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## Landslide susceptibility mapping along road corridors in west Sulawesi using GIS-AHP models

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**Abstract.** Landslide susceptibility mapping (LSM) along road corridors is a fundamental tool for road planners and transportation decision-makers in determining the severity of slope failure areas, and in planning effective landslide prevention strategies. The accuracy of LSM relies on sufficient spatial database from the data of relevant landslide contributing factors. However, for roads located in remote areas in the Eastern Part of Indonesia, the database remains poor, leading to difficulty in mapping landslide prone areas. This study presents a framework of LSM along road corridors in the area with a limited database. The framework comprises identification and classification of several landslide contributing factors including slope angle, the distance of slope to the road, the distance of drainage to the road, the distance of faults to the road, lithology where road located, and precipitation on the area. These factors are weighted based on causative relation to landslide occurrence by using the analytical hierarchy process (AHP), then converted into the grid in a raster map by using Arc-GIS. The maps are then overlaid to generate landslide susceptibility ratings over the area. The LSM framework is tested in a landslide-prone area along road corridors of Polewali – Malabo, West Sulawesi Indonesia. The accuracy of the obtained LSM is evaluated with R-index, which is the index of how closed predicted slide area in the LSM and real slide area in the field obtained from landslide inventory undertaken during the field survey. It is found that R-index of the LSM is 91.3%, indicating a better prediction of landslide hazard with the LSM framework. The framework of LSM for road corridors would be useful for landslide hazard mitigation in the road infrastructure of developing countries.

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### 1. Introduction

Landslide is a geological hazard that causes significant damage to road infrastructures in Indonesia. Landslide occurrence comprises 18% of the occurrence of all natural hazards in the country, leading to the hazard becoming the third common natural hazard after flood and hurricane [1]. A landslide can temporarily disconnect road networks for at least a week, up to a month, causing a significant impact on the economic system in the region. Landslide hazards must be assessed and managed with accurate information on landslide occurrence [2]. The main objective of landslide hazard assessment is to provide accurate landslide susceptibility mapping (LSM) that can be used by the governmental department, private and public sectors, and scientific community [3]. LSM, particularly for road infrastructure, is fundamental for road planners and transportation decision making to plan a priority of the area along road corridors requiring landslide countermeasures within the effective cost allocated budget.



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LSM can be undertaken with landslide zonation. This means the process of dividing the land surface into areas and ranking of the areas based on the degree of hazard from landslide [4]. Several approaches of landslide zonation have been extensively developed, such as inventory based on zoning, heuristic approach, probabilistic assessment, deterministic approach, statistical analysis, and multi-criteria decision analysis approach [5]. A well-established framework used for tropical environment, GIS-based mathematical model, and remote sensing [6]. For the area with the poor database, however, their structure requires such modifications. Therefore, in this study, newly framework of LSM is proposed application on landslide areas, particularly along road corridors, with the use of GIS and the analytical hierarchy process (AHP). The accuracy of the proposed LSM framework was evaluated by conducting a case study of LSM for road corridor from Polewali to Malabo in the Province of West Sulawesi, Indonesia.

## 2. A new framework of landslide susceptibility mapping for road corridors

The first step in the landslide susceptibility mapping is constructing a spatial database from data of relevant landslide conditioning factors. These include slope angle of natural slope located around the road, the distance of the natural hill to the road, distance of the natural drainage networks (river, creek, flow path of other surface water) to the road, lithology of the area around the road, the distance of observed faults to the road, and precipitation (maximum daily rainfall) of the area around the road (Figure 1).

