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MODELING OF LANDSLIDE SUSCEPTIBILITY IN THE CORE ZONE OF THE LORE LINDU BIOSPHERE RESERVE USING GIS

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ABSTRACT

Landslide is a very dangerous natural disaster and often occurs in many hilly or mountainous areas, it often occurs without warning and causes loss of life and property, marked by the displacement of slope-forming material in the form of rocks, soil, or material down the slope. This study aims to model landslide-prone areas in the core zone of the Lore Lindu biosphere reserve in Central Sulawesi Province using the overlay method with a score between 6 parameters. The research parameters included land cover/use, rainfall, elevation, slope, soil type, and lithology. The weighting analysis produces three variables that determine the level of landslide vulnerability: slope, land use, and rainfall. The results showed that the level of vulnerability to landslides in the study area was divided into 4 classes, namely 17.482,15 ha (8,10%) non-prone areas, 98.372,96 ha (45,60%) low vulnerability areas, 98.032,51 ha (45,45%). moderate hazard area, and 1.832,04 ha (0,85%) high hazard area. In high vulnerability zones small or large-scale landslides often occur due to high rainfall and steep to very steep slopes, the rock forms in the form of sediment. Vegetation conditions are generally lacking. The areas included in this class are the villages of Bulili, Lawua, Sedoa, Katu, and Karunia.

Keywords: *Geographic Information System; Landslide Susceptibility; Scoring; Modeling; Lore Lindu Biosphere Reserve*

INTRODUCTION

The establishment of biosphere reserve areas in the Man and the Biosphere Program by UNESCO has the main objective of achieving a balance between biodiversity conservation and sustainable development. These nature reserves function as areas designated as places for the protection and preservation of the natural environment and support activities that contribute to the welfare of local communities. (Xu et al., 2019).

The establishment of biosphere reserves under UNESCO's Man and the Biosphere Programme has the main objective of achieving a balance between biodiversity conservation and sustainable development (Van Cuong et al., 2017). These nature reserves serve as designated areas where efforts are made to protect and preserve the natural environment while encouraging activities that contribute to the well-being of local communities. (Van Cuong et al., 2017).

Lore Lindu National Park has an important role as a conservation area with important values such as endemic wildlife protection, water management, cultural and historical values, representation of the Sulawesi mountain rainforest ecosystem, local community wisdom values, and landscape compactness. Until now, the area of Lore Lindu National Park continues to change. Based on the Regulation of the Minister of Forestry Number 869/Menhut-II/2014 concerning Forest Areas and Water Conservation in Central Sulawesi Province, the area is recorded as reaching 215,733.70 ha (Suni et al., 2024)

Indonesia is a country prone to natural disasters because it is located in an active tectonically and volcanically active region due to the meeting of three tectonic plates, namely the Indian-Australian, Pacific, and Eurasian plates. One of the natural disasters that often occurs in Indonesia is flooding. (Sigit et al., 2011).

The territory of Indonesia is basically in a disaster-prone zone. There is not a single district or sub-district in Indonesia that is free from the threat of disaster. Whether in the form of earthquakes, landslides, floods, or a combination of all of them which are commonly called multi-disasters. Good regional planning is needed by considering various aspects, especially disasters, to overcome the impact of disasters and mitigation so that the number of losses and fatalities due to disasters can be minimized. (Ketut et al., 2023).

The occurrence of landslides depends on local terrain conditions and is controlled by geological and geomorphological processes. However, landslides can be triggered on unstable slopes by external factors such as heavy rainfall, earthquakes, floods, snowmelt, river erosion, changes in groundwater levels, volcanic eruptions, or a combination of these natural factors (Fadli et al., 2023). The frequency, magnitude, and volume of landslides are expected to increase due to both internal and external factors. In addition, the frequency and magnitude of landslides are increasing due to extreme climates in fragile hilly, or mountainous areas. Despite this fact, many countries in the world are facing large-scale human tragedies, material damage, and economic losses due to landslides (Promper et al., 2014).

Some symptoms that can be observed visually include the appearance of cracks on slopes that are parallel to the direction of the cliff, buildings that are starting to look cracked, trees or electricity poles that are leaning, and the appearance of new springs (Kinanti et al., 2023). Geographic Information Systems (GIS) are tools/instruments that can be used to process, analyze, and make decisions in determining vulnerable zones in an area using a parameter approach (Suni et al., 2023). Landslides can occur due to natural faults and weather factors in soil and rocks, especially in areas with humid and hot climates. Other causes of landslides are human activities, such as illegal logging, logging that causes slope instability, changes in slope steepness, excessive building loads in hilly areas, and so on (Kurniawan, 2019).

