Landslide susceptibility map of Bogor Area using analytical hierarchy process

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Abstract. Landslide is one of the most common disaster in Bogor City and Bogor Regency. BNPB stated that between 2013–2018 there are 44 landslides with death toll of 68 persons. Therefore, it is important to generate map to identify landslide susceptibility in research area. In this study, we try to create landslide susceptibility map of Bogor area (Bogor Regency and Bogor City) using Analytical Hierarchy Process (AHP). We use various factors to identify landslide susceptibility, including slope curvature, slope gradient, topographic wetness index, slope aspect, elevation, stream power index, distance to river, river density, distance to lineament, lineament density, lithology type, soil type, normalized differential vegetation index, rain intensity, land cover, distance to road, and building density. Various factors above are derivative from openly accessed data of Digital Elevation Model (DEM), landslide distribution, Bakosurtanal Map, Landsat 8 Imagery, engineering geology map, rain intensity data, and soil type map. After all, input data collected, the landslide susceptibility map is created using the AHP method. To validate the result, Receiver Operating Characteristic (ROC) applied, the value of the area under the curve (AUC) to determine the success rate of the AHP method is 0.834, this value represents that the landslide susceptibility map produced by the AHP method is a good model.

Keywords: Landslide, AHP, Bogor, susceptibility, ROC

1. Introduction
A landslide disaster is a movement of soil mass and rock down the slope [1]. landslide can occur simultaneously with other geological disasters, such as volcanic eruptions and earthquakes. Landslides have a very detrimental impact, high rates of death and property damage caused by landslides make it one of the most damaging natural disasters in the world [2]. Landslides are natural disasters that occur a lot in Indonesia, causing various economic and social problems. the low awareness and knowledge of the community towards landslides is the cause of many deaths and economic losses. as well as in the Bogor area, landslides are the most frequent natural disaster, so further research on landslides in this area is important.

Landslide susceptibility analysis is carried out using landslide inventory data and its causative factors to determine the distribution of landslide, the level of landslide susceptibility, and predicting future landslide [3]. Important aspects of landslide mitigation are the quality of the landslide inventory and landslide susceptibility map, containing information that can be used by the government for urban planning and land-use policies [4].
Analysis of landslides susceptibility can be done with quantitative and qualitative methods. The use of qualitative methods in landslide susceptibility analysis is done by considering expert opinions and in descriptive ideas [5]. Heuristic approach and landslide distribution analysis are the types of qualitative approaches commonly used in landslide susceptibility modeling [5]. Qualitative and semi-qualitative methods have disadvantages because they depend on expert judgments that are subjective and it is difficult to determine the weights of contributing landslide factors, so the results of both methods are highly dependent on expert knowledge [6]. Quantitative methods in landslide susceptibility mapping use mathematical approaches to determine the probability of landslides and identify landslide susceptibility zones [7]. Quantitative methods that are widely used are landslide frequency analysis methods [8], deterministic analysis methods [9], statistical analysis methods [10] and distribution-free methods [11].

The semi-quantitative method commonly used for landslide susceptibility analysis is the Analytical Hierarchy Process (AHP) [5]. Analytical Hierarchy Process (AHP) method proposed in the study of social science [12]. AHP method is used to determine the value of pairwise comparisons, the value of this comparison is obtained from direct measurements or from a fundamental scale that reflects the relative strength of preferences and feelings [13]. Pairwise comparisons are important and fundamental in the AHP method, the results of the pairwise comparisons are the relative importance of each factor that has been compared, these results are processed into a pairwise comparison matrix [13]. The pairwise comparison matrix is processed into a normalized pairwise comparison matrix to get the weight of each factor.

2. Study area

The research area is in Bogor Regency and Bogor City which has an area of around 3106.88 km² (figure 1). Geographically, the research area is located at latitude coordinate 6°18'0''–6°47'10'' S and longitude coordinate 106°23'45''–107°13'30'' E.