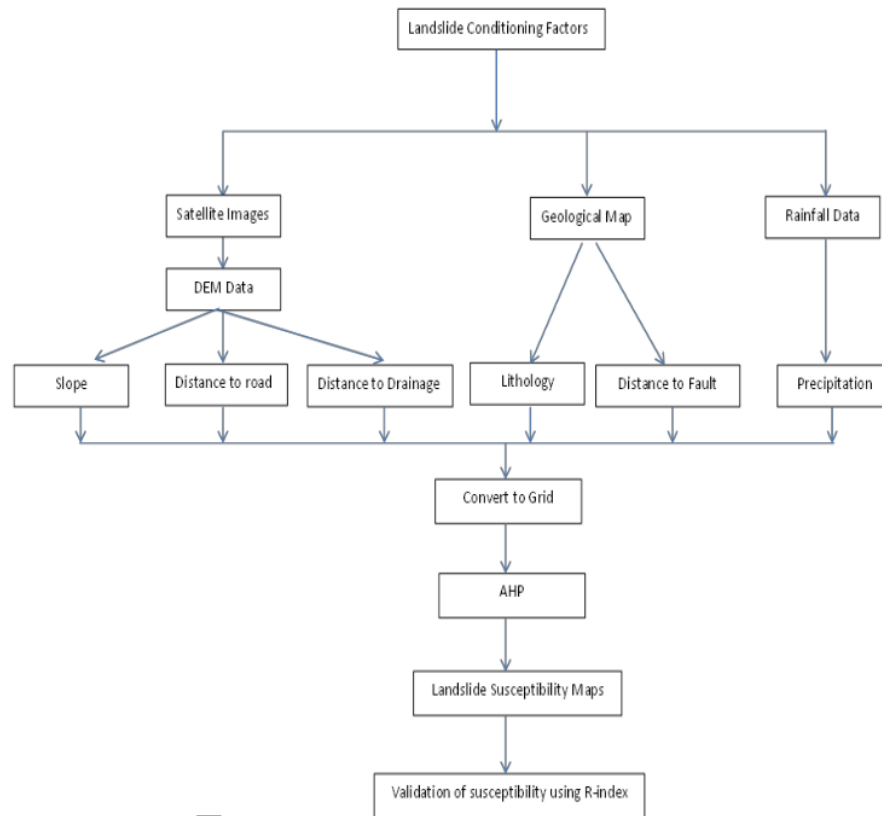
The natural slopes around the road can be obtained from remotely sensed satellite images. SRTM1S03E119V3 is available accessed via the USGS website [7]. The digital elevation model (DEM) of the study area was obtained from SRTM images through the triangulated irregular network (TIN) model. Arc-GIS can perform a rastering slope angle from DEM. The distance from the road was calculated using Google Earth Map, converted from kml file to Arc-GIS-layer. A 50 m buffer zone was selected due to the closeness of the occurred landslides to the road. The precipitation data was prepared for the last 10 years. However, some data is just available in a period of fewer than 10 years. Nonetheless, the maximum daily rainfall in the data was employed, and this is sufficient to perform class weight analysis. Polygon Thiessen was employed to locate the influenced area rainfall posts. The distance of drainage to the road can be generated from Arc-GIS hydrology tools. All the landslide related factors were converted to a raster grid (10 × 10-m cells) for application of the GIS-based statistical approach, including an analytical hierarchy process (AHP).

### 2.1. Analytical hierarchy process

AHP is a multi-criteria decision-making and multi-objective approach [9]. AHP enables the participation of decision making in selecting and weighting landslide contributing factors in a more rational manner [10]. The factors were assigned according to their importance with reciprocal pair-wise comparisons matrix in a 9 point rating scale. Its weight class multiplied the weight of each factor from the matrix weighting factor. The factors are several parameters, including slope, lithology, distance to road, distance to drainage, and precipitation. In the AHP, the consistency ratio (CR) is used to evaluate the probability that the judgment matrix was randomly created.

$$CR = \frac{CI}{RI} \quad (1)$$

Where  $\lambda_{max}$  is the largest eigenvalue of the matrix, calculated from the matrix, and  $n$  is the order of the matrix.



