Comparative Study of Determination of Landslide Susceptibility Based on Weighting Methods and Analytical Hierarchy Processes in Pringapus, East Ungaran

D Trisnawati1, Najib1*, A S Hidayatillah1, A Z Robbany1, Y A L Pellokila1

1Geological Engineering, Diponegoro University, Semarang, 50275, Indonesia. *najib@ft.undip.ac.id

Abstract. Landslide is a geological disaster that is still an interesting topic to study its behavior and its management, especially for tropical regions such as Indonesia. One form of landslide countermeasures is the mapping of landslide susceptibility. The most commonly used landslide susceptibility mapping method is the GIS-based weighting and classification method. In the weighting method, each parameter and class has a definite weight as in the reference for making vulnerability maps that have been issued by BBSDL (Center for Agricultural Land Resources) and PVMBG (Center for Volcanology and Geological Hazard Mitigation). However, the exact weight of each parameter sometimes does not match the real conditions in the field, so many researchers modify it. For this reason, this study tries to present an accuracy comparison of mapping the vulnerability of landslide with the weighting method and the Analytical Hierarchy Process (AHP) method. The research location is in the Pringapus and East Ungaran areas, Semarang Regency. The results showed that the mapping of landslide susceptibility using the weighting method showed an accuracy of 77.58% while using the AHP method showed better accuracy of 84.48%.

Keywords. Landslide, Susceptibility, Weighting, Analytical Hierarchy Process

1 Introduction

From 2005 to 2015, Indonesia has a tendency to increase the number of disaster events. About 22% of disasters are geological disasters including earthquakes, tsunamis, volcanic eruptions, and landslides [1]. Landslide is one of the geological disasters which is also considered a hydrometeorological disaster [2,3]. As much as 21% of geological disasters in Indonesia are landslides, and it ranks second after flooding. Central Java is the province with the most landslides in the last 10 years with the number of events reaching 2,259 [4]. Figure 1 shows a graph of the occurrence of landslides in Central Java in the last 10 years [4,5]. Semarang Regency as one of the administrative regions of Central Java experienced an increase in the incidence of movements in several administrative areas in 2016-2017 [6]. One of these areas is the Pringapus area. The decrease in the number of incidents in 2018 and followed by another increase in 2019 (Figure 1) shows that these events can still pose a potential danger to the community.

Landslide susceptibility map is a map that shows the potential for an area to occur landslide based on its natural conditions. Several institutions have issued guidelines for the preparation of landslide

1* Corresponding author: najib@ft.undip.ac.id
susceptibility maps. Among them are the Center for Agricultural Land Resources (BBSLDP), the Center for Volcanology and Geological Hazard Mitigation (PVMBG), and the National Disaster Management Agency (BNPB) [7,8]. The preparation of existing susceptibility maps generally adopts weighting of parameters namely: factors in the occurrence of landslide such as slope, type of lithology, rainfall, distance from the geological structure, land cover, etc. Several publications have adopted guidelines for the preparation of susceptibility maps [9, 10, 11, 12]. In addition to the above method, the use of the Analytical Hierarchy Process (AHP) method can also be used to determine the weight of the parameters in the preparation of landslide susceptibility maps. Several studies have been conducted by adopting this method [13,14].

Figure 1. Landslide occurrence data collected by BNBP and BPBD of Semarang Regency.

Since weighting method and AHP method are different, the authors are interested in comparing the results of both method. Similar research has been conducted by Nugraha, et al [6] at the same location of Semarang Regency, but with a wider area coverage. What is different from previous research is we conduct direct observation in the field to map landslide occurrences in the 2021 period, so that better accuracy will be obtained.