Based on the triggering factors for landslides, the area around the core zone of the Lore Lindu biosphere reserve is an area that has the potential for landslides. One of the methods used to predict landslide hazards is the remote sensing method integrated with the Geographic Information System (GIS). This study aims to examine the model and distribution of landslide vulnerability levels in the core zone of the Lore Lindu biosphere reserve based on Geographic Information.

METHOD

This research was conducted from August to December 2023, located in the core zone of the Lore Lindu biosphere reserve as shown in Figure 1. The tools used in this study were stationary, camera, a compass, GPS (Global Positioning System), laptop equipped with the ArcGIS version 10.8 program used to operate, manage maps, and analyze field data. The materials used in implementing this research were a 1:50,000 scale Indonesian topographic map (RBI) sourced from the Geospatial Information Agency (BIG), National Digital Elevation Model (DEMNAS) data from the Geospatial Information Agency (BIG), Lore Lindu Biosphere Reserve Boundaries, Sentinel-2A imagery recorded in January 2022 sourced from USGS, Thematic Map of the Central Sulawesi Provincial Spatial Plan 2013-2033 and Rainfall Data for the last 5 years from BMKG.

The method used in processing this research data is overlay by providing scoring and weighting on landslide-prone parameters. Assessment and determination of scoring and weighting with the expert judgment method, namely expert opinion. The parameters used include slope, rainfall, land use, elevation, soil type, and lithology (Table 1).

Qualitative scoring determination is guided by several research results on landslide susceptibility through the classification of landslide-causing parameters. The landslide susceptibility value is obtained from the total score and weight of the 6 parameters used in this study, namely slope gradient, rainfall, land use, elevation, soil type, and lithology. The determination of the level of landslide susceptibility is carried out using the multiplication of the arithmetic parameter model with the formula (Kusumo & Nursari, 2016; Wahid et al., 2021):

$$\mathrm{B} = 20\mathrm{r} + 20\mathrm{lu} + 10\mathrm{st} + 10\mathrm{e} + 25\mathrm{s} + 15\mathrm{l}$$

Information:

B	= Landslide susceptibility	lu	= Land use
st	= Soil type	l	= Lithology
r	= Rainfall	s	= Slope
e	= Elevation		