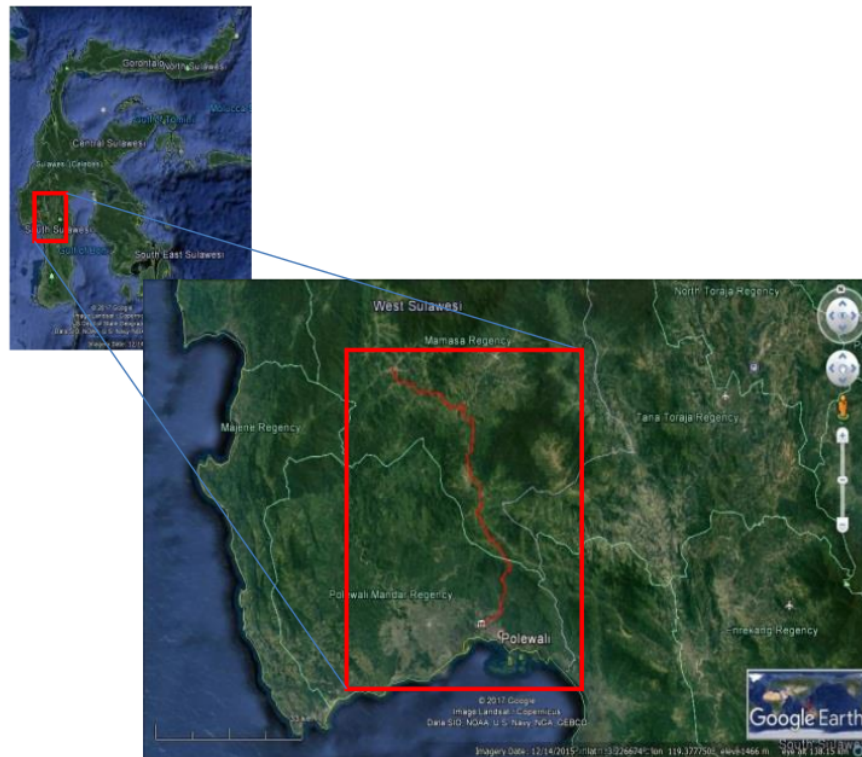
**Figure 1.** The framework of preparing the map for landslide susceptibility mapping for road corridors.

AHP results were automatically rejected if  $CR > 10\%$ . The AHP results consist of acquisitive weights in vectors value in raster. In the case of national road Polewali – Malabo West Sulawesi, the AHP process employed expert choice software of AHP-OS. The rating values of each class of each contributing factor were calculated by AHP-OS in which the weight of each factor calculated and then prioritized.

*2.2. Characteristics of the study area*

The national road of Polewali – Malabo is located in the Province of West Sulawesi, with about 63 km long (figure 2). The road is a part of the new national road route, connecting inner hinterland of the regency of Mamasa, to Mamuju the capital of the province of West Sulawesi, and it extensively can connect Mamasa to Makale in the Province of South Sulawesi. The geomorphology of the area along the road is mountainous, and its altitude ranging from 300 m to 1200 m. The relatively flat terrain is about 10% of the total area, situated in Sumarorong. The road is quite adjacent to the Mamasa River. In Polewali, geological formation is alluvium. However, geological features dramatically change from alluvium to intrusive rocks of granite and granodiorite. The intrusive rock dominates the geological features in the road from km. 4 to km. 6. Then it changes to be metamorphic rocks of silicified breccia, phyllite, and shale of Latimojong Formation at Km. 6 to Km. 8. In the middle corridors, the geological formation of the area is mostly volcanic rocks of lava of basalt, and partly pillow of lava of Walimbong Formation. The volcanic rocks are moderate to highly weathered, particularly in the area closed to the

road due to slope cut in the construction period. From km. 50 to km. 63, intrusive rock of granite and granodiorite with extremely weathered is found in the area around the road. Landuse in the area is a mostly traditional plantation, some parts are rice fields, and scattered forest areas. The average rainfall of between 289 mm to 468 mm per day and the climate is tropical wet with temperature from 23°C to 30°C. During the field survey, it was found 48 landslide spots in the road corridors from Polewali to Malabo. Figure 3 presents some conditions of slope failures of the areas along the road.



**Figure 2.** The study area of National Road of Polewali – Malabo, West Sulawesi.



**Figure 3.** Several landslide spots in the road were observed during the field survey.

### 2.3. Mapping of landslide contributing factors

The distribution of slope angle in the road corridors was obtained from DEM of SRTM image (figure 4) within slope angles classification using the AHP class. It can be seen from figure 5, slope angle  $> 45^\circ$  is mostly located in the first 30 km, and in the last 10 km of the road corridors. It can be seen in table 1, AHP weight of slope angle was found to be highest among other AHP weights of landslide contributing factors. This reveals the slope angle is the most significant parameter in the occurrence of a landslide in the road corridors from Polewali to Malabo with AHP weight (0.445), whereas the distance to fault (0.03) and the distance to road (0.07) area less significant to landslide occurrence.