2 Method

2.1 Study Area

The research area is included in the administrative area of Semarang Regency. Physiographically, the research location is in the physiographic zone of the Kendeng Basin. This means that the study area is affected by geological structures and volcanic activity. The division of landforms in the research area is based on direct and image observations, showing that there are 3 landform units (Figure 2) at the research location, namely: structural landform unit, fluvial landform unit, and denudational landform unit. The shape of the elongated ridge with a notch perpendicular to the ridge indicates the process of erosion by water. The process of water erosion on the slopes has the potential to cause landslide. Previous researchs have stated that there is a link between structural landforms and the potential for landslides [15, 16, 17, 18].
2.2 Weighing Method Parameters

In this study, the determination of susceptibility level of landslide is based on the research of Dewi, et al (2017) [9]. Dewi, et al combined the weights of landslide parameters from DVMG, BBPLSDP, and PVMBG. The weighing parameters adopted are slope (35%), rock type (25%), land use (10%), distance to geological structure (10%), and annual rainfall (20%).

| Parameters               | Score          | Weight |
|--------------------------|----------------|--------|
| Slope                    | 1 (very low)   |        |
|                          | 2 (low)        |        |
|                          | 3 (moderate)   |        |
|                          | 4 (high)       |        |
|                          | 5 (very high)  |        |
| Lithology                |                |        |
| Andesite Breccia Unit    |                |        |
| Calcareite Limestone     |                |        |
| Lapili Tuff              |                |        |
| Calcareaeous Sandstone   |                |        |
| Calcareaeous Claystone   |                |        |
| Landcover                |                |        |
| Plantation               |                |        |
| Bush                     |                |        |
| Rice Field               |                |        |
| Settlement               |                |        |
| Open Area                |                |        |
| Distance to fault (m)    |                |        |
| >800                     |                |        |
| 500 – 800                |                |        |
| 300 – 500                |                |        |
| 100 – 300                |                |        |
| <100                     |                |        |
| Rainfall (mm/years)      |                |        |
| -                        | 1997 – 2000    |        |
| 2001 – 2500              | 2501 – 3000    |        |

2.3 Analytical Hierarchy Process (AHP) Method

The AHP method is designed to collect people's perceptions rationally, especially those related to certain problems through a procedure to get a preference scale among various alternatives [20]. The basic principles that must be understood in solving problems using AHP are decomposition, comparative judgment, synthesis of priority and logical consistency. In AHP, the setting of policy priorities is done by rationally capturing people's perceptions, then converting the intangible factors into ordinary rules, so they can be compared. The final weighting assessment process carried out there is a rule that the CR value (Consistency Ratio) must have a value of less than 10% or 0.1.
3 Results and discussion

3.1 Landslide Parameter Maps

3.1.1 Lithology

Lithology that made up the research area is part of the Miocene Kerek and Kalibeng Formation, the Kaligetas Formation, and Quaternary Volcanic Deposits. Based on the results of field mapping carried out at the research area, 5 types of lithology were found, namely: Andesite-breccia, Lapilli tuff, Calcarenite Limestone, Calcareous Sandstone, and Calcareous Claystone (Figure 4). Generally, the lithology found at the research area is weathered - fresh condition. There is occurrence of landslides in the lithology of Calcareous Claystone. This lithology is often found on riverbanks with joint structures (Figure 3). The process of surface water erosion through the fractures makes this lithology has a greater potential for landslides to occur. Each lithology unit has a different score, depending on the effect of the type of lithology on landslides. The higher the score, the more influential lithology to the landslide. Based on this, the scores given to each lithology are as seen on Table 1.

Figure 3. Calcareous Claystone lithology found at one of the field observation locations

Figure 4. Geological map resulting from geological mapping at the study area [19].
3.1.2 Slope

The slope of the research area was obtained from the DEM image processing using Arc GIS software. Slope grade 15 to > 45 dominates the study site (Figure 5). The occurrence of the landslide at the research area generally occurs at a slope of > 20. Slope is one of the causative factors that cause landslides. The higher the slope, the more potential to be exposed to geomorphic processes. The geomorphic process will degrade the slope material into loose material. Loose material resulting from rock degradation has a greater possibility of landslides. The slope class at the research area is divided into 5 classes. The greater the slope, the higher the score will be given.

![Figure 5. Slope map resulting from slope analysis using Arc GIS.](image)

3.1.3 Rainfall

The rainfall in the research location was obtained from the results of CHIRPS (Climate Hazards Group InfraRed Precipitation with Station data) processing. Rainfall at the research location is known to be 2500 – 3000 mm/year (Figure 6). Landslides are a common occurrence during heavy rains. Several landslide events at the study site were initiated with high rainfall intensity [5]. With an average rainfall of 2500-3000 mm/year, the research area is included in an area with high rainfall. Thus, the score for the rainfall parameter for that class is given 4.