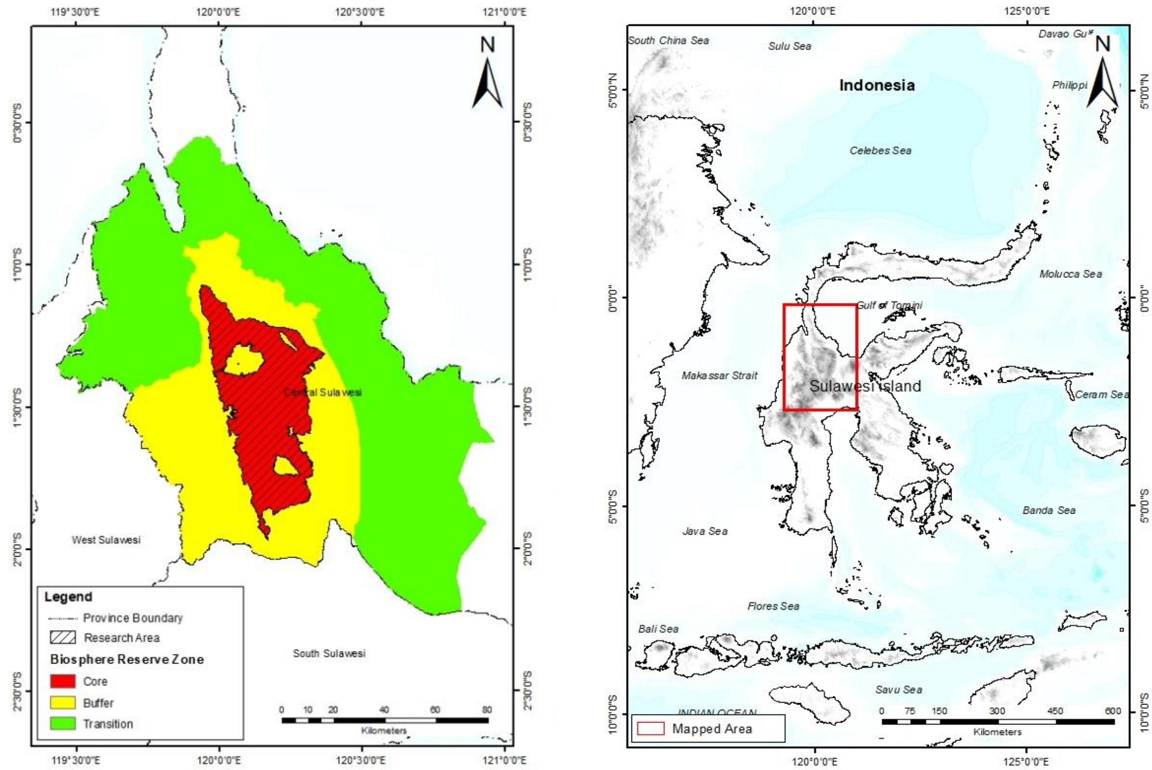


Figure 1. *Research Location in the Core Zone of the Lore Lindu Biosphere Reserve*

Threat modeling can be done using overlays (Faizana et al., 2015). Geographic Information Systems can be used to map landslide areas (Rahmad et al., 2018), Several methods can be used in Geographic Information Systems (GIS), one of which is the weighting method. This method is a spatial analysis that includes several maps related to factors that influence vulnerability. (Akbar et al., 2020). Classification to classify landslide hazard classes or landslide vulnerability class intervals is calculated using the interval class obtained based on calculations using the following formula. (Reppi et al., 2021 ; Suni et al., 2023).

$$I = R/K$$

Information:
I = class intervals
R = range/range of highest values and lowest values
K = number of class intervals

Landslide susceptibility values are obtained from the total score of six parameters used in this study, namely rainfall, slope gradient, elevation, soil type, land use, and lithology. Accuracy calculations are carried out by comparing the analysis data with the results of field inspections. The accuracy test aims to see the analysis error so that the percentage of accuracy can be determined. Commission error is a classification error in the form of an excess number of pixels in one class due to the inclusion of pixels from other classes. The level of mapping accuracy is determined using a classification accuracy test that refers to (Hanifa & Suwardi, 2023) with the formula:

$$MA = (Xcr\ piksel)/(Xcr\ piksel + Xo\ piksel + Xco\ piksel) * 100\%$$

Information:
MA = mapping accuracy
Xcr = corrected number of class X
Xo = number of class X included in another class
Xco = number of additional class X from another class

Table 1. Scores and Weights of Landslide Susceptibility Parameters

Parameter	Class	Score	Weight
Slope	> 45%	9	25
	25 - 45%	7	
	15 – 25%	5	
	8 - 15%	3	
	0 - 8%	1	
Soil type	Vertisol, oxisol	9	10
	Alfisol, Ultisol, Molisol	7	
	Inceptisol	5	
	Entisol, Histosol	3	
	Spodosol, Andisol	1	
Lans use	Mining	9	20
	Rice fields	9	
	Open land	9	
	Dryland farming	7	
	Mixed dryland agriculture	7	
	Swamp Bush	7	
	Shrubs	7	
	Savannah	7	
	Settlement	5	
	Swamp	5	
	Plantation	5	
	Secondary swamp forest	5	
	Secondary dryland forest	3	
	Primary dryland forest	3	
	Waterbody	1	
Elevation	>2000 masl	9	10
	1500 – 2000 masl	7	
	1000 – 1500 masl	5	
	500 – 1000 masl	3	
	0 – 500 masl	1	
Rainfall	> 3000 mm/years	9	20
	2500 – 3000 mm/years	7	
	2000 – 2500 mm/years	5	

Parameter	Class	Score	Weight
	1500 – 2000 mm/years	3	
	< 1500 mm/years	1	
Lithology	Metamorphic	9	15
	Igneous Rocks	7	
	Volcanic	5	
	Sediment	3	
	Alluvial	1	

Source: (Nugroho et al., 2010;Sholikhan et al., 2019;Eraku et al., 2019;Krisnandi et al., 2021;Suni et al., 2023;Hanifa & Suwardi, 2023)

RESULTS and DISCUSSION

Landslide Susceptibility Parameters

Mapping of landslide vulnerability and risk in the TNLL buffer village was obtained through scoring and weighting results for 6 (six) landslide parameters. Scoring is based on the influence of class on the event. The greater the influence on the event, the higher the value. Scoring is intended as a value assignment for each class in each parameter (Nurlina et al, 2017).

