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LANDSLIDE SUSCEPTIBILITY ZONATION BASED ON FREQUENCY RATIO METHOD, IN KARAHA BODAS GEOTHERMAL FIELD, WEST JAVA

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Sari - Indonesia memiliki potensi energi panas bumi yang cukup unik karena letak sumber panas bumi yang berada di kawasan pegunungan dengan kondisi lereng yang cukup terjal dan struktur geologi yang cukup kompleks. Pada umumnya lapangan panas bumi bertemperatur tinggi berada di daerah vulkanik dengan relief yang tinggi, morfologi curam, terdapat batuan dengan alterasi hidrotermal yang menghasilkan tanah yang cukup tebal, dan curah hujan yang tinggi. Hal tersebut yang menjadi ancaman dalam pengembangan panas bumi yang menyebabkan bencana longsor. Penelitian ini bertujuan untuk mengevaluasi parameter yang sangat berpengaruh terhadap kejadian longsoran di daerah penelitian, memetakan kerentanan longsoran di area panasbumi Karaha Bodas dengan metode Frequency Ratio (FR), metode Fuzzy Logic (FL), dan kombinasi metode FR - FL serta mengetahui dan mengevaluasi metode statistik yang lebih tepat untuk menentukan zonasi kerentanan longsoran pada daerah penelitian. Berdasarkan inventaris kejadian longsor yang didapat dari PVMBG, BPBD setempat, dan penginderaan jauh, terdapat 538 longsoran pada daerah penelitian. Data kejadian longsor tersebut kemudian dibagi menjadi dua kelompok secara acak, yaitu data training 70% (377 longsoran) dan data test 30% (161 longsoran). Terdapat 16 parameter yang digunakan untuk mengetahui pengaruhnya pada kejadian longsor, diantaranya ketinggian, kemiringan lereng, arah lereng, kurvatur, litologi, arah aliran, jarak dari jalan, densitas kelurusan, jarak dari kelurusan, densitas sungai, jarak dari sungai, Stream Power Index (SPI), Topographic Wetted Index (TWI), curah hujan, Normalized Differential Vegetation Index (NDVI) dan penggunaan dan penutupan lahan. Nilai Area Under Curve (AUC) dari parameter penyebab longsoran yang berpengaruh terhadap kejadian longsoran adalah ≥ 0,6. Berdasarkan nilai AUC, parameter yang sangat berpengaruh terhadap kejadian longsoran pada daerah penelitian dengan metode FR adalah kemiringan lereng, tata guna tutupan lahan, densitas sungai, ketinggian, jarak dari jalan, litologi, jarak dari sungai, curah hujan, NDVI, TWI, dan kurvatur. Hasil evaluasi nilai AUC success rate menunjukan metode FR (0,786) dan hasil evaluasi nilai AUC prediction rate menunjukan metode FR (0,793). Berdasarkan hasil penelitian disimpulkan bahwa metode FR memiliki akurasi nilai AUC yang berpengaruh untuk zonasi kerentanan longsoran pada area panas bumi Karaha Bodas dan sekitarnya.

Kata kunci: Karaha Bodas, longsoran, frequency ratio

Abstract *– Indonesia has the potential of geothermal energy which is quite unique because of the location of geothermal resources in mountainous areas with fairly steep slopes and complex geological structures. In general, high temperature geothermal fields are located in volcanic areas with high relief, steep morphology, thermal alteration rocks that produce thick soil, and high rainfall. It has become challenge in developing geothermal since it may cause landslides. This study aims to evaluate the parameters that have a strong influence on landslides in this research area, map the landslide susceptibility in Karaha Bodas geothermal area by using Frequency Ratio (FR) method, Fuzzy Logic (FL) method and FR – FL combination method, to knowing and evaluate more precise statistical methods to determine landslide susceptibility zoning in the study area. Based on the inventory of landslides obtained from PVMBG, local BPBD, and remote sensing, there were 538 landslides in study area. The landslide event data are divided randomly into two groups, namely 70% training data (377 landslides) and 30% test data (161 landslides). About 16 parameters were used to determine their effect on landslides. It is including elevation, slope, aspect slope, curvature, lithology, flow direction, distance from the road, lineament density, distance to lineament, drainage density, distance to drainage, Stream Power Index (SPI), Topographic Wetted Index (TWI), rainfall, Normalized Differential Vegetation Index (NDVI) and Land Use and Land Cover (LULC). The value of the area under curve (AUC) of the parameters causing landslides that affect landslides is ≥ 0.6. Based on the AUC value, the parameters that affect occurrence of landslides in the study area using the FR method are slope, LULC, drainage density, elevation, distance to road, lithology, distance to drainage, rainfall, TWI, NDVI, and curvature. The results of the evaluation of the AUC success rate value show the FR method (0.786) and the evaluation results of the AUC prediction rate value show the FR method (0.793). Based on the results of the study, it was concluded that the FR method has an accurate AUC value which affects the landslide susceptibility zoning in the Karaha Bodas geothermal area and its surroundings.*

Keywords*: Karaha Bodas, landslide, frequency ratio*

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1. INTRODUCTION

Landslides are the movement of slope-forming materials in the form of rock, debris, soil, or mixed materials that move down or out of the slope (Center of Volcanology and Geological Hazard Mitigation, 2015). Landslides are usually caused by internal and external factors. Internal factors that cause landslides are areas which are steep hilly areas and can disrupt the stability of the soil or constituent rocks, while external factors that cause landslides are high rainfall because Indonesia is a country with a tropical climate, dense population, forest conversion, low awareness society and less supervision.