3.1.4 Distance to Fault (Structure)

The geomorphology of the research area is formed by structural processes. At the research area, many joint structures are found which are an indication of structural influences on the existing landform. The fault structure lines on the geological map become the basis for determining the distance to the fault (Figure 7). The closer the distance to the structure, the greater the potential for landslides to occur.
Figure 6. Rainfall map resulting from CHIRPS image processing.

Figure 7. Fault buffer map showing the distance of the fault structure to the presence of landslides

3.1.5 Land Cover

The land cover at the research area was obtained from the Indonesian topographic map. In general, the land cover in the research area is in the form of: plantation, bush, rice field, settlement, and open area (Figure 8). Land use is very influential on the determination of susceptibility maps. This is because landslides greatly affect the social and economic aspects of citizens. For this reason, every land use has different score. Each score is determined for its effect on the landslides.
Figure 8. Landcover map that shows land use at the research area.

3.2 Landslide Susceptibility Map and Accuracy Assessment

In this research, the preparation of the landslide susceptibility map was produced by multiplying the weight of each parameter by the score of each component of the causative parameters of the landslide. The weighting is carried out using 2 methods, first using the modified guideline and the second is AHP method. Briefly, the difference in parameter weight values can be seen in Table 2.

| No | Parameters       | Modified from Guideline | AHP Method |
|----|------------------|--------------------------|------------|
| 1  | Slope            | 35%                      | 34.4%      |
| 2  | Lithology        | 25%                      | 24.1%      |
| 3  | Landcover        | 10%                      | 7.5%       |
| 4  | Distance to fault| 10%                      | 11.4%      |
| 5  | Rainfall (m)     | 20%                      | 22.6%      |

The weight of the AHP value was obtained using the help of Expert Choice 11 software. By entering the opinion about the weight of the parameters against other parameters as the cause of landslides from 5 respondents. The calculation results show that there is no significant difference between the modified weights from the guidelines and the AHP. Using the scores of each component on the same parameters (Table 1), the resulting map from the weighting can be seen in Figure 9 and Figure 10.
Based on the results of making maps with two different methods, then validation is carried out. Landslide hazard map validation is done by comparing the suitability of the data from the analysis with field data. Field data in the form of an inventory of landslide events encountered during field mapping. Based on field data, there were 58 landslide occurrence points. Landslides that occur in the research area are generally associated with fluviatile processes. The fluviatile process is a means of erosion on the cliffs on riverside. In addition, the type of lithology that passes by water on the fluviatile process also affects the landslides that occur in the research area. Calcareous Claystone is type of the lithology that
contains carbonates which are easily react with water. In addition, this rock also has a composition of clay grain size and minerals that have abilities to holding-water, as of slope is saturated with water and unable to withstand the driving force.

Based on the validation process, suitable value was obtained as shown in Table 3. The map resulting from the modified guideline as seen in Figure 9 contained 45 points out of 58 points of landslide occurrence which are suitable to the susceptibility class. On the other hand, Figure 10 which is the result of the AHP weighting map has suitability of 49 points out of 58 points. The validation calculation shows that map making using the AHP method produces a higher percentage of accuracy than the modified guideline. For this reason, the utilization of the AHP method in the establishment of the landslide susceptibility map is considered to give more suitable results. The process of assigning weights to each parameter that causes landslide by involving several respondents is the key on producing a more appropriate assessment. The composition of the weights produced by AHP is not much different from the composition of the modified guidelines, so it can be said that making a susceptibility map using modified guidelines can also be used for all regions in Indonesia in the context of time efficiency. Because it takes time to make decisions using the AHP method.

| Table 3. Accuracy assessment of two model landslide susceptibility maps |
|-----------------------------------------------|
| Model map | Number of points validated from 58 samples | Percentage |
| Combination of existing weighting references | 45 | 77.58% |
| AHP | 49 | 84.48% |

**4 Conclusion**

Based on the results of the studies that have been carried out in the research, it can be concluded that the results of weighting using the guidelines that have been developed and AHP have similarities. However, the level of accuracy using AHP has greater accuracy. This is because on, the AHP weighting, the measured parameters are weighted according to their portion so that they can be adjusted to the area being researched.