Figures 6 and 7 show lithology in road corridors and distance to road, respectively. Lithology of the area comprises alluvium, metamorphic Latimojong, Volcanic Walimbong, Loka, and Intrusive. Lithology AHP weight was calculated as 0.043. Intrusive rocks in the road corridor have the highest AHP weight (0.495), indicating the rock formation is significantly contributing to landslide occurrence. This is due to the heavily weathering process of the rock in relation to hydrothermal alteration. The intrusive rock is followed by volcanic rocks of Walimbong formation with AHP weight (0.280). The AHP weight is quite high as the rock seems to be folded and tectonically fractured. In a tropical climate with high precipitation, Walimbong volcanic rocks become weathered.

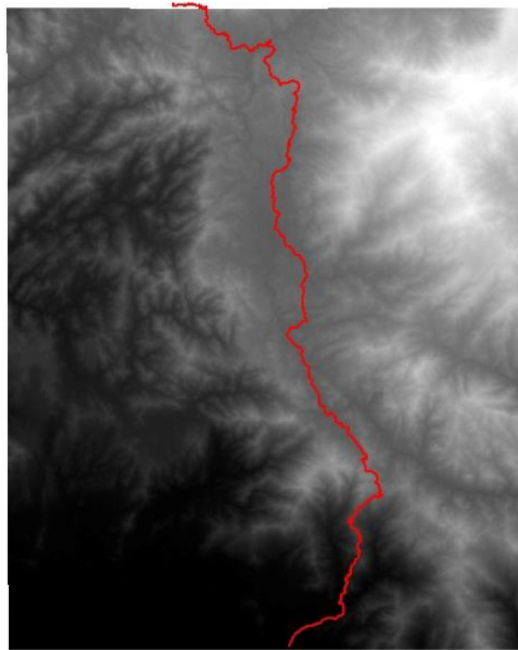
Several faults were identified based on the geological maps. The distance to the faults can be seen in figure 8. The closeness of fault to the road (50 m), the higher AHP weight will be (0.450), while the farthest distance of the fault to the road ( $> 500$  m) just has the smallest AHP weight (0.035). Some faults are located adjacent to road corridors. However, as the distance of fault AHP weight is quite small (0.03), it means probable seismic events generated by the faults are not significant to landslide occurrence in the area.

Regarding precipitation data, it must be noted that precipitation data was derived from several rainfall observation posts, including Lantora, Mamasa, Sumarorong, and Tabulahan. The areas representing the rainfall data were determined by using Polygon Thiessen (figure 9). Daily rainfall maximums were identified and categorized according to class in table 2, and then the AHP rating was calculated using the AHP-OS expert system. AHP weight for precipitation is 0.290.

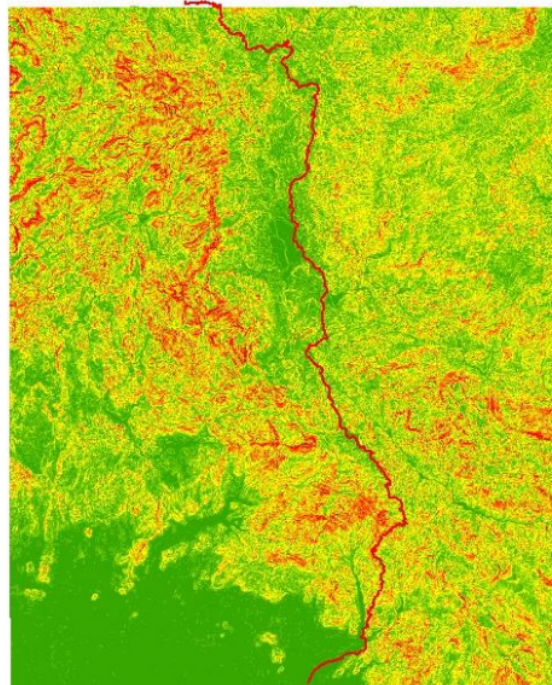
**Table 1.** The class weight, factor weight, and consistency ratio of the landslide contributing factors.