Geothermal Energy is a renewable (sustainable) energy and environmentally friendly compared to fossil energy. Geothermal energy is local energy that must be processed immediately (site specific) so thus the processing of geothermal steam into electricity is not far from the location where geothermal steam is produced. One of the characteristic of geothermal potential areas that is quite unique and becomes a challenge for Indonesia is the location of geothermal sources in mountainous areas with fairly steep slope conditions and quite complex geological structures. Leynes (2005) states that in general, high-temperature geothermal fields are located in volcanic areas with high relief, steep morphology, thermal alteration rocks that produce thick soil, and high rainfall. This is a threat in geothermal development which causes landslides.

There were 4 landslides in the geothermal area in West Java in 2012, 12 locations in 2013, 5 locations in 2014, 12 locations in 2016, 18 locations, and 6 locations in 2017. Landslide data in the PLTP area located in West Java Province can be seen in **Table 1** and **Figure 1** is data from the Geothermal Directorate regarding the frequency of landslides at the Geothermal Power Plant (PLTP) in West Java in a period of six years.

PLTP Karaha Bodas is one of the geothermal areas owned by PT Pertamina Geothermal Energy (PGE) which has a large number of landslides. Based on these facts, PLTP Karaha Bodas is one of the geothermal areas that has a high enough landslide vulnerability in West Java Province. (**Figure 1** and **Table 1**).

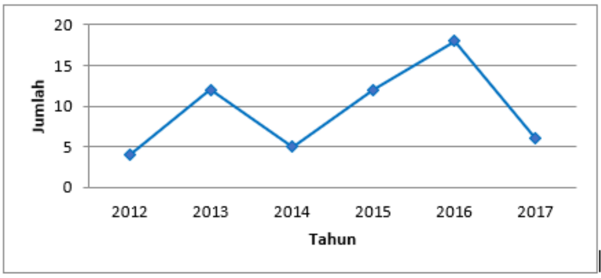

Figure 1. Frequency of landslides in PLTP West Java 2012-2017 (Directorate of Geothermal, 2019).

Table 1. Landslide data at PGE Karaha Bodas 2013 - 2016 (Directorate of Geothermal, 2019).

PLTP/ Kabupaten	Tahun	Total kejadian longsor	Volume longsor (m^3)	Dampak
Karaha Bodas/ Tasikmalaya	2013	3	60	Menutup akses jalan dan portcamp drilling
	2014	2	140	Tanah tebing longsor masuk ke dalam balong
	2016	7	985	Menutup akses jalan

In this study, the research area is located in Tasikmalaya Regency, Garut Regency, Ciamis Regency, Majalengka Regency, and Sumedang Regency, West Java (**Figure 2**). The research location is bordered by Garut Regency in the west, Ciamis Regency in the east, Sumedang Regency in the north, and Tasikmalaya Regency in the south. The research area is approximately 99 km from Bandung City or approximately 3 hours by car.

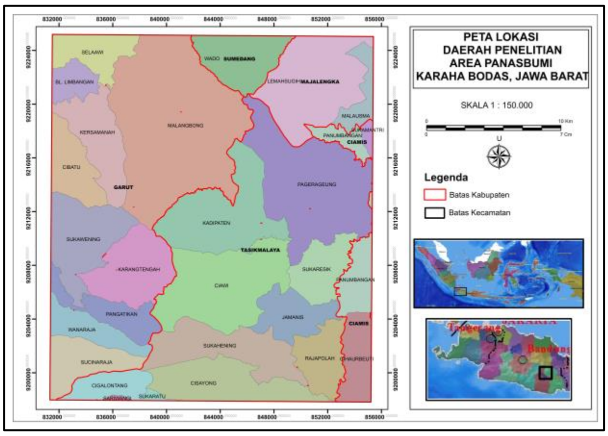

Figure 2. The study area locations (www.indonesia-geospasial.com).

The research area is physiographically located between the Bogor Zone and the Bandung Zone, specifically Mount Galungggung is located in the Quarter Mountain Zone. This zone is included in the middle depression zone, which is formed by depression between mountains and the peak of the West Java anticline which collapsed after uplift, then filled with young volcanic deposits. The presence of volcanoes in West Java is associated with a west-east trending depression in the central part of West Java.

The geological structure of the study area can cause variations in rock strength and the stratigraphic soil texture of the study area that are affected the occurrence of landslides. Based on the Geological Map of the Karaha-Talaga Bodas area (Ganda et al., 1986 in the Geothermal Directorate, 2017) it is composed of 17 rock units. All rock units can be grouped into 2 geological age groups, namely:

1) Tertiary rock unit group, in the form of Volcanic Breccia I Mount Sadakeling which is composed of lava deposits and molten lava with a rock age of 1.74 million years and
2) Quaternary rock unit group, consisting of 16 rock units,

In this research, it is necessary to map the landslide susceptibility in the Karaha Bodas geothermal area using the Frequency Ratio (FR) method and to evaluate the parameters that are very influential on the occurrence of landslides in the study area (**Table 2**).

2. DATA AND METHODOLOGY

2.1 Data

At the data collection stage, data was obtained from related agencies, derived from the Digital Elevation Model (DEM) and Landsat 8 data. The data used in the study are shown in **Table 2.**

Table 2. The data used in the study (Mandal and Mondal, 2018).