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**Appendix**

| Table A1. Tabulation of landslide occurrence data at the research area. |
|-----------------------------|-----------------|-----------------|-----------------|-------------|------------------|
| No | Coordinate Location | Landslide Type | Direction of Landslide | Dimension (m) | Lithology | Occurrence |
|----|----------------------|----------------|-------------------------|--------------|-----------|------------|
| 1  | 441426, 9208909      | Rotational     | N 285 E                 | 30 x 7       | Calcareous Claystone | River Cliffs |
| 2  | 441955, 9208130      | Rotational     | N 273 E                 | 20 x 15      | Calcareous Claystone | Cliffs |
| 3  | 442016, 9209302      | Rotational     | N 55 E                  | 20 x 10      | Andesitic Breccia   | River Cliffs |
| 4  | 441413, 9211734      | Rotational     | N 120 E                 | 30 x 50      | Andesitic Breccia   | Cliffs |
| No | Coordinat e Location | Landslide Type | Direction of Landslide | Dimensio n (m) | Slope | Lithology | Occurrence |
|----|---------------------|----------------|------------------------|----------------|-------|-----------|------------|
| 5  | 441271, 9212944     | Falls          | N 325 E                | 4 x 7          | 43    | Andesitic Breccia | Cliffs |
| 6  | 444460, 9208623     | Translational  | N 35 E                 | 15 x 10        | 21    | Calcareous Claystone | Cliffs |
| 7  | 444975, 9208813     | Translational  | N 190 E                | 20 x 16        | 36    | Calcareous Claystone | Cliffs |
| 8  | 445145, 9211187     | Falls          | N 280 E                | 7 x 10         | 37    | Andesitic Breccia | River Cliffs |
| 9  | 443126, 9209551     | Translational  | N 120 E                | 32 x 20        | 57    | Calcareous Claystone | Cliffs |
| 10 | 442408, 9211085     | Flows          | N 25 E                 | 4 x 10         | 26    | Calcareous Claystone | Cliffs |
| 11 | 442610, 9210472     | Falls          | N 250 E                | 32 x 21        | 73    | Calcareous Claystone | River Cliffs |
| 12 | 442464, 9210792     | Rotational     | N 110 E                | 30 x 7         | 48    | Calcareous Claystone | River Cliffs |
| 13 | 441664, 9211208     | Translational  | N 360 E                | 18 x 10        | 72    | Calcareous Claystone | River Cliffs |
| 14 | 441317, 8213231     | Falls          | N 285 E                | 28 x 41        | 63    | Calcareous Claystone | River Cliffs |
| 15 | 440866, 9213406     | Flows          | N 50 E                 | 60 x 18        | 63    | Calcareous Claystone | Cliffs |
| 16 | 444816, 9210258     | Flows          | N 298 E                | 40 x 34        | 43    | Andesitic Breccia | River Cliffs |
| 17 | 444379, 9210384     | Translational  | N 295 E                | 30 x 15        | 65    | Andesitic Breccia | River Cliffs |
| 18 | 444399, 9210933     | Flows          | N 250 E                | 20 x 15        | 57    | Calcareous Claystone | River Cliffs |
| 19 | 444238, 9211272     | Falls          | N 325 E                | 20 x 15        | 78    | Calcareous Sandstone | Cliffs |
| 20 | 442815, 9211850     | Translational  | N 296 E                | 10 x 7         | 50    | Calcareous Claystone | River Cliffs |
| 21 | 442437, 9212520     | Flows          | N 150 E                | 25 x 37        | 28    | Calcareous Sandstone | River Cliffs |
| 22 | 442247, 9212687     | Rotational     | N 350 E                | 15 x 10        | 70    | Calcareous Claystone | River Cliffs |
| 23 | 442435, 9212702     | Flows          | N 170 E                | 5 x 10         | 29    | Colluvium | Cliffs |
| 24 | 442648, 9212807     | Rotational     | N 168 E                | 10 x 5         | 77    | Calcareous Claystone | River Cliffs |
| 25 | 442743, 9212680     | Falls          | N 362 E                | 10 x 7         | 81    | Calcareous Claystone | River Cliffs |