Factor	Class	Class weight	Factor weight
Slope (°)	0 - 10	0.031	0.445
	10 - 20	0.047	
	20 - 30	0.083	
	30 - 45	0.151	
	> 45	0.269	
	CR = 7.9%, $\lambda = 5.355$		
Distance to road (m)	0 - 50	0.521	0.071
	50 - 100	0.225	
	100 - 200	0.125	
	200 - 500	0.066	
	>500	0.039	
	CR = 6.1%, $\lambda = 5.078$		
Distance to drainage (m)	0 - 50	0.388	0.121
	50 - 100	0.281	
	100 - 150	0.141	
	150 - 200	0.075	
	200 - 300	0.050	
	300 - 500	0.039	
	>500	0.023	
	CR = 4.1%, $\lambda = 7.121$		
Lithology	Alluvium	0.032	0.043
	Latimojong	0.138	
	Loka	0.052	
	Walimbong	0.280	
	Intrusif	0.495	
CR = 5.9%, $\lambda = 5.269$			
Distance to Fault (m)	0 - 50	0.450	0.03
	50 - 100	0.310	
	100 - 200	0.147	
	200 - 300	0.075	
	300 - 500	0.05	
	>500	0.035	
CR = 6.2%, $\lambda = 6.350$			
Precipitation (mm)	0 - 100	0.025	0.29
	100 - 200	0.047	
	200 - 300	0.069	
	300 - 400	0.105	
	400 - 500	0.159	
	500 - 600	0.249	
	600 - 700	0.354	
CR = 3.06%, $\lambda = 7.244$			

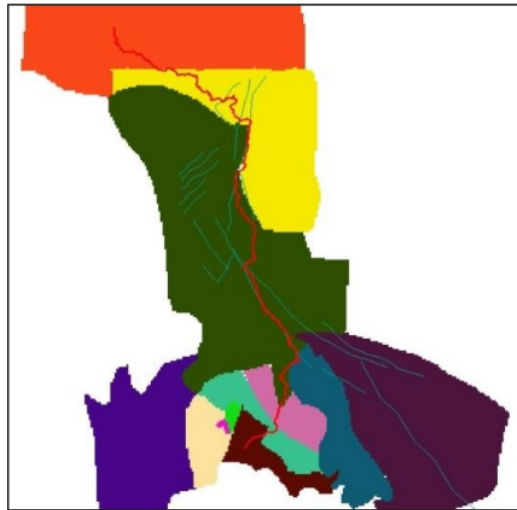
For the case of distance to drainage, several steps were undertaken by using Arc-GIS on DEM of SRTM images. Hydrology analysis in Arch-GIS enables surface water stream in the road corridor to be mapped. This is initiated by modeling hydrological fill from DEM. Then, flow direction and flow accumulation in the area where surface water stream affecting road, were modeled. Arc-GIS were used to generate a raster image of the surface water stream, and surface water stream order images. They provide information about the drainage system around the road corridor consisting of primer, secondary, and tertiary drainage, and the buffer proximity of the drainage networks was generated based AHP class. AHP rating calculates the weight of the distance water stream to the road. The closer the water stream to the road ( $< 50$  m), the AHP weight class would be (0.388). Distance to drainage has a 0.121 of AHP weight. This reveals distance to drainage is the third significant factor in landslide occurrence before slope and precipitation.



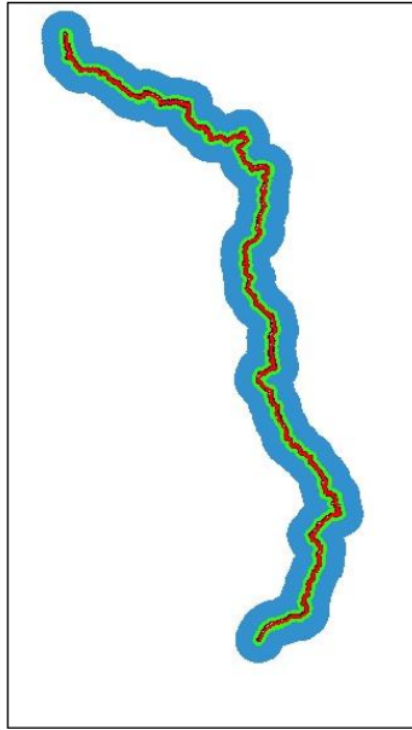
**Figure 4.** DEM of road corridor Polewali – Malabo.



