide Susceptibility Analysis

The determination of landslide susceptibility areas was carried out using a model from the ICALRD (BBSDLP 2009). Based on the ICALRD model the parameters used to estimate landslide-prone areas are soil type, rock type, rainfall, land use, slope, and vulnerability to soil movement. The determination of landslide susceptibility areas is based on the total score obtained from the parameter score multiplied by the weight of the parameter of landslide susceptibility (Eq. 1).

The results of the analysis of six parameters using the ICALRD model obtained three criteria of landslide susceptibility, namely low, medium, and high. Landslide class intervals are made based on the average value and standard deviation of the total score (Eq. 1). The total score is divided into three classes of landslide susceptibility:

1. Low Susceptibility = Minimum Score – Low Susceptibility
2. Medium Susceptibility = Mean ± Standard Deviation (SD)
3. High Susceptibility = >Medium Susceptibility – High Score

The results of the analysis of the total score in study area obtained classification with the score intervals for each class:

Table 3. Total score classification

Susceptibility	Range Score
Low	1.65 – 2.4
Medium	2.4 – 4.1
High	4.1 – 4.65

The following figure shows the level of landsliding in the study area which is overall dominated by the medium level of landsliding (yellow colour) (Figure 8).

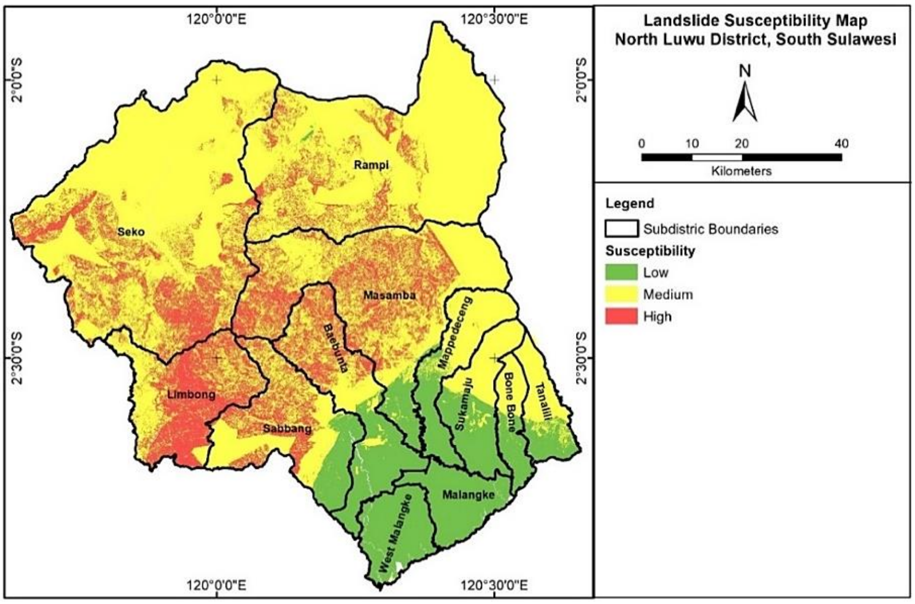

Figure 8. Landslide susceptibility map of study area

The analysis results of the total score can be obtained from the classification of landslide susceptibility classes with the score intervals of each level, where the higher the total score is the higher the landslide susceptibility level. Based on the landslide susceptibility level, the landslide susceptibility was mapped in the study area and the results of the landslide susceptibility map in the North Luwu Regency shown in Figure 8.

Based on the landslide susceptibility map in the North Luwu, the Low-Medium landslide susceptibility level covers 6 districts, and the Medium-High landslide susceptibility level covers 6 districts (see Table 4).