1) Land Use

Land Use Map was obtained from the analysis of Sentinel-2A Imagery in 2023. Based on the classification results, 15 land use classes were obtained, namely primary dryland forest, secondary dryland forest, secondary swamp forest, dryland agriculture, mixed dryland agriculture, plantations, rice fields, shrubs, shrubs, swamps, settlements, open land, mining, savanna/grassland and water bodies (Figure 2).

Land use will have a major impact on the height of landslides. Heterogeneous forests that are not sensitive to erosion, homogeneous forests that are less sensitive to erosion, agricultural land that is somewhat sensitive to erosion, occupation and rice fields that are sensitive to erosion, then dry fields and open land that are very sensitive to erosion. Changes in land use or conversion of the main function of forest land to non-forest can damage groundwater sedimentation which can cause more sensitive landslides to occur (Eraku et al., 2019 ; Suni et al., 2023).

Table 2. Land Use Class

Class	Area (ha)	Percentage
Primary dryland forest	21.916,40	10,16
Secondary dryland forest	173.876,40	80,60
Secondary swamp forest	274,49	0,13
Settlement	16,81	0,01
Plantation	13.934,34	6,46
Rice fields	30,62	0,01
Mining	15,80	0,01
Dryland farming	604,45	0,28
Mixed dryland agriculture	702,75	0,33
Swamp	112,44	0,05

Savannah	1.618,83	0,75
Shrubs	1.674,95	0,78
Swamp bush	141,14	0,07
Open land	630,35	0,29
Water	169,89	0,08
Total Area	**215.719,65**	**100**

2) Elevation

The land elevation/height map is obtained from Digital Elevation Model (DEMNAS) data processing. From the results of the analysis obtained 5 altitude classes in in meters above sea level, <500 masl, 1000-1500 masl, 1500-2000 masl, 2000-2500 masl, 2500-3000 masl, and > 3000 masl (Figure 2). The elevation parameter results in a greater gravitational force affecting the material on the slope. Elevation also plays a role in the high potential for landslides, the higher an area, the greater the chance of landslides.

Table 3. Elevation Class

Class	Area (ha)	Percentage
100 - 500 masl	2.935,06	1,36
500 - 1000 masl	32.807,36	15,21
1000 - 1500 masl	110.309,56	51,14
1500 - 2000 masl	64.054,47	29,69
>2000 masl	5.613,21	2,60
Total Area	**215.719,65**	**100**

3) Slope

Slope Map obtained from Digital Elevation Model (DEMNAS) data processing. From the results of the analysis obtained 5 classes of slope. It is classified using the percentage of slope0-8 % is categorized as flat class, 9-15 % is categorized as Sloping class, 16-25 % is categorized as rather steep, 26-45 % is categorized as steep, and >45 % is categorized as very steep. (Figure 2).

The slope parameter also plays a role in the potential height of landslides, the steeper the slope, the higher the potential for landslides. This means that the lower (slope) a slope is, the smaller the possibility of a landslide. Areas with a large slope will cause the downward force acting on the slope to increase, so that the slope has a large role in the occurrence of landslides, such as in the research area with a slope of > 45% which is included in the very steep high category. (Krisnandi et al., 2021).

Table 4. Slope Class

Class	Area (ha)	Percentage
0 - 8%	14.645,75	6,79
8 - 15%	26.715,03	12,38
15 - 25%	30.792,77	14,27
25 - 45%	50.193,88	23,27
> 45%	93.372,22	43,28
Total Area	**215.719,65**	**100**

4) Rainfall

The rainfall map is obtained from the processing of rainfall data for the last five years using the Inverse Distance Weighting (IDW) interpolation method. According to Erfani et al., (2023) absorbed rainwater saturates the soil and can weaken slope-forming materials and trigger landslides. Heavy rainfall and its intensity increase the risk of landslides.

From the analysis of rainfall data, it is divided into 5 classes, <1500 mm/year, 1500-2000 mm/year, 2000-2500 mm/year, 2500-3000 mm/year and > 3000 mm/year (Figure 2). Rainfall is one of the determining factors for the potential level of landslide hazard in the study area. The higher the rainfall value, the possibility that the area is an area that has the highest potential for landslides (Krisnandi et al., 2021).