| 26 | 444678, 9208792     | Falls          | N 160 E                | 25 x 9         | 79    | Calcareous Claystone | River Cliffs |
| 27 | 446896, 9209057     | Falls          | N 170 E                | 30 x 10        | 60    | Calcareous Claystone | River Cliffs |
| 28 | 447122, 9209274     | Rotational     | N 150 E                | 38 x 17        | 29    | Calcareous Claystone | River Cliffs |
| 29 | 447412, 9209393     | Rotational     | N 170 E                | 15 x 30        | 26    | Calcareous Claystone | River Cliffs |
| 30 | 447676, 9209279     | Falls          | N 325 E                | 40 x 15        | 65    | Calcareous Claystone | River Cliffs |
| No | Coordinate Location | Landslide Type | Direction of Landslide | Dimension (m) | Slope | Lithology | Occurrence |
|----|---------------------|----------------|------------------------|---------------|-------|-----------|------------|
| 32 | 447916, 9209272     | Rotational     | N 245 E                | 35 x 15       | 45    | Calcareous | River Cliffs |
| 33 | 448948, 9210347     | Flows          | N 180 E                | 35 x 35       | 30    | Calcareous | Cliffs |
| 34 | 449696, 9210502     | Flows          | N 110 E                | 7 x 15        | 45    | Calcareous | Cliffs |
| 35 | 449745, 9210111     | Rotational     | N 350 E                | 8 x 15        | 40    | Calcareous | Cliffs |
| 36 | 449903, 9210711     | Falls          | N 340 E                | 20 x 15       | 46    | Calcareous | Cliffs |
| 37 | 449477, 9211617     | Flows          | N 345 E                | 40 x 25       | 40    | Calcareous | Cliffs |
| 38 | 447404, 9213235     | Falls          | N 96 E                 | 30 x 25       | 72    | Andesitic Breccia | Cliffs |
| 39 | 445987, 9209559     | Flows          | N 350 E                | 50 x 10       | 35    | Calcareous | River Cliffs |
| 40 | 446285, 9209791     | Flows          | N 345 E                | 40 x 20       | 25    | Calcareous | Cliffs |
| 41 | 446605, 9210024     | Flows          | N 290 E                | 15 x 20       | 40    | Calcareous | Cliffs |
| 42 | 446312, 9210099     | Falls          | N 190 E                | 30 x 15       | 48    | Calcareous | Cliffs |
| 43 | 445403, 9215797     | Rotational     | N 340 E                | 20 x 10       | 8     | Calcareous | Sandstone Cliffs |
| 44 | 445625, 9215743     | Translational  | N 109 E                | 15 x 8        | 40    | Calcareous | River Cliffs |
| 45 | 446177, 9214207     | Rotational     | N 340 E                | 30 x 60       | 25    | Calcareous | Sandstone Cliffs |
| 46 | 445380, 9214041     | Translational  | N 339 E                | 24 x 13       | 25    | Calcareous | Sandstone Cliffs |
| 47 | 445094, 9213989     | Translational  | N 225 E                | 15 x 17       | 68    | Calcareous | River Cliffs |
| 48 | 448736, 9212455     | Flows          | N 145 E                | 4 x 10        | 65    | Calcareous | Sandstone Cliffs |
| 49 | 448565, 9212311     | Flows Translational | N 160 E | 15 x 5  | 63  | Calcareous | Sandstone Cliffs |
| 50 | 447146, 9212557     | Translational  | N 310 E                | 5 x 7         | 70    | Calcareous | Sandstone Cliffs |
| 51 | 445098, 9212532     | Rotational Translational | N 308 E | 30 x 20 | 25  | Calcareous | Sandstone Cliffs |
| 52 | 443924, 9214847     | Translational  | N 260 E                | 35 x 10       | 68    | Calcareous | River Cliffs |
| 53 | 4441782, 9216379    | Translational  | N 335 E                | 28 x 6        | 26    | Calcareous | Cliffs |
| 54 | 449903, 9210711     | Translational  | N 340 E                | 20 x 15       | 65    | Calcareous | River Cliffs |
| 55 | 443680, 9214564     | Rotational     | N 350 E                | 20 x 15       | 25    | Calcareous | Sandstone Cliffs |
| 56 | 442109, 9212730     | Translational  | N 95 E                 | 15 x 8        | 56    | Calcareous | Sandstone Cliffs |
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