The boundaries of the research area, namely:

a. The North is bordered by Tangerang Regency, South Tangerang City, Depok City, and Bekasi City/Regency.
b. The West is bordered by Lebak Regency.
c. The East is bordered by Kerawang Regency, Cianjur Regency and Purwakarta Regency.
d. The South is bordered by Sukabumi Regency and Cianjur Regency.
Based on the physiographic division of West Java [14], the research area was included in the Bogor zone. The Bogor zone is an anticlinorium due to the intensity of very strong folding of the coating layer formed in Neogene, with some hypabyssal volcanic necks, stocks and bosses intrusion. The Bogor zone is generally a hilly morphology that extends west-east with a maximum width of about 40 km. Composition rocks consist of tertiary sedimentary rocks, intrusive igneous rocks, and extrusive igneous rocks. Based on the Engineering Geological Map of the Western Java Sheet, the study area has many types of lithology, such as breccia, claystone, intrusive rock, limestone, sandstone, and volcanic rock.

3. Landslide inventory and parameter maps
To analyze the landslide susceptibility, it’s important to know the characteristic of landslide inventory and parameter maps. Landslide inventory map contains the distribution of landslides in the study area, the distribution can be compared with the data generated by the parameter map. The landslides data of study area obtained from the National Disaster Management Agency (BNPB) and Geological Agency of the Ministry of Energy and Mineral Resources (ESDM), with 84 locations of landslides (figure 2). The landslide causative factors consist of geomorphological factors (elevation, slope gradient, slope curvature, and slope aspect), geological factors (lithology type, distance to lineament, soil type, and lineament density), hydrological factors (stream power index, topographic wetness index, distance to river, rain intensity, and river density), and anthropological factors (normalized differential vegetation index, land cover, distance to road, and building density). The all landslide causative factor maps in this study has 44,751,091 pixels count (figure 3 and figure 4).

Elevation and slope gradient are related to landslides. In the study area, many landslides occur at elevations above 550 meters and slope gradient above 15°. Slope aspect shows the direction of the slope refers to geographical conditions, slope aspects related to rainfall, the level of sun exposure, and morphogenesis [15]. Slope curvature shows the shape of the slope surface, namely concave, convex, or straight. In the study area, landslides often occur in concave and convex slope curvature.

Distance to river and river density can affect the stability of the slope, the slope near the river is affected by the process of erosion by water, it can produce slope instability [16]. Stream Power Index (SPI) shows flow conditions with moderate erosion rates associated with sudden changes in topography and slopes. Topographic Wetness Index (TWI) analyzes the point to point upstream cumulative flow rate with the slope gradient of each runway [15]. Rainfall can affect the stability of slopes and increase the probability of landslides, the study area has a high level of rainfall.

Lithology is an important factor in the analysis of landslide susceptibility, because the stability of slopes is influenced by the type of lithology [17]. Soil type shows soil characteristics and engineering, has a relation with slope stability. Distance to lineament and lineament density can affect slope failure and slope vulnerability, the closer to the structure the more susceptible to landslides.

Distance to road is related to landslides, many landslides occur as a by-product of excavation, road construction, trenching, and settlement construction [18]. Building density can also be a factor causing landslides, many landslides that occur in settlements because the land is not able to hold the building on it. Land cover provides physical information on the study area, such as geomorphological, pedological, vegetation, agriculture, animal husbandry, etc [19]. Normalized Difference Vegetation Index (NDVI) describes areas that have live vegetation or not, most of the research areas have living vegetation. In this study, landslides are generally found in areas with low greenness and no vegetation.

The Digital Elevation Model (DEM) data in this study is separated into 12 scenes, so it is necessary to combine each of these scenes to obtain DEM data of the study area. The DEM data has a resolution of 27-arcsecond, with a vertical datum EGM2008. DEM data is used to create elevation map, slope gradient map, slope curvature map, slope aspect map, SPI map, and TWI map. The elevation map, slope gradient map, SPI map, and TWI map are classified into 10 classes based on quantile method. The slope curvature map is classified into 3 classes: concave, convex, and flat, whereas slope aspect map has been classified automatically into 10 classes. The equation used to make the SPI and TWI maps in sequence:
SPI = Ln(("flow_accumulation.tif" + .001) * ("slope_degree.tif" / 100)+.001))

TWI = Ln(("flow_accumulation.tif" + .001) / ("slope_degree.tif" / 100)+.001))

The landsat 8 imagery data in this study is separated into 2 scenes, so it is necessary to combine each of these scenes to obtain landsat 8 imagery data of the study area. Landsat 8 imagery data is used to create NDVI map, lineament density map, and distance to lineament map. NDVI map is made by measuring the difference between Band 5 (near-infrared radiation) and Band 4 (red visible light). The NDVI map, distance to lineament map, and lineament density map are classified into 10 classes based on quantile method.

