

Effect landslide hazard mitigation using an integrated of Analytical Hierarchy Process and Multi Criteria Evaluation: A case study the Jeneberang watershed

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Abstract. Jeneberang watershed has an important role in maintaining environmental stability, especially for the surrounding area. In 2004 a landslide occurred in the Jeneberang watershed which caused casualties and material losses. This study aims to determine the distribution and level of vulnerability to landslides in the Jeneberang watershed and to formulate an effective scenario to reduce the level of vulnerability. This research is located the Jeneberang watershed, South Sulawesi Province. The data used include data on the weight of each parameter and criteria for determining landslide susceptibility obtained from expert interviews, land use maps obtained from analysis of Landsat 8 OLI satellite imagery in 2020, slope maps, rainfall maps, forest area status maps, and map type. soil. The method used is the integration of AHP and MCE for landslide hazard assessment, GIS analysis and spatial decision-making for scenario simulation. The results of the analysis show that the rainfall parameter has the highest weight in determining the level of landslide susceptibility with a value of 0.327, the results of the MCE analysis for assessing the level of landslide susceptibility in the Jeneberang watershed show an area of 18.829 ha. or 18% of the Jeneberang watershed area which is classified as high hazard. The results of the analysis show that the use of an effective scenario reduces the landslide hazard at a high level of hazard. In the optimistic scenario, it can reduce the high vulnerability level by 9.14%, while in the moderate scenario it is effective in reducing the high vulnerability level by 8.72%.

1 Introduction

In the last ten years, landslide-related decision-making methodologies with a spatial approach are increasingly being used [1]. A El Jazauly using the AHP method to map landslide susceptibility in the highlands of Oum Er Rbia, Morocco [2]. The Jeneberang River has an important and very large role in several areas, especially for Gowa Regency and Makassar City, but in 2004 a large-scale landslide occurred on the Bawakaraeng caldera wall which

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resulted in 10 people and several million sediment material falling and entering in Jeneberang river [3].

Geographic analysis of the history of landslides is important to be able to identify spatial patterns so that mitigation efforts can be carried out. To strengthen the results of the spatial analysis, expert opinion was used, namely by conducting in-depth interviews with experts (Academics, BNPB Practitioners, DLH, Bappedalda) so that the best alternative was obtained from several choices of existing results. The focus of this research is to minimize losses due to landslide susceptibility by using the integration of the AHP and MCE methods which then produces several scenarios based on several limiting factors carried out in the Jeneberang watershed area, where many previous studies have discussed the level of erosion, land use changes that have the potential to cause landslides [4].

2 Material and methodology

2.1 Data and data sources

The data used in this study include primary data and secondary data. The primary data used include data on the weight of each parameter determining landslide susceptibility obtained from expert interviews using the AHP questionnaire. Secondary data used include land use maps obtained from analysis of Landsat 8 OLI satellite imagery in 2020 and slope maps obtained from GIS analysis using SRTM (Shuttle Radar Topography Mission) data with a resolution of 30 meters sourced from USGS (United States Geological Survey), rainfall maps and soil type maps were obtained from the Bappeda of South Sulawesi Province, and a forest area status map was obtained from the Ministry of Environment and Forestry of the Republic of Indonesia.

2.2 Analysis method

The 2020 land use map was obtained from the analysis of the Landsat 8 OLI 2020 Satellite Imagery using the guided classification method. The slope map is generated from the analysis of SRTM (Shuttle Radar Topography Mission) data with a resolution of 30 meters using the GIS analysis method. The assessment of the level of vulnerability to landslides in the Jeneberang watershed uses an integrated approach between the Analytical Hierarchy Process (AHP) and Multi Criteria Evaluation (MCE). The data analysis process was carried out on the Terraset Geo-Spatial and Modeling System (Clark Labs) software. The integration of the AHP and MCE methods is used to reduce the researcher's single subjectivity to collective subjectivity by involving various experts in the assessment process, so that the resulting weight values are more representative as has been done. Before running the model, the spatial data is first converted from vector data format to raster data format with a pixel size of 100 x 100 m with imaginary data type (img), then the raster data is converted back to raster arc data format (first) as a data format that can be used. processed by the model [5]. The landslide hazard mitigation scenario is carried out to reduce the level of vulnerability in the research area through efforts to reduce the level of landslide vulnerability. Efforts to reduce the level of landslide vulnerability are carried out through land use simulations using the Spatial Decision-Making method based on three scenarios, namely optimistic scenarios, moderate scenarios, and pessimistic scenarios. The results of the landslide hazard assessment can then be seen in the flow chart of the methodology presented in Figure 1.