No	Parameter Data	Sumber	Tipe
1	Landslides	Badan Geologi, BPBD dan remote sensing	Point
2	Elevation	SRTM DEM	ARC/INFO grid
3	Slope	SRTM DEM	ARC/INFO grid
4	Slope aspect	SRTM DEM	ARC/INFO grid
5	Curvature	SRTM DEM	ARC/INFO grid
6	Lithology	Badan Geologi, Peta Geologi Lembar Tasikmalaya (Budhitrisna, 1986).	ARC/INFO polygon coverage
7	Flow direction	SRTM DEM	ARC/INFO polyline
8	Distance to road	Badan Informasi Geospasial (BIG)	ARC/INFO polygon
9	Lineament density	SRTM DEM dan Badan Geologi	ARC/INFO polyline
10	Distance to lineament)	SRTM DEM dan Badan Geologi	ARC/INFO polyline
11	Drainage density	Badan Informasi Geospasial (BIG)	ARC/INFO polyline
12	Distance to drainage)	Badan Informasi Geospasial (BIG)	ARC/INFO polyline
13	Stream power index (SPI)	SRTM DEM	ARC/INFO grid
14	Topographic wetted index (TWI)	SRTM DEM	ARC/INFO grid
15	Rainfall)	The Center of Hydrometeorology and Remote Sensing (CHRS)	ARC/INFO polygon
16	Normalized differential vegetation index (NDVI)	SRTM DEM dan Landsat 8	ARC/INFO grid
17	Land use and land cover (LULC)	Kementerian lingkungan Hidup dan Kehutanan RI	ARC/INFO polygon

2.2 Methodology

The inventory of landslides in the study area was obtained by combining primary data and secondary data in a spatial digital format represented in the form of a point (geo-referenced point). The total landslide incidents in the study area were 538 landslide locations, which were obtained from plotting the landslide point from PVMBG, BPBD and remote sensing, mapped then digitized and converted into raster form in ArcGIS 10.3 with a grid of 30.9 x 30.9 m cells.

The landslide data is divided into 2 sets randomly as test data for the effect of parameters on landslide events and validation. The greater the percentage of the data set for analysis, the greater the validation value (AUC) obtained. This is because the more data point landslide locations used in the analysis, the higher the AUC value obtained, for example in the data set of 85% : 15%. However, 15% of data sets for validation are considered less representative for validation. This study used a data set of 70% : 30% because the data set of 70% was considered representative enough for the analysis and 30% was considered sufficient to represent the validation analysis. Data sharing is done automatically using “the feature subset toolbox” in ArcGIS with the division of the proportion 70% for test (Ls_train) or about 377 landslide location and 30% for validation (Ls_test) or around 161 landslide location (**Figure 3**).

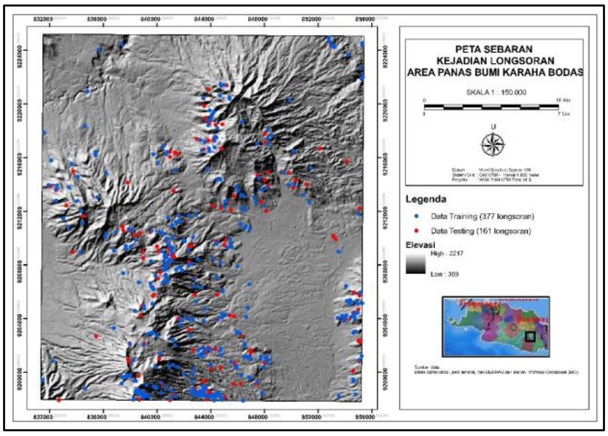

Figure 3. Distribution map of landslides for testing (training data) and validation (test data) of the Karaha Bodas geothermal area.

The landslide parameter is one of the important things in a landslide susceptibility zoning modeling, which aims to determine the spatial relationship of each parameter class and landslide points in predicting landslide vulnerability in the study area. The parameter data obtained are used as factors causing landslides and are classified according to their nature. The required parameter is a factor causing landslides.

First of all, in this process, corrections are carried out to homogenize the data. The parameter spatial data must have the same projected coordinate system, namely the UTM 48S Zone of the SRTM DEM. Corrections are made to the number of pixels in each parameter, if the number of pixels is not uniform it will affect and produce less valid data. The trick is to use “the toolbox” (spatial analysis tools - hydrology - fill). DEM data is used to populate the analysis raster. The result of this correction is the uniformity of the number of pixels for each parameter, namely 30.9 x 30.9 m. This study uses a spatial and statistical approach as the unit of analysis in accordance with the provisions and guidelines of the Badan Geologi (2015).

The next process is reclassification for each landslide parameter to get the area of each class and then multiplied it by the landslide point training data so that the number of landslides in each class is obtained in a landslide parameter. All area data, the number of landslide points and weighted data are compiled in a Microsoft Excel systematic table to calculate the frequency ratio (Bonham, 1994 in Wilopo and Pradana, 2018).

The frequency ratio method is a bivariate statistical method that connects past landslides and the factors that cause landslides by using ArcGIS software to assess the potential for landslides from each class of all data layers (Mandal and Mondal, 2018). Furthermore, the FR for each type and factor is calculated by dividing the ratio of landslide events by the area ratio (Karim et al., 2011) in **Equation 1**.

$$\mathrm{Fr_i} = \frac{N_{pix(s_i)}/N_{pix\,(N_i)}}{\sum N_{pix\,(s_i)}/\sum N_{pix\,(N_i)}} \qquad \text{……. \textbf{Equation 1}}$$

with,

FR = frequency ratio for each particular factor class

$N_{pix(s_i)}$ = Number of pixels in a class (i) in a certain factor

$N_{pix\,(N_i)}$ = Number of pixel area in a class (i) in a

certain factor
$\sum N_{pix\,(s_i)}$ = Number of avalanche pixels in a certain factor
$\sum N_{pix\,(N_i)}$ = The total number of pixel areas in the entire study area

Parameters that affect landslide susceptibility are selected based on the AUC parameter value. The value of the area under curve (AUC) = 0.6 is the minimum limit allowed to state a parameter that affects landslides. The recommended parameter is to use 4 valid parameters.