\[
NDVI = \frac{(\text{Band 5} - \text{Band 4})}{(\text{Band 5} + \text{Band 4})}
\]

Bakosurtanal map contains information on the shape of the earth in a shapefile format in the form of polygons or polylines. The coordinate system of the bakosurtanal map is geographical coordinate system. Bakosurtanal map is used to create river density map, distance to river map, building density map, distance to road map, and land cover map. The river density map, distance to river map, building density map, and distance to road map are classified into 10 classes based on quantile method, while the land cover map is classified into 11 classes: lake, building, forest, plantation, settlement, rice field, shrubs, river, heath, field, and other vegetation. Lithology maps are made by registering the Engineering Geological Map of the Western Java Sheet into Arc-GIS software and digitizing. Digitization aims to make several polygons in the new shapefile containing information about the type of lithology in the polygon. The lithology type map is classified into 6 classes: breccia, claystone, intrusive rock, limestone, sandstone, and volcanic rock. In the study area, volcanic rock has the widest distribution, while sandstone has the narrowest distribution.

Rainfall intensity data is annual rainfall data in several places in the study area collected in one Microsoft Excel worksheet, the place for collecting rainfall data in the study area: Bogor Climate Station, Jasinga, Cianten, Gunung Mas, Empang, Kebun Raya, Citeko, Katulampa, Cibinong, Dayeuh, Cibodas, Atang Sanjaya Airport, Klapa Nunggal, Kuripan, Cikasungka, Cibalagung, and Tunggilis. Rainfall intensity data is processed in the Arc-GIS software to get rainfall intensity map. Rainfall intensity map is classified into 5 classes based on quantile method.

![Landslide inventory map of research area](image-url)

Figure 2. Landslide inventory map of research area.
The soil type map was carried out using soil type map that published by the Ministry of Agriculture’s Research and Development Center in 2010 on 1:250.000 scale. The soil map type is processed in ArcGIS software. The soil type map is classified into 7 classes: tropaquepts, dystrandepts, tropudults, paleudults, tropudalfs, dystropepts, and eutropepts.

Based on the Frequency Ratio (FR) analysis of landslide causative factors maps, it was found that:

a. If the value of elevation, slope, SPI, lineament density, distance to lineament, river density, and building density are higher, then the FR value will be relatively higher (directly proportional).

b. If the value of TWI, NDVI, distance to river, distance to road, and rainfall intensity are higher, then the FR value will be relatively lower (inversely proportional).

c. The value of the Frequency Ratio (FR) on the slope aspect factor shows that each class has a relatively equal FR value, so the significance of each class is relatively the same.

d. The value of the frequency ratio (FR) on the slope curvature factor indicates that the concave and convex slope forms have relatively similar frequency ratio values, but have a significant difference FR values with the flat slope shape.

e. The value of the frequency ratio (FR) of soil type, lithology type, and land cover shows non-uniformity, this indicates that there is a class that has a higher significance than the other classes.

4. Analytical hierarchy process

AHP method is used to determine the value of pairwise comparisons, the value of this comparison is obtained from direct measurements or from a fundamental scale that reflects the relative strength of preferences and feelings [13]. AHP has special attention to deviations from consistency, measurement, and dependence between groups of structural elements. AHP is a method that can be used to establish assessments in the physical and social domains, so that AHP is a multi-criteria Decision Making (MCDM) analysis method.

Pairwise comparisons are important and fundamental in the use of AHP, this comparison is done on two factors or criteria by setting priorities to determine the relative importance of the two factors, so that it can produce a pairwise comparasion matrix [13]. The Pairwise comparasion matrix that has been generated is reprocessed into a normalized paired comparasion matrix to get the weight (Wi) of each factor or criterion.