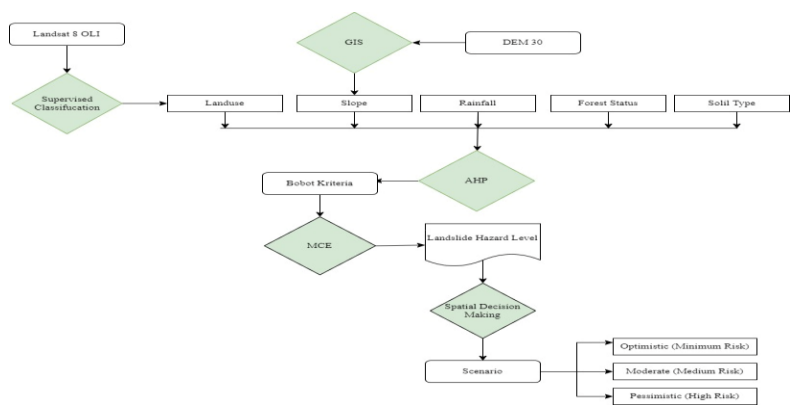


Fig. 1. Methodology flowchart.

2.2.1 Analytical hierarchy process (AHP)

The AHP method was chosen to reduce the subjectivity of the weight assessment of each landslide parameter at the research site. The AHP method can help in decision-making to find the best alternative from many elements of choice [6-10]. AHP data was obtained based on a questionnaire containing a comparison of the effect between each parameter and the criteria for each parameter [11]. The questionnaire was filled out by experienced experts in the landslide field. Parameters and criteria that have been assessed by experts are then compared, so that the weight of each parameter and criterion is known [12]. The weights are then used as input data in the landslide hazard assessment using the MCE method.

2.2.2 Multi criteria evaluation (MCE)

MCE is a decision-making method with a multi-Criteria Approach. MCE in this study was used to assess the level of landslide susceptibility in the Jeneberang watershed. The criteria used include land use, slope, rainfall, forest area status, and soil type. MCE was run using integration with AHP as a source of weight values for each criterion. Before running the model, the parameter data and criteria for each parameter are first weighted. The scoring is based on its effect on the level of vulnerability to landslides using expert judgment using the AHP method.

The weights are used to develop a set of parameter weights in a multi-criteria evaluation. The weights are developed by providing a series of pairwise comparisons of the relative importance of the factors for pixel fit based on the purpose of the analysis. This pairwise comparison is then analyzed to produce a set of weights with a maximum value of 1.

The weights of each parameter and the resulting criteria are used as input for the MCE module with the Weighted Linear Combination model. In this method, the criteria include weighting factors and constraints. WLC starts by multiplying each factor by the factor weight/tradeoff and then summing the results. This procedure is characterized by an average tradeoff between factors and risk. In this case, the higher the weight of the factor, the greater the influence of that factor on the resulting landslide hazard. In the WLC model, the suitability score is multiplied by the appropriate weight and then summed to get the overall suitability score [13]. The equation for the WLC model is as follows:

$$F = \sum_{i=1}^n W_i \times f_i = \sum_{i=1}^n W_i \times \frac{1}{m_i} \sum_{j=1}^{m_i} f_{ij}$$

(1)

Where: F = Overall suitability score;
Wi =Parameter weight i-evaluation;
fi = i-th evaluation parameter suitability score;
fij =The suitability score of the j-th sub parameter on the i-evaluation parameter
n = Number of parameters; and
mi = The total number of sub-parameters in the i-th parameter

2.2.3 Landslide hazard mitigation scenario

The landslide hazard mitigation scenario at the research location is based on 3 scenarios, namely an optimistic scenario, a moderate scenario, and a pessimistic scenario obtained through land use simulation using the Spatial Decision Making (SDM) method. The optimistic scenario is an attempt to reduce the landslide hazard to a high hazard level by simulating a 25% increase in forest land use as a constraint. The moderate scenario is to increase forest land use by 50%, and the pessimistic scenario is to increase forest by 75% (Table 1). The use of constraints in this method is to encode data based on boolean logic, namely 0 and 1, where the value 0 represents the value of the constraint factor, and the value 1 represents the non-constraint factor. The value of 0 is obtained from the results of the selection of each type of land use, where the optimistic scenario uses 25% of the area of each type of land use, scenario 2 using 50%, and scenario 3 using 75% of the area of each type of land use. While the value of 1 represents the area of land use that is not selected or is not a constraint factor.

Table 1. Use of constraints in each scenario.

Land use	Area (ha)	Optimistic Scenario	Medium Scenario	Pessimistic Scenario
		25% Forest	50% Forest	75% Forest
Forest	12,408	2.91	5.81	8.72
Dryland farming	47,160	11.05	22.09	33.14
Open Ground	502	0.12	0.24	0.35
Plantation	174	0.04	0.08	0.12
Residence	5,919	1.39	2.77	4.16
Ricefield	30.051	7.04	14.08	21,12
Shrubs	6,937	1.62	3.25	4.87
Water body	3,573	0.84	1.67	2.51
Total	106.724	25	50	75

3 Data analysis and interpretation

3.1 AHP analysis results

The AHP method was chosen because it is still useful, especially for large-scale assessments or for areas that do not have a landslide inventory [14]. The rainfall parameter has the highest weight in determining the level of landslide hazard with a value of 0.327, the next highest parameter is the slope with a value of 0.301 and land use parameters with a value of 0.209. The lowest is the soil type parameter with a value of 0.074 in terms of determining the level of landslide susceptibility (Table 2).