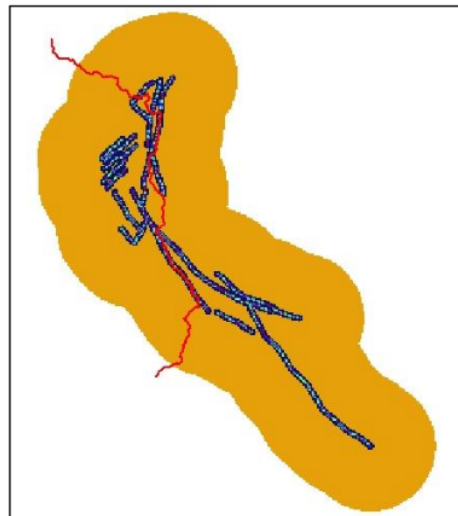
**Figure 5.** Distribution of slope along the road corridor of Polewali – Malabo.



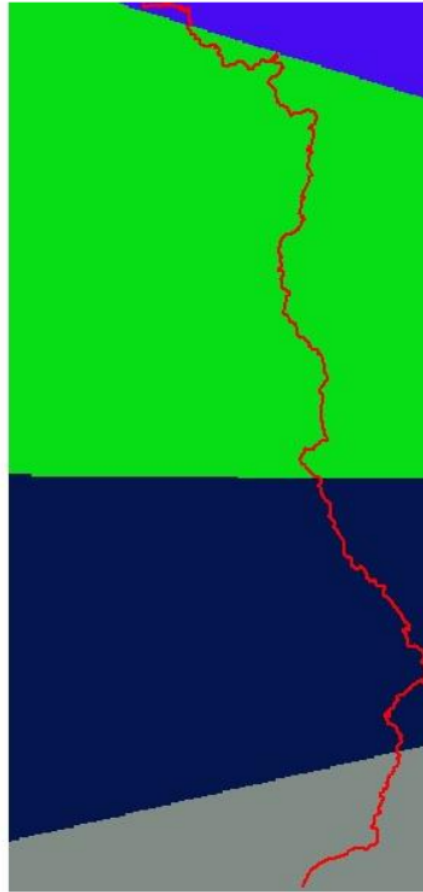
**Figure 6.** The lithology of the area around road Polewali – Malabo



**Figure 7.** Distance to road buffering in Polewali – Malabo.



**Figure 8.** Distance to a fault in the road corridor of Polewali – Malabo.



**Figure 9.** Rainfall zones in the road corridor of Polewali – Malabo.

### 3. Results and discussion

Based on the AHP analysis, Landslide Susceptibility Rating (LSR) was calculated using the following equation:

$$LSR = \sum_{i=1}^n (R_i \times W_i) \quad (2)$$

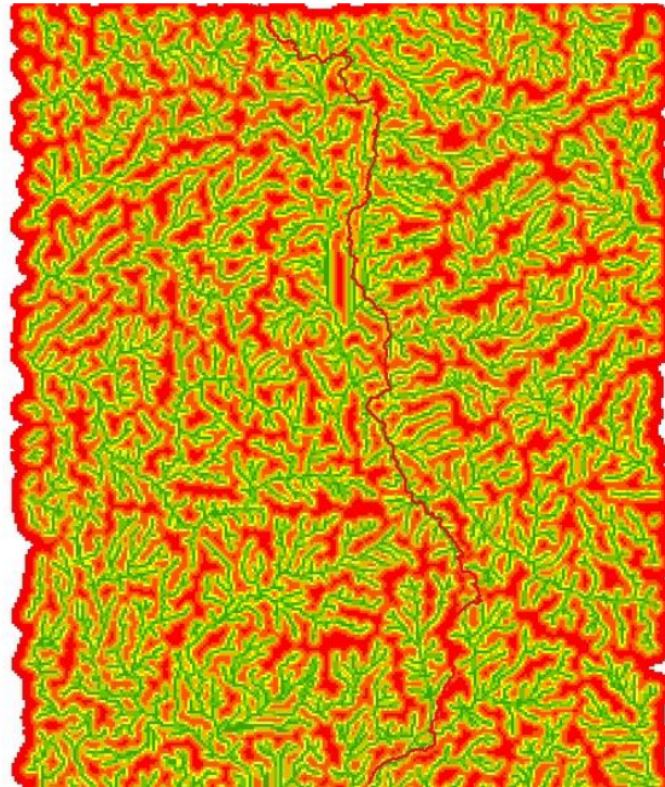
where  $R_i$  is the rating class of each layer, and  $W_i$  is the weights for each of the landslide conditioning factors.