In the AHP Model, Consistency Ratio (CR) is used to represent the probability that matrix assessments are generated randomly [20]. If the CR value is smaller or equal to 10% then the results of the matrix calculation in the AHP method can be accepted, the CR value becomes important in determining the results of an acceptable study [13].

\[
CR = \frac{CI}{RI}
\]  

(4)

\[
CI = \frac{\lambda \text{max} - n}{n - 1}
\]  

(5)

where, CR is consistency ratio, CI is index of consistency, and RI is random consistency index, \( \lambda \text{max} \) is the highest eigenvalue value, and n is the number of matrices.
Figure 3. Parameter maps: (a) lithology type, (b) lineament density, (c) slope curvature, (d) NDVI, (e) land cover, (f) SPI, (g) river density, and (h) TWI.
Figure 4. Parameter maps: (a) rain intensity, (b) distance to lineament, (c) elevation, (d) soil type, (e) distance to river, (f) distance to road, (g) building density, (h) slope aspect, (i) slope gradient.
5. Results and discussion

5.1. Analytical Hierarchy Process

Pair-wise comparison matrix is carried out to know the weight of each factor by making a comparison between each factor based on the scale of comparison of importance (table 1). The landslide causative factor that have the highest weight is distance to road, which is equal to 0.18, while the landslide causative factor that have the lowest weight is the distance to lineament, which is equal to 0.01.

Distance to road have a high weight because it has a strong relationship with the location of the landslide, while the distance to lineament has a weak relationship with the location of the landslide. Thus, the higher the weight of the factors causing landslides, the higher the relationship between these factors and the location of the landslide. Then, the weight represent the relationship between each landslide causative factor and the actual landslide events. The weight will be processed into the landslide susceptibility map of Bogor Area. The Consistency Ratio value is 0.048, so the AHP model can be accepted.

After obtaining the weight of each landslide causative factor, calculations are made using the raster calculator in ArcGIS show in equation 6.

\[
LSM = ((\text{Elevation } \times Wi) + (\text{Slope Gradient } \times Wi) + (\text{Slope Aspect } \times Wi) + \\
(\text{Slope Curvature } \times Wi) + (\text{SPI } \times Wi) + (\text{TWI } \times Wi) + \\
(\text{Rain intensity } \times Wi) + (\text{Lithology Type } \times Wi) + (\text{River Density } \times Wi) + \\
(\text{Distance to Lineament } \times Wi) + (\text{Distance to River } \times Wi) + (\text{Distance to Road } \times Wi) + \\
(\text{Lineament Density } \times Wi) + (\text{Building Density } \times Wi) + \\
(\text{NDVI } \times Wi) + (\text{Land Cover } \times Wi) + (\text{Soil Type } \times Wi))
\]  

(6)

The landslide susceptibility map of Bogor Area with AHP method is divided into 6 classes, namely very low, low, moderate, moderately high, high, and very high (figure 5). Based on the map produced, getting to the south, the susceptibility of landslides is relatively higher. This is directly proportional to the spread of the landslide location in the Bogor Area which are increasing to the south.

| Table 1. Weight of landslide causative factors. |
|-----------------------------------------------|
| Landslide causative factors | Weight (Wi) |
|--------------------------------|-------------|
| Elevation                     | 0.12        |
| Slope Gradient                | 0.13        |
| Slope Aspect                  | 0.04        |
| Slope Curvature               | 0.01        |
| SPI                           | 0.01        |
| TWI                           | 0.02        |
| Rain Intensity                | 0.07        |
| Lithology Type                | 0.06        |
| River Density                 | 0.03        |
| Distance to Lineament         | 0.01        |
| Distance to River             | 0.02        |
| Distance to Road              | 0.18        |
| Lineament Density             | 0.02        |
| Building Density              | 0.06        |
| NDVI                          | 0.04        |
| Land Cover                    | 0.09        |
| Soil Type                     | 0.09        |
In the very low class, the area of the class covers 16.35% of the total area of study, the number of landslides that occur in the first class is 1. Furthermore, in the second class (low), the total area of the class includes 16.86% of the total area of research, the number of landslides that occur in the second class is 4. Furthermore, in the third class (moderate), the area of the class includes 17.34% of the total area of research, the number of landslides that occur in the third class is 7. Furthermore, in the fourth class (moderately high), the total area of the class covers 16.95% of the total area of research, the number of landslides that occur in the fourth class is 6. Furthermore, in the fifth class (high), the area of the class covers 16.27% of the total research area, the number of landslides that occur in the fifth class is 15. Furthermore, in the sixth class, the area of the class includes 16.22% of the total research area, the number of landslides that occur in the sixth class is 51. Based on these data, it can be concluded that the sixth class has the highest number of landslides and the third class has the largest area.