Table 5. Rainfall Class

Class	Area (ha)	Percentage
<1500 mm/years	47.612,66	22,07
1500-2000 mm/years	80.024,45	37,10
2000-2500 mm/years	74.408,38	34,49
2500-3000 mm/years	13.674,16	6,34
Total Area	**215.719,65**	**100**

5) Soil Type

Knowledge of this soil type is very important in determining the possibility of landslides caused by different soil types. This is because they have different physical and chemical properties, such as water absorption, slope stability, and mineral content. Soil Texture Maps are obtained by processing soil type data which is then classified based on the National Soil Classification with the 2014 Soil Taxonomy (Subardja et al., 2014). From the results of the classification, there are 3 types of soil namely, ultisols, entisols, and inceptisols (Figure 2).

Table 6. Soil Type Class

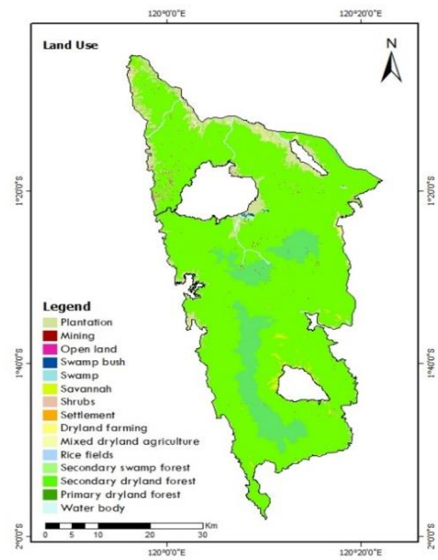
Class	Area (ha)	Percentage
Entisols	9.314,05	4,32
Inceptisols	42.492,18	19,70
Ultisols	163.913,42	75,98
Total Area	**215.719,65**	**100**

6) Lithology

Knowledge of these rock types is very important in determining the likelihood of landslides caused by rock types with different physical and chemical properties. In terms of lithology, the study site is divided into 3 main rock classes, igneous, volcanic, and sedimentary. Most of its area consists of igneous and sedimentary rocks. Complete rock types can be seen in (Figure 2).

Table 7. Lithology Class

Class	Area (ha)	Percentage
Igneous Rocks	142.795,61	66,19
Volcanic	5.998,33	2,78
Sediment	66.925,72	31,03
Total Area	**215.719,65**	**100**



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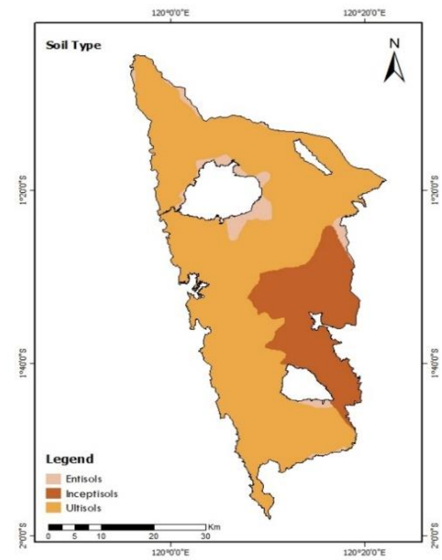

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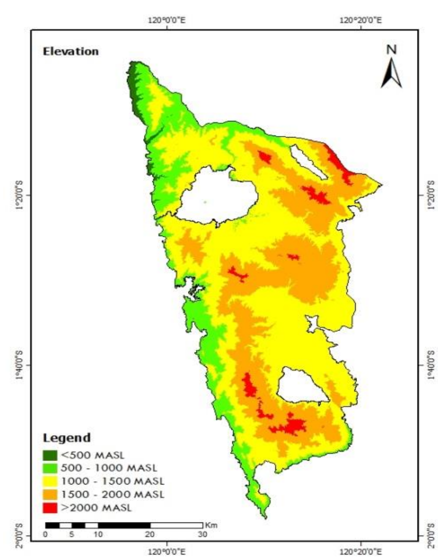

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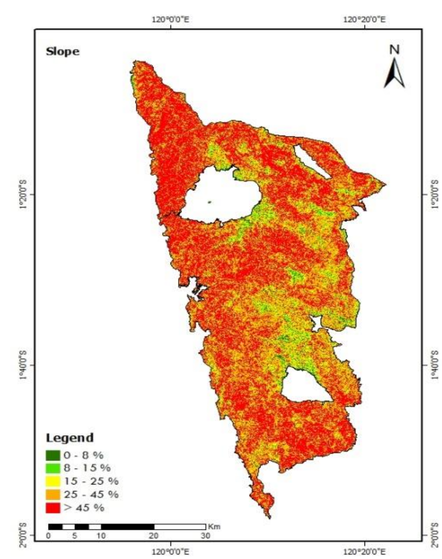

