Mapping of Landslide Susceptibility based on Analytical Hierarchy Process (AHP) in Sermo Dam and its Surrounding Areas, Kokap, Kulon Progo

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ABSTRAK
Formasi Nanggulan sebagai formasi tertua di Pegunungan Kulon Progo tidak hanya tersingkap di lokasi tipe di daerah Nanggulan, Kalibawang. Namun, di daerah barat Waduk Sermo tepatnya di perbukitan sekitar Kokap Formasi Nanggulan dijumpai di beberapa tempat. Keberadaan Formasi Nanggulan di sekitar Waduk Sermo ini ditengarai memicu adanya kejadian gerakan tanah di daerah ini. Maksud penelitian ini adalah untuk melakukan pemetaan gerakan tanah. Tujuan penelitian adalah untuk mengetahui potensi gerakan tanah di daerah penelitian. Daerah penelitian termasuk ke dalam Zona Pegunungan Kubah Kulon Progo bagian selatan. Pemetaan zonasi gerakan tanah ini dilakukan berdasarkan metode AHP (*Analytical Hierarky Process*) mengggunakan pembobotan nilai dari empat parameter. Parameter yang digunakan adalah kelerengan, litologi, tata guna lahan dan curah hujan. Hasil pemrosesan AHP menggunakan sofware Arc GIS menghasilkan peta zonasi kerentanan gerakan tanah yang terbagi atas 5 kelas (sangat rendah, rendah, menengah, tinggi dan sangat tinggi). Berdasarkan hasil pemetaan gerakan tanah dengan metode AHP, daerah paling rawan adalah Desa Hargowilis yang tersusun atas litologi batulempung dari Formasi Nanggulan.
Kata Kunci: Gerakan tanah, Nanggulan, Sermo, AHP, Kulon Progo

ABSTRACT
The Nanggulan Formation as the oldest formation in the Kulon Progo Mountains is not only exposed in a type location in the Nanggulan area, Kalibawang. However, in the western area of the Sermo Reservoir, precisely in the hills around the Kokap, the Nanggulan Formation is found in several places. The existence of the Nanggulan Formation around the Sermo Reservoir is suspected to have triggered the occurrence of ground movements in this area. The purpose of this research is to map the ground motion. The purpose of the study was to determine the potential for ground motion in the study area. The research area is included in the southern Kulon Progo Dome Mountain Zone. This ground motion zoning mapping was carried out based on the AHP (methodAnalytical Hierarchy Process) using the weighted values of four parameters. The parameters used are slope, lithology, land use and rainfall. The results of AHP processing using Arc GIS software produce a landslide susceptibility zoning map which is divided into 5 classes (very low, low, medium, high and very high). Based on the results of mapping using the AHP method, the most vulnerable area is Hargowilis Village which is composed of claystone lithology from the Nanggulan Formation.
Keywords: Landslides, Nanggulan, Sermo, AHP, Kulon Progo

1. INTRODUCTION

The existence of the Nanggulan Formation as the oldest formation plays a vital role in contributing to the understanding of basin formation and stratigraphy in the Kulon Progo Mountains. The distribution of Nanggulan Formation according to [1] spreads in the location of the Nanggulan area type, both are in the Kalisonggo and Watupuru rivers. This formation is located in the Sermo, Gandul, and Kokap areas [2] (Figure 1.1). Several previous researchers have studied studies on tectonics and stratigraphy in the Kulon Progo Mountains. The stratigraphy of the Nanggulan Formation in the Kalisonggo area has been studied by [3], [4], Nur'aini [5], [6], [7], [8], also Hani and Pandita [9].

The research area is in Hargorejo Village, Kokap District, Kulon Progo Regency. In contrast to the Nanggulan Formation located in the Nanggulan Region, regionally, it is included in the Nanggulan Formation [1] which is composed of lignite inserted sandstone, sandstone rich in foraminifera, claystone, marl, volcanic tuff and arkose sandstone.