The AUC calculation formula is as follows (Chung and Fabbri, 2003 in Pamela, 2017):

$$\text{AUC} = \sum_{i=1}^{n+1} \frac{1}{2}\sqrt{(x_i - x_{i+1})^2 (y_i} + y_{i+1}) \quad \text{...... \textbf{Equation 2}}$$

with,
x_i = the percentage of area
y_i = the percentage of landslides.

From the values of the frequency ratio of each parameter whose AUC value is ≥ 0.6 are then added up (**Equation 3**) using the raster calculator feature in ArcGIS 10.3 so that the Landslide Susceptibility Index (LSI) value is obtained to produce a landslide vulnerability index map (Pradhan, 2010).

$$\text{LSI} = Fr_1 + Fr_2 + \ldots + Fr_n \quad \text{......\textbf{Equation 3}}$$

with,
LSI = Landslide susceptibility index
Fr = Frequency ratio of each range / rating for each class / range of factors causing landslides

Furthermore, validation is carried out on the landslide susceptibility index map of the FR method to determine the performance of the method based on the AUC value by reclassifying (265 classes) with the natural break method using the reclassify tool feature in ArcGIS 10.3. The reclassified map results are then multiplied by the training landslide data to validate the success rate and the landslide test data to validate the prediction rate, in order to obtain a range of values for susceptibility, area, and landslide.

Furthermore, the zoning of susceptibility is carried out using the provisions in SNI 8291 (BSN, 2016) by dividing the landslide zone for the very low zone as 0-5%, 5-15% low zone, 15-25% medium zone, and more than 25% high zone, respectively of the total landslide occurrences in ArcGIS 10.3, resulting in a landslide susceptibility zoning map with the FR method.

3. RESULTS

The total landslide in the study area were 335 landslide locations. The landslide event data is then divided randomly into two groups, 70% training data (235 landslide location) and 30% test data (100 landslide location).

There are sixteen parameters used to determine their effect on landslides, including elevation, slope, slope aspect, curvature, lithology, flow direction, distance to road, lineament density, distance to lineament, drainage density, distance to drainage, Stream Power Index (SPI), Topographic Wetted Index (TWI), rainfall, Normalized Differential Vegetation Index (NDVI), and Land Use Land Cover (LULC).

Furthermore, reclassification is carried out for each landslide parameter to obtain the area of each class and then multiplied by the landslide point training data so that the number of landslides in each class is obtained in a landslide parameter. All the area data, the number of landslide points and the weighted data are arranged in a Microsoft Excel systematic table and the frequency ratio is calculated. The following are maps of parameters that have been classified and received an AUC value ≥ 0.6.

1) Slope
Slopes was classified into 7 classes (**Figure 4**), manually in ArcGIS (equal interval). In the study area, the most prone to landslides occurred in slope class 4 (15 - 30%) with 164 landslides and slope class 3 (8 - 15%) with 115 landslides. AUC value is 0,729.

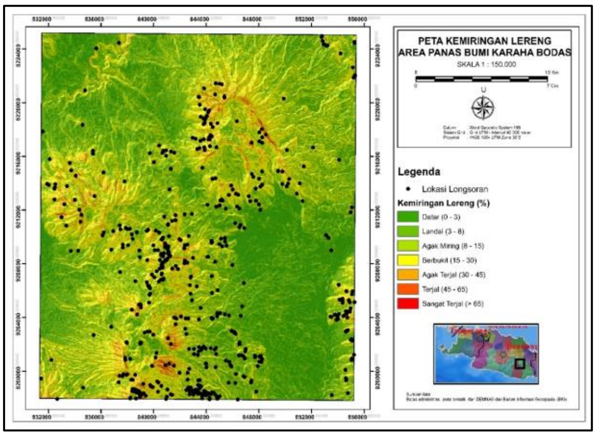

Figure 4. Map of slope to landslide distribution.

2) LULC

LULC was classified into 10 classes (**Figure 5**) based on data from forestry sites. Most landslide events were found in class 3, namely 172 landslides in Industrial Park Forests and in class 9, which was 112 landslides in Dry Soil Mixed with Fat Agriculture. AUC value is 0,709.

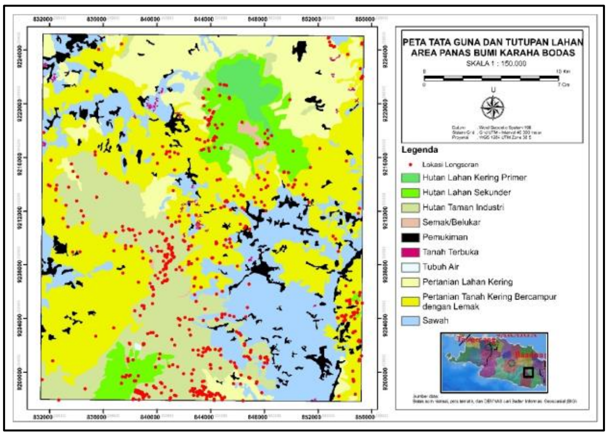

Figure 5. Map of land use land cover on landslide distribution.

3) Drainage Density

Drainage density was classified into 9 classes (**Figure 6**), manually on ArcGIS (equal interval). The river density which is most prone to landslides occurs in class 2 with river density of 0.5 - 1 with 101 landslides, classes 3 and 4 with river density of 1 - 1.5 and 1.5 - 2 with 94 and 82 landslides. AUC value is 0,654.