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Table 4. Landslide susceptibility level of study area

Districts	Landslide
Seko	Medium-High
Rampi	Medium-High
Masamba	Medium-High
Baebunta	Medium-High
Sabbang	Medium-High
Limbong	Medium-High
Mappedeceng	Low-Medium
Sukamaju	Low-Medium
Bone-Bone	Low-Medium
Tanalili	Low-Medium
Malangke	Low-Medium
West Malangke	Low-Medium

The ICALRD model shows that the parameter that has the most influence on the occurrence of landslides is the type of rock, so that the weight factor for type rock value is higher than other parameters. On the landslide susceptibility map, there are six sub-districts that have medium-high levels, such as Seko, Rampi, Masamba, Baebunta, Sabbang, and Limbong.

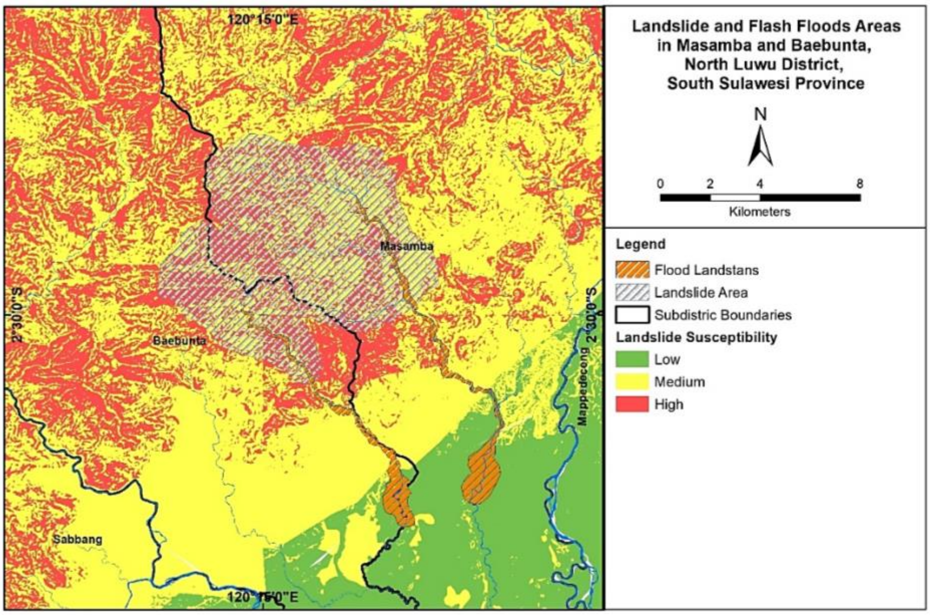

Figure 9. Landslide and flash floods area in Masamba and Baebunta

The flash flood disaster occurred in North Luwu Regency on Tuesday, July 14, 2020, it shows that there have been land movements and flash floods in Masamba, Sabbang, Baebunta, and Malangke. The disasters that occurred were flash floods or overflows of water due to the Masamba river, landslides in the upstream part, and lateral erosion along the channel in which they passed were triggered by high rainfall with long intensity. The location of the disaster has a high level of landslide susceptibility. Masamba, Sabbang, and Baebunta are areas that have the potential for landslides because they are very steep slope areas with high rainfall and cambisol soil. The location of the disaster is plotted on a landslide susceptibility map based on the ICALRD model and showed compatibility with a high level of susceptibility (Figure 9).

CONCLUSION

Landslide susceptibility mapping in tropical mountainous areas is usually difficult because of vegetation and cloudy weather situations. This research included three main stages including analysis of landslide inventories, susceptibility mapping, and validation. The conclusion based on the ICALRD in study area shown that there are three classes of landslide susceptibility, namely Low, Medium, and

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High susceptibilities. There are six subdistricts which are in medium to high landslide susceptibility, and the others are low to medium landslide susceptibility. The locations of landslides and flash floods that occurred in Masamba and Baebunta indicate areas with medium to high landslide susceptibility. Landslide types are very diverse, and cosenquently landslide susceptibility assessment can only be carried out with certain landslide model. Therefore, the determination of dominant landslide types and selection of appropriate suitable landslide models for landslide susceptibility mapping is difficult and will strongly influence the final landslide susceptibility map.

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