The research area is also included in the physiography of the Kulon Progo Mountains Zone. Volcanostratigraphically, the research area belongs to the Mount Ijo area which is composed of shallow intrusive lithology, agglomerates, andesite breccias, tuff and lapilli [10] The volcanic formation of Mount Ijo is estimated to have occurred during the Miocene to Pliocene or around 11-2 million years ago [11]. The diversity of volcanic rocks in Mount Ijo and its surroundings has been studied by [12], [13], and [14]. Structural geology in Kulon Progo such as fault identification has been studied by [15].

In terms of disasters, the research area, especially in the Kokap area, often experiences landslides. [16] conducted research on the identification of ground motion. This study examines the ground motion influenced by slope, rock, geomorphology, fault distance and vegetation. The level of potential damage to buildings has been studied by [17]. [18] have also conducted micro-seismic measurements around the Sermo reservoir. Publications regarding the potential for landslides around the Sermo Reservoir have never been studied in detail, especially for Analytical Hierarchy Process (AHP).

In the Kokap area, there has never been an in-depth study of the stratigraphy of the Nanggulan Formation. The Nanggulan Formation which is composed of sandstone and claystone lithology is located between the Old Andesite Formation rocks in a hilly area with a reasonably steep slope. The characteristics of the rock that make up the slopes are one of the causes and controllers of soil movement. In addition, vegetation and geological structures also play a role in influencing the occurrence of ground movements [19]. The aspect of land use is also a factor to be considered, especially settlements as the focal point of the landslide hazard assessment compared to other parameters in AHP processing.

This study intends to assess the parameters by weighting four factors: the slope, lithology, land use and rainfall. The purpose of this study was to produce a Landslide Hazard Zoning Map in the research area. Through this disaster-prone zoning map, it is hoped that it will educate the surrounding community and be a reference for the local government in tackling landslides.

2. METHODS

This research on landslide-prone zones is descriptive quantitative using the Overlay technique. The data used are secondary in the form of microseismic measurement data and geological maps used to obtain the distribution of rocks and the presence of geological structures. The database in the form of topographic data, land use data and Digital Elevation Model (DEM) data obtained from the BIG (Geospatial Information Agency) which is processed using a Geographic Information System (GIS) application that produces slope maps, and land use maps. All data were pasted using a GIS application and then weighted using the Analytical Hierarchy Process (AHP) method (Figure 1).

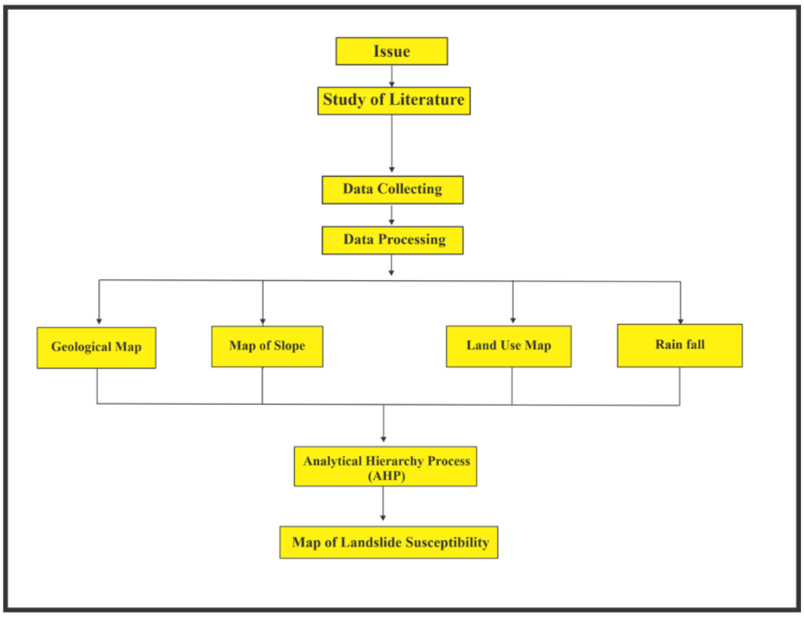

Figure 1. The scheme of Research

Each parameter that determines landslide susceptibility is weighted using the AHP method. A very complex multi-criteria decision-making method is translated into a hierarchical arrangement, by converting variables into numbers based on a paired comparison scale [20]. These figures indicate the magnitude of the influence between one variable and another on landslide susceptibility. The numbers are presented in a pairwise comparison matrix to calculate the priority weights [21]. The determination of the numbers in the matrix is based on theoretical logic, previous research related to landslide hazard using similar parameters.