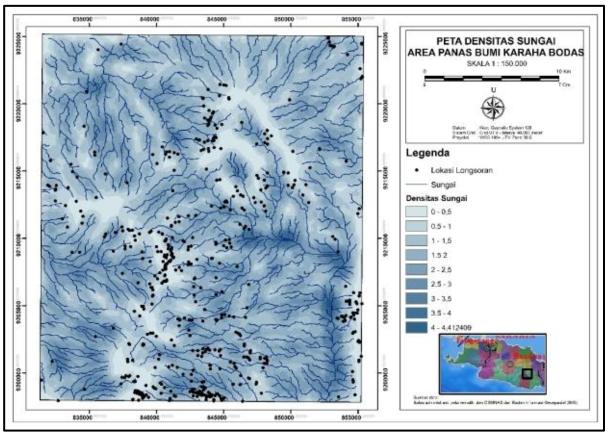

Figure 6. Map of drainage density to landslide distribution.

4) Elevation

Elevation was classified into 10 classes (**Figure 7**), manually on ArcGIS (equal interval). In the study area, the most prone to landslides occurred at altitude class 3 (700 – 900 m) with 88 landslides, altitude class 4 (900 – 1100 m) with 72 landslides, and altitude class 2 (500 – 700 m) with 61 landslides. AUC value is 0,651.

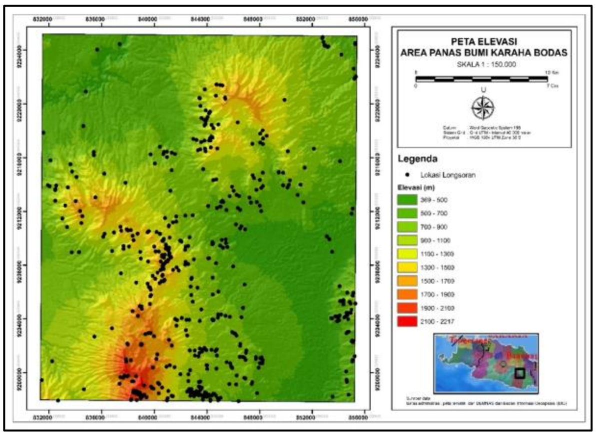

Figure 7. Map of the elevation to the landslides distribution.

5) Distance to Road

Distance to road was classified into 10 classes (**Figure 8**), manually in ArcGIS (equal interval). The distance from the road that is most prone to landslides occurs in class 1 with a distance from the road of 0 - 430 m as many as 201 landslide events and class 2 with a distance from the road 430 - 860 m as many as 64 landslide events. AUC value is 0,632.

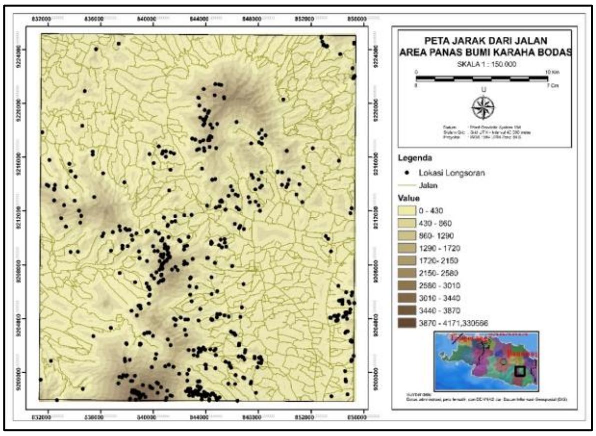

Figure 8. Map of distance to road to landslide distribution.

6) Lithology

Lithology was classified into 8 classes (**Figure 9**), based on the geological map from the Geological Survey Center. The most vulnerable landslide events occur in class 1, namely Qvt (Old Volcanic Rock Unit of Mount Talagabodas) as many as 126 landslide and QTvd (Old Volcanic Rock Unit of Mount Sadakeling Breccia) with 117 landslide. AUC value is 0,631.

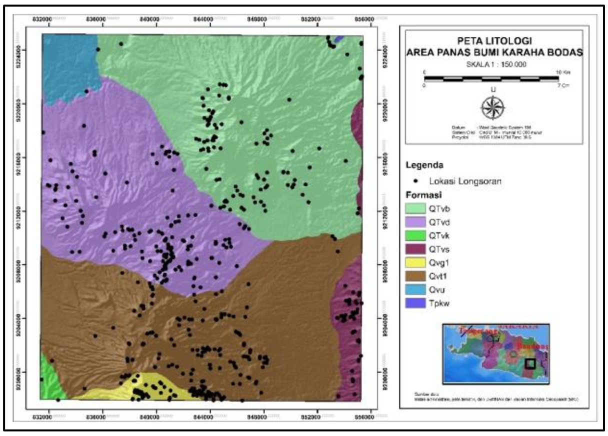

Figure 9. Lithology map of landslide distribution.

7) Distance to Drainage

Distance to drainage was classified into 12 classes (**Figure 10**), manually in ArcGIS (equal interval). The distance from the river that is most prone to landslides occurs in class 4 with a distance from the river of 300 - 400 m as many as 77 landslides, class 1 with a distance from the river of 0 - 100 m as many as 76 landslides, class 2 with a distance from the river of 100 - 200 m as many as 68 landslides, and class 3 with a distance from the road 330 - 400 m as many as 65 landslides. AUC value is 0,625.

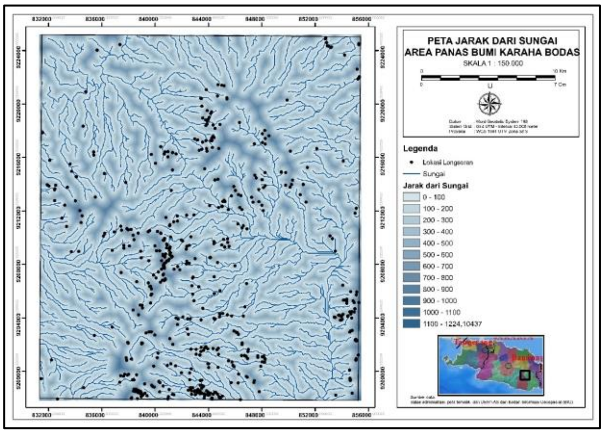

Figure 10. Map of distance to drainage to landslide distribution.