5.2. Receiver Operating Characteristic (ROC) Curve
The ROC curve is a comparison between sensitivity and 1-specificity (figure 5). When sensitivity = 100% and specificity = 100% (1-specificity = 0%), the resulting model is a perfect model. So, the closer the ROC curve to the reference line, the worse the resulting model will be. The ROC curve generated from the AHP method is fairly good because it forms far above the reference line. The area under the curve (AUC) value is useful to measuring how good the ROC curve is produced. If the ROC curve is further above the reference line, the area under the ROC curve will be even greater. So that the greater the AUC value, the better the landslide susceptibility map produced by the AHP method. The AUC value in the AHP method is 0.834, the value is fairly good, so the landslide susceptibility map produced from the method is also fairly good.

6. Conclusion
In the presented work, we evaluate the spatial landslide susceptibility of Bogor Area (West Jawa, Indonesia). By using 17 landslide causative factors and 84 landslide location, we created a landslide susceptibility model in the study area, then the data are processed using the AHP method. The landslide susceptibility model of the AHP method was validated with Receiver Operating Characteristic (ROC) curve.

The all landslide causative factors are associated with landslides in the study area. Distance to road, elevation, and slope gradient are the most influential controlling factors on the landslide susceptibility model in the study area. Based on the AHP model, distance to road is the factor that has the highest weight, indicating that these factors have a strong relationship with the landslides that occur in the study...
area. Based on the landslide susceptibility map, we can conclude that the southern part of the study area has a higher landslide susceptibility than the surrounding area. The Consistency Ratio value of AHP models is 0.048, the value is acceptable because it shows that the assessment of the matrix has been generated randomly. Based on the results of the validation, the landslide susceptibility map of study area has good results, with the AUC value is 0.834.

Landslide mitigation actions in the Bogor Area must be improved, because 16.22 % of the research area is a very high level of landslide susceptibility. Government concern and community participation in preventing landslides can reduce the risk of landslides. In addition, the landslide susceptibility map can be used as information for the government in regional development plans, thus providing better economic benefits for the Bogor Area.

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References
[1] Cruden D and Couture R 2011 The Working Classification of Landslides: Material Matters available at http://geoserver.ing.puc.cl/info/conferences/PanAm2011/panam2011/pdfs/GEO11Paper1106.pdf
[2] Schuster R 1996 Socioeconomic significance of landslides Landslides: Investigation and Mitigation: Special Report vol 247 ed Turner et al. (Washington DC: National Academic) pp 12-36
[3] Cheng C T, Huang C M, Wei L W, Lee C F and Lee C T 2013 Landslide susceptibility map ICL Landslide Teaching Tools Int. Consortium on Landslides 50-5
[4] Erkanoglu M 2005 Nat. Hazards Earth Syst. Sci. 5 979-92
[5] Mandal B and Mandal S 2018 Adv. Space Res. 62 3114-32
[6] Aditian A, Kubota T and Shinohara Y 2018 Geomorphology 318 101-11
[7] Guzzetti F, Carrara A, Cardinali M and Reichenbach P 1999 Geomorphology 31 181-216
[8] Giannechini R, Naldini D, Avanzi G D and Puccinelli A 2007 Quat. Int. 171 108-17
[9] Tazik E, Jahantab Z, Bakhttari M, Rezaei A and Alavipanah S K 2014 The Int. Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences vol XL-2/W3 1st ISPRS Int. Conf. on Geospatial Information Research (Tehran, Iran)
[10] Lee S, Ryu J H and Kim I S 2007 Landslides 4 327-38
[11] Lee S and Pradhan B 2007 Landslides 4 33-41
[12] Saaty T L 1977 J. Math. Psychol. 15 234-81
[13] Saaty R W 1987 Mathematical Modelling 9 161-76
[14] Van Bemmelen R W 1949 The Geology of Indonesia (The Hague: Government Printing Office)
[15] Ortiz J A V and Martinez-Gran A M 2018 Geomat. Nat. Haz. Risk 9 1106-28
[16] Gokceoglu C and Aksoy H 1996 Eng. Geol. 44 147-61
[17] Meinhardt M, Fink M and Tünschel H 2015 Geomorphology 234 80-97
[18] Regni A D et al. 2014 Arab J. Geosci. 7 725-42
[19] Pascale S et al. 2013 Int. Conf. Comput. Sci. Appl. 2013 473-88
[20] Saaty T L 1994 Interfaces 24 19-43