Tabel 1. Scale of Wieghting [20]

Scale	Parameters
1	*Equally importan* (sama penting)
3	*Moderately more important* (sedikit lebih penting)
5	*Strongly more important* (lebih penting)
7	*Very strongly more important* (sangat penting)
9	*Extremely more important* (mutlak lebih penting)
2,4,6,8	*Intermediate values* (nilai yang berdekatan)

This study's controlling parameters for landslide susceptibility are slope, rock distribution, rainfall, and land use. Parameters and variables used are weighted using AHP. Parameter weights are then used as a multiplier for each variable weight obtained. These weights are then summed to obtain a landslide susceptibility index in the study area [22]. Landslide susceptibility is grouped into 5 classes : low landslide susceptibility, moderate landslide susceptibility, and high landslide susceptibility [23].

3. RESULT AND DISCUSSION

3.1 Slope of Research Area

The slope of Hargowilis and its surroundings, as reflected in the DEM data is the slope percentage. The percentage of slope in the study area is divided into 5 classes (Table 2) [24]. The Hargowilis area has the highest slope value at > 16^o and the lowest at 0-2^o distribution of the slope in the Hargowilis area in the middle is dominated by gentle slopes due to the Sermo Reservoir. The east and west sides have steeper slopes (8^o – 16^o). The higher the slope value, the higher the risk of landslides. The difference in slope causes this landslides susceptibility and the influence of the gravitational force acting on the material on the slope is getting bigger [25].

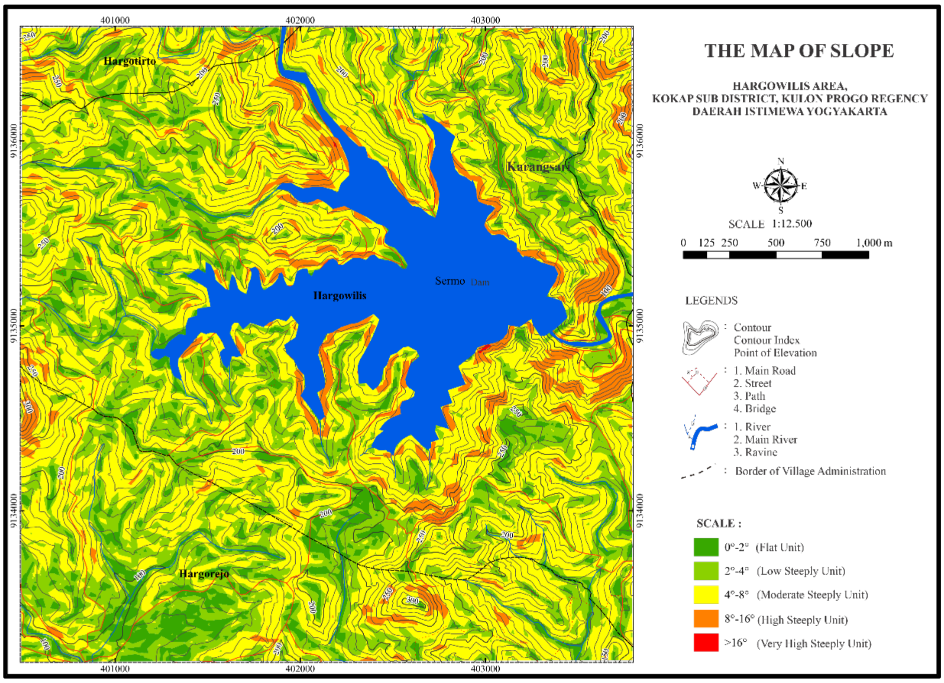

Figure 1. The slope map in research are

The calculation of the slope class is divided into five classes with the results of the comparison matrix for slopes > 16° being 2.233 and 0 – 2° being 16.00 (Table 2). The normalized Eigen calculation shows the number 1 for each slope class (Table 3). Final results calculation of weights and priorities resulted in slope class 42.6% (highest) and 5.88% (lowest) (Table 4).