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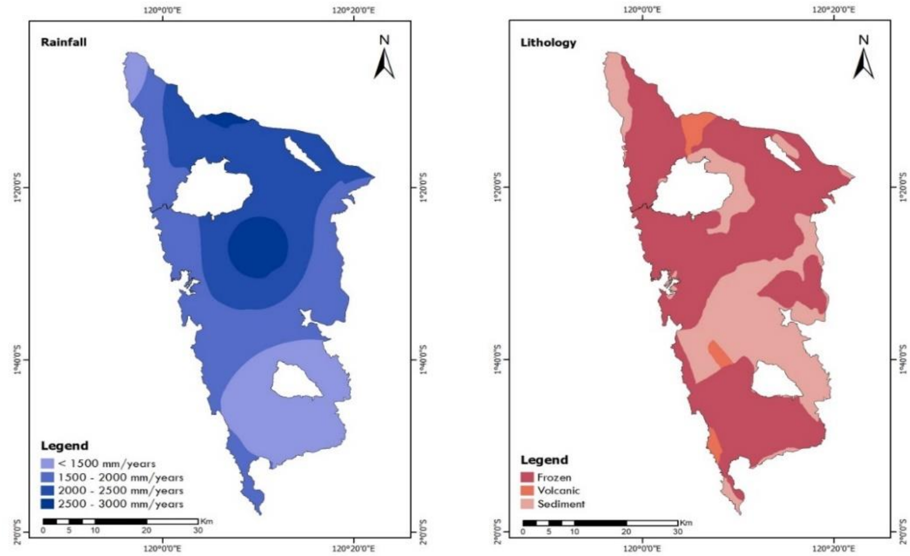

e. f.

Figure 2. Landslide Susceptibility Parameters (a. Land Use, b. Soil Type, c. Elevation, d. Slope Slope, e. Rainfall, f. Lithology)

Classification of Landslide Susceptibility Level

Threat modeling can be done using overlays (Faizana et al., 2015). Geographic Information Systems can be used to map landslide areas (Rahmad et al., 2018), several methods can be used in a Geographic Information System (GIS), one of which is the weighting method. This method is a spatial analysis that includes several maps related to factors that influence vulnerability (Akbar et al., 2020).

Based on the results of the calculation of the hazard value, the landslide hazard class can be determined in the study area by dividing the landslide hazard into four classes, namely non-prone, low-moderate, and high-risk. The classification of landslide hazard classes is presented in (Table 8).

Table 8. Landslide Susceptibility Level

Susceptibility level	Value	Area (ha)	Percentage (%)
Not prone	230-360	17.482,15	8,10
Low	361-490	98.372,96	45,60
Moderate	491-620	98.032,51	45,45
High	621-750	1.832,04	0,85
Total Area		**215.719,65**	**100**

The results of the analysis carried out show that areas that are highly prone to landslides are areas that have a value of 621 – 750, the medium class has a value of 491 – 620, the low class has a value of 361 – 490, and is not prone to have a value of 230 – 360 from the sum of the parameter scores. Based on the results of tracing the points of the landslides that occurred in several villages, the landslides were caused by steep to very steep slope conditions, and land use dominated by shrubs. Topographically, the Lore Lindu biosphere reserve is dominated by steep to very steep slopes and relatively high rainfall. Aditama et al., (2020) stated that the high vulnerability to landslides is caused by moderate to very steep slopes (25-49%) which results in greater gravitational forces acting on the material on the slopes. The landslide vulnerability map can be seen in Figure 3.

Accuracy Test and Validation

Based on Table 9, it is known that the largest commission error is found in digitized areas with a low and moderate level of vulnerability, 12%, and the smallest commission error is found in digitized areas with a non prone and high level of vulnerability, 9%. Meanwhile, the largest commission error is at a moderate vulnerability level of 13,88% and the smallest commission error is at a non prone level of 9%. The highest mapping accuracy was found in digitizing areas with a non prone and high level of vulnerability, 84%, while the lowest mapping accuracy was found in digitizing areas with a low level of vulnerability, 80%. Overall the accuracy of landslide hazard mapping is 82,50%. Aellera menjelaskan, hasil akurasi sebesar 85% dinilai sangat memuaskan. Sedangkan Susanto menjelaskan kriteria ketepatan pemeringkatan sebagai berikut 80% (sangat baik) dan 60-70% (baik) (Akhbar et al., 2013).