8) Rainfall

Rainfall was classified into 10 classes (**Figure 11**), manually in ArcGIS (equal interval). Most landslide events were found in class 6, namely rainfall with an average of 4031,67 - 4092,07 mm/year as many as 101 landslides and class 5 was rainfall with an average of 3971,28 - 4031,67 mm/year as much as 83 landslides. AUC value is 0,621.

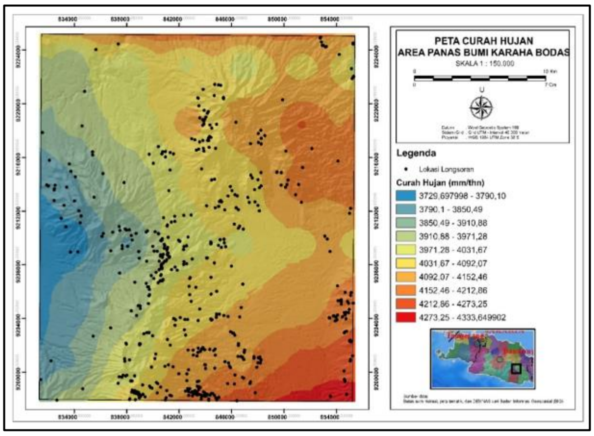

Figure 11. Map of rainfall to landslide distribution.

9) TWI

TWI was classified into 10 classes (**Figure 12**), manually on ArcGIS (equal interval). The TWI class that is most susceptible to landslide occurs in class 2 with a range of 4,24 - 5,70 with 188 landslides and class 3 with a range of 5,70 - 7,16 with 102

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landslides. AUC value is 0,631.

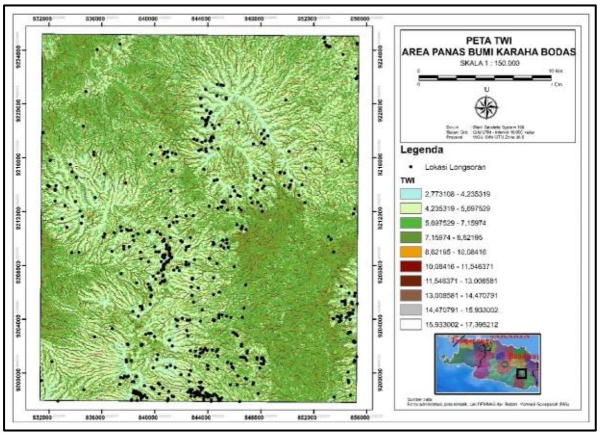

Figure 12. Map of TWI to landslide distribution.

10) NDVI

NDVI was classified into 8 classes (**Figure 13**), manually on ArcGIS (equal interval). The NDVI class that is most susceptible to landslide occurs in class 8 with a range of 0,45 - 0,632467 (extreme lush) with 120 landslides and class 7 with a range of 0,40 - 0,45 with 105 landslides. AUC value is 0,605.

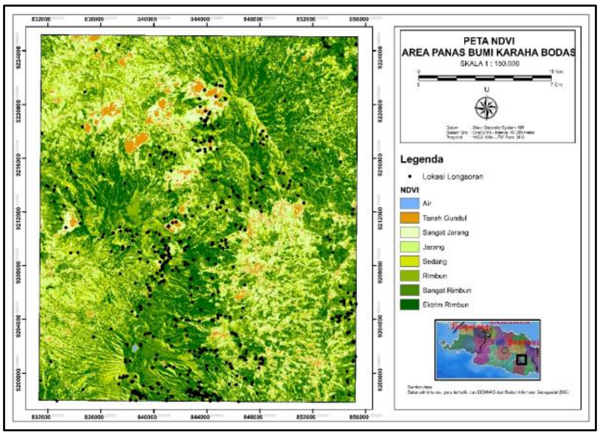

Figure 13. Map of NDVI to landslide distribution.

11) Curvature

Slopes was classified into 3 classes (**Figure 14**), manually in ArcGIS (equal interval). In the study area, the most prone to landslide occurred in class 2 with a range of -0,63 - 0,63 (flat) with 180 landslides. AUC value is 0,600.

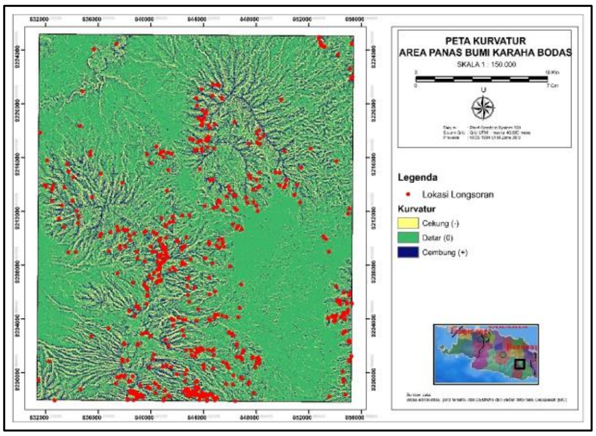

Figure 14. Map of Curvature to landslide distribution.

The values of the frequency ratio of the 11 parameters whose AUC values are ≥ 0.6 (**Table 3**) are then summed using the raster calculator feature in ArcGIS 10.3, so that a landslide susceptibility index map is obtained (**Figure 15**).

Table 3. AUC value of 16 parameters.