In Arc-Map 10.3, the function overlay weight sum was employed to perform this calculation. The function overlaid the layers of slope angle, distance to drainage, distance to road, lithology, distance to fault, and precipitation zones.

#### 3.1. Landslide susceptibility mapping using AHP model

The LSR values were divided into four susceptibility zones, including low (LS), moderate (MS), high (HS), and very high (VHS) based on natural breaks method. It was found that the road of Polewali – Malabo, located from Km. 0 to Km. 3, has low susceptibility of the landslide,

while the road from Km. 7 to Km. 9 has a very high susceptibility to the landslide. From Km. 26 to Km 27, the road is not really susceptible to a landslide. The results can be seen in figure 11. Moderate landslide susceptibility of the road is found to be located from Km. 27 to Km. 33. The rest of the results can be seen in table 2.



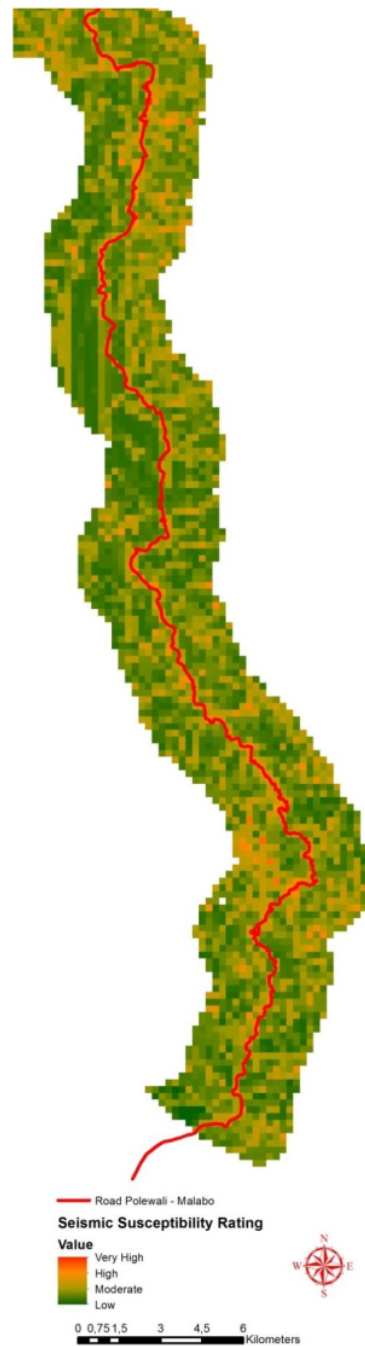
**Figure 10.** Distance to drainage in the road corridor of Polewali – Malabo.

3.2. Evaluation and validation of Landslide Susceptibility Map using Landslide Index and R-index  
 To evaluate the obtained rating the landslide susceptibility map, landslide index was employed. The index has been introduced by Van Westen et al. (2003) to evaluate whether the hazard classes in the landslide susceptibility map is acceptable. The computation of landslide index can be undertaken as follow:

$$Li = \left[ \frac{\sum_i \left( \frac{S_i}{A_i} \right)}{\sum_i \left( \frac{S_i}{A_i} \right)} \right] \times 100 \tag{3}$$

Where  $L_i$  is the index for an occurrence of landslide hazard in each susceptibility zone (percent),  $S_i$  is the slide area in each susceptibility zone,  $A_i$  is the area of each region, and  $n$  is the number of susceptibility classes.