Table 2. Weight of AHP analysis results for each parameter.

Landslide hazard parameter	Weight
Rainfall	0.327
Slope	0.301
Land use	0.209
Forest status	0.089
Type of soil	0.074
Inconsistency = 0.02	

For the assessment of each parameter category, based on the results of expert assessments in the AHP analysis for land use parameters, the plantation criterion has the highest weight of 0.338 and the lowest is the forest criterion with a weight of 0.046. As for the slope parameter, the criterion that has the highest value is on a slope > 40% with a value of 0.517, while the lowest is on a slope of 0-8% with a value of 0.034. As for the rainfall parameter, the highest value is found in rainfall >350 mm with a value of 0.565 and the lowest is in rainfall 125-175 mm with a value of 0.055 (Table 3).

In the forest status parameter, the criterion that has the highest value is the status of other use areas with a value of 0.562, while the lowest is the criteria for protection forest with a value of 0.054. As for the soil type parameter, the criterion that has the highest value is Andosol soil type with a value of 0.572 and the lowest is the Alluvial soil type criterion with a value of 0.052.

Table 3. AHP analysis results for the weight of each criterion parameter.

Land Use Criteria	Weight	Slope Criteria	Weight	Rainfall Criteria	Weight
Plantation	0.338	>40% (Very High)	0.517	>350mm	0.565
Dryland farming	0.230	25-40% (High)	0.257	250-350 mm	0.262
Open field	0.144	15-25% (Medium)	0.115	175-250 mm	0.118
Shrubs	0.091	8-15% (Medium)	0.077	125-175 mm	0.055
Ricefield	0.057	0-8% (Low)	0.034		
Residence	0.047				
Water body	0.047				
Forest	0.046				
Inconsistency = 0.03		Inconsistency = 0.04		Inconsistency = 0.04	
Forest Status Criteria		Weight	Soil Type Criteria	Weight	
Other Use Areas		0.562	andosol	0.572	
Production forest		0.154	Latosol	0.299	
Limited production forest		0.088	Podsolik	0.077	
Forest Nature Reserve		0.079	alluvial	0.052	
Water body		0.063			
Protected forest		0.054			
Inconsistency = 0.05			Inconsistency = 0.06		

3.2 Landslide hazard level

The results of the MCE analysis for the assessment of the level of vulnerability to landslides in the Jeneberang watershed are grouped into 3 levels of vulnerability, namely low, medium, and high vulnerability. Locations where landslides often occur are river valleys and very steep slopes [14]. Based on the results of the analysis, there are 18,829 ha or 18% in the Jeneberang watershed which is classified as a high hazard level (Table 3). This shows that there are areas that are quite high in the research location that have the potential for landslides with a high level of vulnerability. This condition indicates the need for efforts to reduce the level of danger so that its negative impact can be minimized.

Table 4. Landslide hazard Level in Jeneberang watershed.

Not.	Landslide hazard level	Index	Area (ha)	%
1	Low	0.000-0.3812	57,670	54
2	Currently	0.3812-0.4359	30,255	28
3	Tall	0-4359-1	18,829	18
Total			106.724	100

Spatially, the high level of landslide susceptibility in the Jeneberang watershed is mostly in the eastern region and partly in the southern region. This is because most of this area is located on steep-to-steep slopes with high rainfall. Meanwhile, the moderate hazard level is also concentrated in the eastern and southern regions, while the high hazard level is spatially concentrated in the western area of the Jeneberang watershed.

3.3 Mitigation scenario

The results of the analysis show that the use of scenarios is effective in reducing landslide hazards at high and medium hazard levels. In an optimistic scenario, it can reduce the high hazard level by 9.14%, and the moderate hazard level by 21.42%. While the moderate scenario is effective in reducing the high hazard level by 8.72% and the medium hazard level by 19.56%. Meanwhile, the pessimistic scenario effectively reduces the high hazard level by 3.65% and reduces the moderate hazard level by 10.38%. (Table 4).

Table 5. Scenario results.

Optimistic Scenario		% Decrease	Medium Scenario		% Decrease	Pessimistic scenario		% Decrease
Danger Level	Area (ha)		Danger Level	Area (ha)		Danger Level	Area (ha)	
Low	73	69.44	Low	75	71.72	Low	90	85.97
Currently	23	21.42	Currentl y	22	19.56	Currentl y	12	10.38
Tall	10	9.14	Tall	9	8.72	Tall	4	3.65
	106			106			106	

4 Conclusions

This study concludes that landslide susceptibility in the Jeneberang watershed is classified as high vulnerability, with a percentage of 18% of the entire Jeneberang watershed area and is strongly influenced by rainfall with a weight of 0.327 so that the most effective scenario used to reduce the level of landslide susceptibility is to use an optimistic scenario, namely by increasing forest land by 25% so that it can reduce 9.14% high hazard level and 8.72% moderate hazard level.

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