No.	Parameter	AUC Value
1	Slope	0,729
2	LULC	0,709
3	Drainage density	0,654
4	Elevation	0,651
5	Distance to road	0,632
6	Lithology	0,631
7	Distance to drainage	0,625
8	Rainfall	0,621
9	TWI	0,613
10	NDVI	0,609
11	Curvature	0,600
12	Lineament density	0,588
13	Slope aspect	0,585
14	Flow direction	0,582
15	Distance to lineament	0,565
16	SPI	0,516

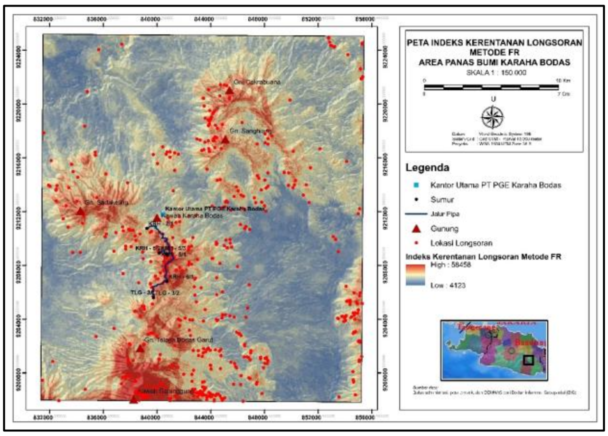

Figure 15. Landslide susceptibility index map of the Karaha Bodas geothermal area.

Furthermore, validation was carried out on the landslide susceptibility index map of the FR method to determine the performance of the method based on the AUC value by reclassifying (256 classes). Then multiplied by the training landslide data to validate the success rate and the landslide test data to validate the prediction rate, in order to obtain a range of values for vulnerability, area, and landslide.

From the calculation results, the FR method obtained AUC success rate of 0.786, AUC prediction rate of 0.793 (**Figure 16**).

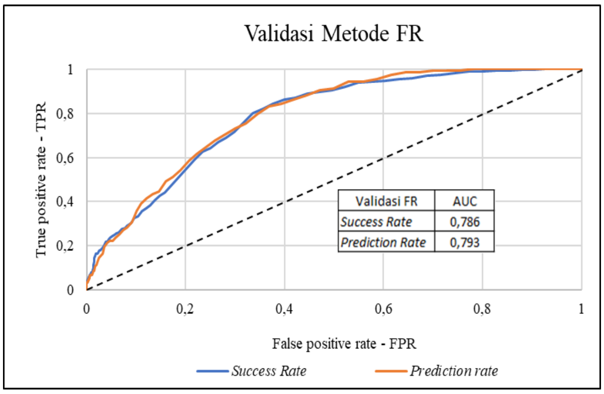

Figure 16. Validation based on the AUC value in the FR Method.

Subsequently, the division of landslide susceptibility zoning was carried out using the provisions in SNI 8291 (BSN, 2016), by dividing the landslide zone for the very low zone by 5%, 10% low zone, 20% medium zone, and 60% high zone to produce landslide susceptibility zone maps (**Figure 17**).

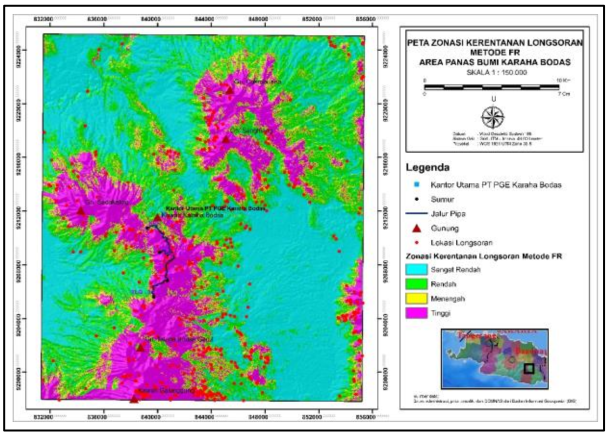

Figure 17. Landslide susceptibility zoning Map of Karaha Bodas geothermal area.

Based on the landslide susceptibility zoning map, the Karaha Bodas geothermal area has a high landslide susceptibility level of 60% with an area of 22% as many as 221 landslide locations, 20% of medium landslide susceptibility with an area of 12% as many as 78 landslide locations, 15% low landslide susceptibility rate with area area of 26% as many as 56 landslide locations, and the level of landslide susceptibility is very low 5% with an area of 40% as many as 19 landslide locations.

The Karaha Bodas geothermal area is a geothermal area that already has 9 wells and a PLTP. In the landslide susceptibility zoning map using the FR method, infrastructure such as main offices, roads, wells, pipes, pipelines, and PLTP in the Karaha Bodas geothermal area (**Figure 17**) or areas that have land clearing for geothermal activities are in the high landslide vulnerability zone that need more attention to landslide disaster mitigation, to avoid from landslides that cause loss of life and loss of damage to structures and infrastructure.

4. DISCUSSION

Landslide events in geothermal areas in West Java in 2012 were 4 locations, in 2013 there were 12 locations, in 2014 there were 5 locations, in 2015 there were 12 locations, in 2016 there were 18 locations, and in 2017 there were 6 locations. Data on landslide events in the PLTP area located in West Java Province from the Geothermal Directorate regarding the frequency of landslides at Geothermal Power Plants (PLTP) in West Java within a period of six years.

If the landslide disaster is not handled, it is possible that in the following years the frequency of landslides will continue to increase. In order to avoid landslides, it is necessary to map the potential for landslide hazards in geothermal areas or projects. Thus, the occurrence of loss of life as well as damage to structures and infrastructure can be avoided or minimized.