Table 9. Results of Landslide Susceptibility Map Accuracy Test

Classification Results	Field Data				Column Total	Commission Error (%)		Map Accuracy	Overall Accuracy
	A	B	C	D		Field Data	Classification		
A	42	4	3	1	50	9	9	84	82,50
B	5	40	3	2	50	12	13,88	80	
C	2	4	41	3	50	12	13,84	82	
D	1	3	4	42	50	9	9,25	84	
Rows Total	50	51	51	48	200				

Information :

A = Non Prone, B = low, C = moderate, D = high

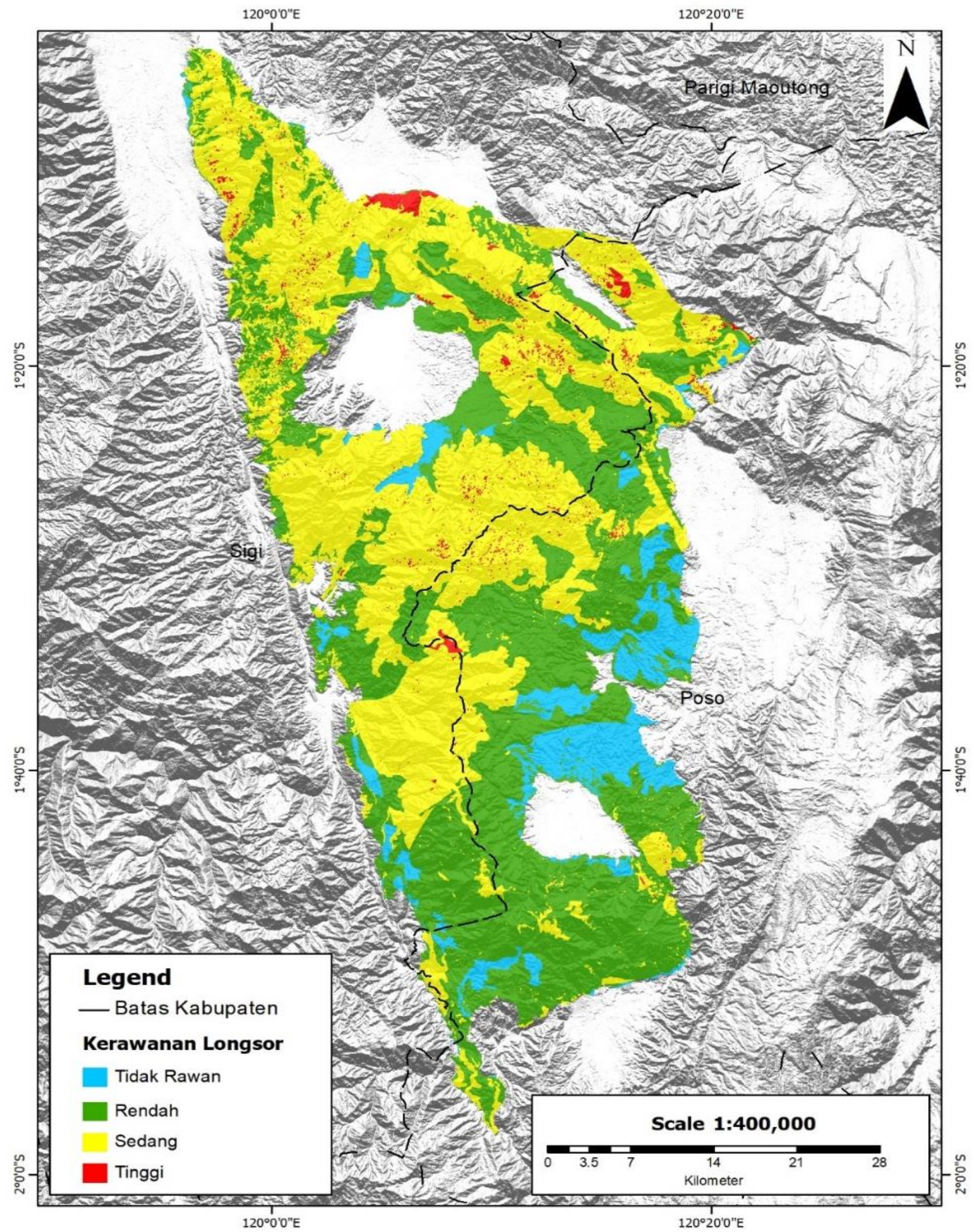

Figure 3. Landslide Susceptibility Model Map

Landslide Susceptibility Zone

a) Non-prone zone

The zone that is not prone to landslides is an area that is safe from the potential or possibility of landslides. This is because this zone has a slope that is gentle to flat, with land use dominated by forest or lots of vegetation, and is in the lowlands, with good soil types and low rainfall so that surface runoff can absorb quickly and not inundate this area. The areas included in this class are the villages of Baliura, Torire, Wanga, and Watutau.

