Mapping of Landslide Susceptibility Using Analytical Hierarchy Process in Sukamaju Area, Tenggarong Seberang, Regency of Kutai Kartanegara

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Abstract. A landslides susceptibility mapping produced as a mitigation effort to reduce risk of landslide. Landslide susceptibility mapping aims to identify most susceptible area to landslide. Analytical Hierarchy Process (AHP) is quantitative method based on qualitative assessment to certain phenomena. This method was applied in Sukamaju area, Tenggarong Seberang, regency of Kutai Kartanegara to determine the weights of each data influencing landslide occured. Data were used to map susceptibility of landslide in study area are relief and slope data, detail geological and geomorphological map, topographic wetness index (TWI), and Normalized Difference Vegetation Index (NDVI) data. The data then were analyzed spatially using overlay function in ArcGIS 10.5 to produce susceptible area to landslide. Susceptibility of landslide in the study area consist of four classes, they are low, moderate, high, and very high. Generally, in the study area dominated by moderately susceptible to landslide by percentage of area 61.68%, low susceptibility about 28.28%, high susceptibility about 9.22%, and very high susceptibility about 0.92%. Very high susceptibility area is located in the eastern part of study area, geologically covered by sandstone form Pamaluan formation and denudational morphology.

Keywords: landslide susceptibility, AHP method, spatial analysis

1. Introduction

1.1 Background

Landslide is one of natural disaster occured most in Indonesia. It is the movement of soil or rock mass in short periods and big volume. The movement of this mass can cause damage of infrastructure and people psychology. An area can be stated susceptible to landslide if it has slope more than 25%, plastic and semipermeable lithology or more geological structure, groundwater can increase susceptibility of landslide.

The information about landslide susceptibility can be presented well and clearly if it is made in a map. Determination of landslide susceptible area is commonly complicated because the less of data needed to predict it. Intarahwicahan dan Dasananda (2010) stated that the accuracy of landslide susceptibility map depended on scale, the number and quality of the data, and appropriate method selection in analysis and modelling. Guzzetti et al. (1999) stated that mapping of landslide susceptibility was very suitable using statistics approach in analyzing historical correlation between factor controlling landslide and distribution of landslide.

The landslide can be influenced by precipitaton, geological, and geotechnical condition, such as relief, slope, lithology, groundwater, mechanical and physical properties of the rock or soil, and even earthquake. In Sukamaju area, if it is assessed from geological condition, it has big potential to landslide. Therefore, mapping of landslide susceptibility very needed in Sukamaju area as preventive effort of landslide risk. This research using geological investigation data, such as detail geological and geomorphological map, and secondary data such as DEM and Landsat 8 OLI. The data analyzed by using Analytical Hierarchy Process (AHP) method to map the landslide susceptible area. This method is selected because very useful on conditions need consideration and complex. It combines logics, knowledge, and experience, then optimized into systematic process. This method used as alternative in analyzing landslide susceptibility from qualitative data or judgement to quantitative data.

2. Method

Sukamaju area is located in Tenggarong district, Kutai Kartanegara regency, East Kalimantan province. In UTM, study area is lying on 507358.851–518165.202 mE and 9988990.296–9971961.093
mS. Spatial analysis was applied to obtain the landslide susceptibility map. Spatial analysis using overlay function in ArcGIS 10.5. Overlay function can be applied to raster data. Applying this function, each variables must have influence weight to occurring of certain phenomena and each variables have attribute data devided to value classes. The influence weights of variables were calculated using Analytical Hierarchy Process (AHP) method.

2.1 Analytical Hierarchy Process (AHP)

This method is solved by developing pairwise comparison matrix (Table 1) by assigning the rank to each factor against other factors. Assigning rank using Table 2 based on degree of preference of factors influencing landslide.

| Importance Rank | Degree of Preference | Explanation |
|-----------------|----------------------|-------------|
| 1               | Equal importance     | Two criteria contribute equally to the objective |
| 3               | Moderately importance of one over another | Judgment and experience slightly to moderately favour one criteria over another |
| 5               | Strongly importance  | Judgment and experience essentially favor one criteria over another |
| 7               | Very strongly importance | Experience and judgements is strongly favored over another and its dominance is showed in practice |
| 9               | Extremely importance | The evidence favouring a criteria over another is the highest degree probable of an affirmation |
| 2, 4, 6, and 8  | Intermediate values between two adjacent judgements | Used to represent compromising between the preferences in weights 1, 3, 5, 7 and 9 |
| Reciprocals     | Opposites            | Used for inverse comparison |

In this model, consistency index, known as the ratio of consistency (CR), is for indicating the probability that the matrix judgments were generated randomly (Saaty, 1977, 1980, 1994 in Mandal, 2018). The consistency ratio is stated valid if it is less or equal to 10%.

\[
CR = CI / RI
\]

Random Index is the average result of the consistency index that depending on the matrix order in Table 3 given by Saaty (1977) in Mandal (2018) and CI is the consistency index and could be formulated as:
\[ CI = \frac{\lambda_{\text{max}} - n}{n - 1} \]  

(2)

Where, \( \lambda_{\text{max}} \) is the principal or largest eigenvalue of the matrix and could be calculated easily from the matrix and \( n \) is the matrix number (Saaty, 1977 in Mandal, 2018).