$$P = \frac{K_s}{S} \tag{4}$$



**28** Figure 11. Landslide susceptibility map along the road corridor of Polewali – Malabo.



**Figure 11.** Landslide spots were observed in the conducted field survey.

**Table 2.** Landslide Susceptibility Rating of the road Polewali - Malabo.

Zone	Location	LSR	Rating
1	Km. 0 – Km. 3	LS	Low
2	Km. 3 – Km. 7	MS	Moderate
3	Km.7 – Km. 9	VHS	Very High
4	Km. 9– Km. 20	HS	High
5	Km. 20 – Km. 26	VHS	Very High
6	Km. 26 – Km. 27	LS	Low
7	Km. 27 – Km. 33	MS	Moderate
8	Km. 33 – Km. 35	VHS	Very High
9	Km. 35 – Km. 38	HS	High
10	Km. 38 – Km. 39	LS	Low
11	Km. 38 – Km. 41	HS	High
12	Km. 41 – Km. 46	LS	Low
13	Km. 46 – Km. 49	VHS	Very High
14	Km. 49 – Km 50	LS	Low
15	Km. 50 – Km. 53	HS	High
16	Km. 53 – Km. 55	MS	Moderate
17	Km. 55 – Km. 57	VHS	Very High
18	Km. 57 – Km. 58	MS	Moderate
19	Km. 58 – Km. 60	HS	High
20	Km. 60 – Km. 63	VHS	Very High

where  $K_s$  is the area of slide zone in moderate to very high susceptibility level, and  $S$  is the area of the landslide in the region.

The results derived from landslide susceptibility using the AHP model were validated using the Relative landslide density index (R-index) analysis to evaluate the correlation between the landslide susceptibility map and landslide inventory, which was collected during field surveys. The validation is based on the following equation:

$$R = \frac{\left(\frac{n_i}{N_i}\right)}{\sum \frac{n_i}{N_i}} \times 100 \quad (5)$$

where  $n_i$  the number of landslides occurred in the sensitivity class  $i$  and  $N_i$  the number of pixels in the same sensitivity class  $i$ .

By comparing the landslide susceptibility map (figure 11) with landslide spots observation obtained from field survey (figure 12), the landslide index was calculated. In the map, one pixel is a 0.093 km<sup>2</sup> area. By performing the con analysis, Arc-GIS calculated how many pixels having very high, high, moderate, and low in landslide susceptibility map. Then, in each hazard class, the area of the landslide in the map was compared to the total area of each class. Landslide index was found to increase from low (1.22%) to very high (23.75%). The results of the landslide index can be seen in table 3. This indicates the hazard classes in the landslide susceptibility map are acceptable. The validity of the map was evaluated with  $R$  value, which is the comparison of the slide area in the upper low to the total area of the slide zone. R-index sample data set for classes of very high susceptibility is 91.30%. The results obtained from R-index indicate that the landslide susceptibility mapping has well prediction accuracy.

**Table 3.** Comparison of the landslide susceptibility maps with the landslide spots distribution.

Susceptibility Classes	Low	Moderate	High	Very High
$S_i$ (km <sup>2</sup> )	0.372	2.604	1.209	0.093
$A_i$ (km <sup>2</sup> )	188.2	150.7	20.9	0.744
Density of Slide	0.002	0.017	0.0577	0.125
Landslide Index (%)	0.38	8.53	28.5	61.75
Ks			3.906	
S			4.278	
P (%)			91.30%	

**4. Conclusion**

In this present research, landslide susceptibility mapping was evaluated on-road corridor of Polewali – Malabo, West Sulawesi Indonesia. This involves susceptibility mapping based AHP model of landslide contributing factors including slope, precipitation, lithology, distance to drainage, distance to fault, and distance to the road. The accuracy of the obtained susceptibility map was evaluated by using R-index, which is an index of comparing slide area in the susceptibility map to real slide area in landslide inventory. AHP model of landslide contributing factors reveals that slope is the most significant effect on landslide occurrences, while the distance to fault is less significant. Mostly road corridor along Polewali – Malabo (61%) is located at moderate susceptible to the landslide, while some parts of the road corridor (28%) are situated at high susceptible to the landslide. Just 2.2% of road corridor is seated on very highly susceptible to landslide, and 8.7% of the road corridor is safe to landslide occurrence. The AHP model reveals that slope and precipitation, and distance to drainage are dominant factors contributing to the landslide. R-index of the landslide susceptibility map is 91.3%, indicating high accuracy and well prediction.

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