b) Low susceptibility class

Areas included in this class have a low level of vulnerability to landslides and are quite safe against the potential or possibility of landslides. In general, failure occurs rarely in this zone if the slope is undisturbed and, if prolonged failure occurs, the slope is stable. Minor landslides may occur, especially on the banks of river valleys (channels). This zone is an area dominated by slopes with a slope of 8% to 15% (flat). In this low-class zone, areas on flat slopes are dominated by volcanic rocks, with latosol soil types, and mostly overgrown with secondary dryland forest. The areas included in this class are the villages of Moa, Tomado, Kolori, and Watutau.

c) Moderate susceptibility class

Areas included in this class are areas that have a moderate level of landslide vulnerability. In this zone, small or large landslides can occur, especially in areas bordering river valleys, hydrological transition areas, or road cliffs. Old landslides can be active again, especially due to prolonged high-intensity rains. In general, this moderate class zone is a rather steep zone with slopes of 15-25% to steep slopes of 15-40% which is dominated by sedimentary rocks, podzolic soil types, and mostly overgrown with shrubs and savanna. The areas included in this class are parts of the villages of Langko, Sedoa, Tomado, and Toro.

d) High susceptibility class

Areas included in this class are areas that have a high level of landslide vulnerability. In this zone, small and large-scale landslides often occur, mainly caused by high rainfall intensity and zones with slopes of 25-40% to very steep or more than 40%, depending on the condition of the physical properties of the soil and forming rocks in the form of sediment. Vegetation conditions are generally lacking or in the form of open land, shrubs, and dry land agriculture mixed with shrubs. The areas included in this class are the villages of Bulili, Lawua, Sedoa, Katu, and Karunia.

This is in line with research results According to Triwahyuni et al., (2017), slope is one of the factors that influence the occurrence of landslides in an area. The high vulnerability of landslides in this area is caused by the moderate to very steep slope (25-49%) which results in a greater gravitational force acting on the material on the slope. In general, this area is in the form of shrubs and dry fields (Aditama et al., 2020). (Hanifa & Suwardi, 2023) their research stated that the high level of landslide vulnerability is influenced by high rainfall intensity in the long term strong lateral erosion and very steep slopes.

Landslide Mitigation Guidelines

The government together with related stakeholders implements various programs to prevent landslides in the surrounding area. Mitigation is generally defined as all actions taken before a disaster occurs that aim to minimize losses due to the disaster. Setiawan, (2017) divides disaster mitigation activities into two, namely structural and non-structural.

a) Non-structural mitigation

Conducting dissemination of landslide disasters using posters or films, conducting simple mapping and identification of communities and houses that are included in the high vulnerability level, and carrying out rehabilitation in open areas and steep slopes.

b) Structural mitigation

Building a landslide early warning system (EWS) and installing ground movement monitoring devices, building roads with concrete construction, wire gabions, building water channels and strengthening slopes on the right and left sides of the road with concrete materials, building health posts in landslide-prone locations, installing information boards and landslide warnings at important points and in areas prone to landslides.

CONCLUSION

The results showed that the level of vulnerability to landslides was divided into 4 classes, namely non-prone area of 17,482.15 ha (8.10%), low vulnerability area of 98,372.96 ha (45.60%), moderate vulnerability area of 98,032.51 ha (45.45%), and high vulnerability area of 1,832.04 ha (0.85%). Villages that do not have a high level of landslide vulnerability are the villages of Baliura, Torire, Wanga, and Watutau. Meanwhile, villages that have a high level of vulnerability are Bulili, Lawua, Sedoa, Katu, and Karunia. Based on the factors that cause landslides, the high level of vulnerability is influenced by relatively high rainfall intensity, land class (dry land agriculture mixed with shrubs, shrubs, open land), slope (steep to very steep), soil type (ultisols) and the rocks that form it. Overall the accuracy of model landslide hazard mapping is 82,50%.

The results of this study are expected to assist in disaster mitigation efforts and disaster mitigation-based spatial planning. For managers as a reference in making policies for pattern development and regional spatial planning. Other erosion susceptibility analysis methods should be compared with this study for further improvement.

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