The object of research that is prioritized is the parameters that affect the occurrence of landslides that meet the value of area under curve ≥ 0.6. The weighting of each parameter is analyzed using the FR method. Influential parameters in reflecting the distribution of landslide susceptibility zoning in each method used. The selection of parameters to be used in the analysis of each method that will affect the level of accuracy of the resulting validation. If the parameter selection is correct, it will produce a better level of validation accuracy.

The FR method is a bivariate statistical method that connects past landslide location and the factors that cause landslides by using ArcGIS software to assess the potential for landslides from each class from all data layers (Mandal and Mondal, 2018).

This method is based on the parameters that are the factors that cause landslides and the distribution of the point of occurrence of avalanches that have occurred in the past. Each parameter of the landslide is classified into several classes in the form of zoning based on its character. Each class of each factor that causes landslides is integrated with the distribution of landslide occurrence points that have occurred in the past. Each class for each factor that causes landslides is calculated the frequency ratio value (Bonham, 1994 in Wilopo and Pradana, 2018).

FR is the ratio between the area of landslide occurrence to the total area and also the ratio of the probability of landslide occurrence to the occurrence of landslides for the given attribute factor. Therefore, the greater the ratio, the greater the relationship between the occurrence of landslides and the factors associated with the landslide. The smaller the ratio, the smaller the relationship between landslide events and related factors (Lee et al., 2005).

The results of the landslide susceptibility research are that the landslide susceptibility zoning map is a map that provides information on an area that has a tendency to landslides and all its aspects (SNI 8291, 2016). Avalanche susceptibility zoning maps were made to determine the classification of landslide susceptibility zones based on the method used. In this study, the zoning classification that will be used is the classification of landslide susceptibility zones with statistical methods.

Classification of landslide susceptibility zones. Statistical methods are divided into four, namely:

1. High landslide susceptibility zone, is an area that has a proportion of landslide events > 25% of the total population of events.
2. Medium landslide susceptibility zone, is an area that has a proportion of landslide events > 10% to 25% of the total population of events.
3. Low landslide susceptibility zoning, is an area that has a landslide incidence proportion of > 5% to 10% of the total population of events.
4. Very low landslide susceptibility zone, is an area that has a proportion of landslide events 0% to 5% of the total population of events.

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Several studies using the FR method as comparison at Darjeeling Himalaya layers (Mandal and Mondal, 2018) is dominated by high landslide susceptibility and followed by moderate, very high, low, and very low. It was also observed that very high and high landslide susceptibility zones were affected mostly by landslide activities. Frequency ratio value of very high, high, moderate, low, and very low landslide susceptibility zones are 2.84, 0.84, 0.34, 0.18, and 0.12, respectively.

Frequency ratio model dealt with the number of pixels affected by landslides and number of pixels prevailing in a specific geographical unit of the study. The landslide susceptibility zonation mapping process each class of landslide conditioning factors and associated pixels with and without landslides were taken into account.

Accuracy in detecting the location of previous landslides is very important, this is because future landslides will occur with the same conditions as past landslides (Shahibi, et al., 2012 in Wilopo and Pradana, 2018).

Study on landslide susceptibility mapping using the FR method in several geothermal areas has been carried out, one of which is the Wayang Windu geothermal area (Handayani and Singarimbun, 2016) which has an area that is very prone to landslides covering an area of 597, 43 Ha (28.71%), The prone area is 1170 Ha (56.23%), and only 313.27 Ha (15.01%) of the total area is safe against landslides.

Based on the map of the landslide susceptibility zone for West Java Province (Badan Geologi – PVMBG, 2009), the PGE Karaha Bodas area and its surroundings generally have a level of vulnerability which is divided into 3 zones of landslide susceptibility:

1. The zone of low ground movement susceptibility indicates that the Kamojang and Karaha Bodas areas rarely have ground movement, either there is disturbance or there is no slope disturbance. Disturbances on the slopes will form soil movements with small dimensions, especially found on river valley cliffs. This zone is found in a small part of the northwestern part of the Kamojang area, while the Karaha Bodas area covers a third of the eastern part.
2. Medium landslide susceptibility zone, especially found in areas directly adjacent to river valleys, escarpments, or road cliffs. Ground motion will occur especially if there is a disturbance on the cliff. Both new and old soil movements can be reactivated by disturbances in the form of high rainfall and strong erosion. In the Kamojang area, this zone is found in most of the central part of the area. In the Karaha Bodas area, this zone is found in more than half of the area and stretches from the north - west - south.
3. The zone of high ground movement vulnerability, shows that in this zone the Kamojang and Karaha Bodas areas experience landslides quite often even though they are not directly adjacent to river valleys, escarpments, or road cliffs. Under conditions of high rainfall and strong erosion, new soil movements can easily form and old soil movements can be active again. This zone is found at the eastern end and southern end of the Kamojang area, while in the Karaha Bodas area it is only found in a small part of the southwest end.

5. CONCLUSION

Geothermal areas located in mountainous areas with fairly steep slope conditions and a fairly complex geological structure and high temperature are in volcanic areas with high relief, steep morphology, thermal alteration rocks that produce thick soil, and heavy rainfall. This is a threat in geothermal development which causes landslides.

Based on research on landslide susceptibility zoning using the frequency ratio method, the Karaha Bodas geothermal area which has 538 landslides location is influenced by 16 parameters, 11 of which have a large effect as the cause of landslides, namely by producing an AUC value ≥ 0.6. The 11 parameters are slope, LULC, drainage density, elevation, distance to road, lithology, distance to drainage, rainfall, TWI, NDVI, and curvature. The results of the evaluation of the AUC success rate value show the FR method (0.786). The results of the evaluation of the AUC prediction rate value show the FR method (0.793). So that from the results of this evaluation a landslide vulnerability zone map is produced in the Karaha Bodas geothermal area which has good accuracy.

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