### Table 3 Random Consistency Index (Saaty, 2000)

| n | RI  |
|---|-----|
| 1 | 0.00|
| 2 | 0.00|
| 3 | 0.58|
| 4 | 0.90|
| 5 | 1.12|
| 6 | 1.14|
| 7 | 1.32|
| 8 | 1.41|
| 9 | 1.46|

3. Results and Discussion

3.1 Data

There are five data used in this study. They are lithology and geomorphology map from detail geological mapping, slope and Normalized Topographic Wetness Index (TWI) map produced from Digital Elevation Model (DEM) data with resolution 8 meters, data obtained from Indonesian Geospatial Agency, and Normalized Difference Vegetation Index (NDVI) map produced from Landsat 8 OLI data with resolution 8 meters, data obtained from Earth Explorer United State Geological Survey. All data must be converted to raster data based on the attribute data before analyzed using Spatial Analyst in ArcGIS 10.5.

3.2 Weights Calculation

The weight of raster data calculated using Analytical Hierarchy Process (AHP). The calculation started by assigning importance rank in pairwise comparison matrix, then calculate the value and weights for each data. The last step, consistency index and consistency ratio calculated, the weight is accepted if consistency ratio value is less or equal to 10% or 0.1.

### Table 4 Pairwise comparison matrix for landslide susceptibility mapping

| DATA       | Slope | Lithology | Morphology | NTWI  | NDVI  |
|------------|-------|-----------|------------|-------|-------|
| Slope      | 0.455 | 0.506     | 0.456      | 0.370 | 0.333 |
| Lithology  | 0.227 | 0.253     | 0.304      | 0.296 | 0.278 |
| Morphology | 0.152 | 0.127     | 0.152      | 0.222 | 0.222 |
| NTWI       | 0.091 | 0.063     | 0.051      | 0.074 | 0.111 |
| NDVI       | 0.075 | 0.051     | 0.038      | 0.037 | 0.056 |
| Total      | 1.000 | 1.000     | 1.000      | 1.000 | 1.000 |
| Value      | 2.120 | 1.358     | 0.874      | 0.390 | 0.257 |
| Weights    | 42%   | 27%       | 18%        | 8%    | 5%    |
| CI         | 0.0245|           |            |       |       |
| CR         | 0.0219|           |            |       |       |

The weight calculated from the matrix shown that slope is the most influencing data, the weight is exactly 42%, lithology 27%, morphology 18%. Normalized-TWI 8%, and Normalized DVI 5%. The value of index consistency is 0.0245, this value used to calculated the consistency ratio. The value of ratio of consistency is 0.0219. less than 0.1, it means the consistency ratio is valid and the weight is accepted to be used in mapping the landslide susceptibility.
Figure 1 Map used in analysis of landslide susceptibility
3.3 Spatial Analysis

Landslide susceptibility mapping produced by applying spatial analysis. Spatial analysis applied to the map is overlay function. This function combines some the raster data to produce a new raster based on the weight of raster data and attribute value of the rasters. Before applying in overlay function, attribute data must be reclassified to be integer value only based on the influence controlling landslide. The result of spatial analysis presented in Figure 2.

![Landslide Susceptibility Map](image)

**Figure 2** Landslide susceptibility map in study area

Based on Figure 2, susceptibility of landslide in the study area consist of four classes, they are low, moderate, high, and very high. Generally, in the study area dominated by moderately susceptible to landslide by percentage of area 61.68%, low susceptibility about 28.28%, high susceptibility about 9.22%, and very high susceptibility about 0.92% (Table 5). Very high susceptibility area is located in the eastern part of study area, geologically covered by sandstone form Pamaluan formation and denudational morphology.

**Table 5** Landslide susceptibility class, area, and percentage

| Landslide Susceptibility | Area (km²) | Percentage (%) |
|--------------------------|------------|----------------|
| Low                      | 14.34      | 28.18          |
| Moderate                 | 31.39      | 61.68          |
| High                     | 4.69       | 9.22           |
| Very High                | 0.47       | 0.92           |
4. Conclusion

Mapping of landslide susceptibility on this study using five raster data, they are slope, lithology, morphology, Normalized TWI, and Normalized VDI. Based on calculation using Analytical Hierarchy Process (AHP), the slope is the most influencing data for landslide occurring by weight 42%, then lithology 27%, morphology 18%, Normalized TWI 8%, and Normalized VDI 5%. The value of ratio consistency of this weight is about 0.0219, less than 0.1, and this shown that the weight is valid and acceptable used in spatial analysis.

Based on the map of landslide susceptibility, the study area dominated by moderately susceptible to landslide by percentage of area 61.68%, low susceptibility about 28.28%, high susceptibility about 9.22%, and very high susceptibility about 0.92%. Very high susceptibility area is located in the eastern part of study area, geologically covered by sandstone form Pamaluan formation and denudational morphology.

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