Table 2. The Slope class comparison matrix

Parameter	**>16°**	**8° – 16°**	**4° – 8°**	**2° – 4°**	**0° – 2°**
>16°	1	2	3	5	5
8° -16°	0.5	1	2	3	5
4° - 8°	0.33	0.5	1	2	3
2° - 4°	0.20	0.33	0.50	1	2
0° - 2°	0.20	0.20	0.33	0.50	1
Total	2.233	4.033	6.83	11.5	16.00

Tabel 3. Eigen calculation for slope class normalization

Normalization	**>16°**	**8°-16°**	**4°-8°**	**2°-4°**	**0°-2°**	Total
>16°	0.45	0.50	0.44	0.43	0.31	2.13
8°-16°	0.22	0.25	0.29	0.26	0.31	1.34
4°-8°	0.15	0.12	0.15	0.17	0.19	0.78
2°-4°	0.09	0.08	0.07	0.09	0.13	0.46
0°-2°	0.09	0.05	0.05	0.04	0.06	0.29
Total	1	1	1	1	1	5

Tabel 4. Calculation of weights and priority of slope classes

Elevation (m)	Weighting	Percentage (%)	Correction	
>16°	**0.43**	42.60	5.09	max
8°-16°	**0.27**	26.76	0.02	CI
4°-8°	**0.16**	15.62	0.02	CR
2°-4°	**0.09**	9.15		
0°-2°	**0.06**	5.88		
Total	1	100		

3.2 The Geology of Research Area

The geology of the study area is composed of the lithology of the constituent rocks from oldest to youngest, namely the Nanggulan claystone unit with quartz sandstone inserts. Above the Nanggulan Formation unconformably deposited andesite breccia OAF. The youngest rock unit was deposited by OAF Andesite intrusion. The geological structure found in the field is in the form of minor ascending faults and minor normal faults. Both are seen in the Nanggulan claystone which is in contact with the andesite intrusion. In the south of the Sermo Reservoir there is also a northwest-southeast trending fault. This fault is interpreted as a dextral strike -slip fault [26] (Figure 2).

Analysis and weighting were carried out to determine the pairwise comparison matrix for the lithology class. Nanggulan claystone has a ratio of 2 matrices, andesite breccia with a weight of 3.5, and andesite intrusion with a weight of 5 (Table 5). The eigen calculation for lithology class normalization obtained a value of 1.47 for claystone, 0.94 for andesite breccia and 0.59 for andesite intrusion (Table 6). The final calculation resulted in the calculating of the weight and priority of the lithology class with Nanggulan claystone with a weight of 0.49. This claystone value is the maximum value (Table 7).

Table 5. The lithology class comparison matrix

Parameter	Claystone	Andesitic Breccia	Andesitic Intrusion
Claystone	1	2	2
Andesitic Breccia	0.5	1	2
Andesitic Intrusion	0.5	0.5	1
Total	2	3.5	5

Tabel 6. Eigen calculation for lithology class normalization

Normalization	Claystone	Andesitic Breccia	Andesitic Intrusion	Total
Claystone	0.50	0.57	0.40	1.47
Andesitic Breccia	0.25	0.29	0.40	0.94
Andesitic Intrusion	0.25	0.14	0.20	0.59
Total	1	1	1	3

Tabel 7. Calculation of weights and priority of lithology classes

Parameter	Weighting	Percentage (%)	Correction	
Claystone	**0.49**	49.05	3.06	max
Andesitic Breccia	**0.31**	31.19	0.03	CI
Andesitic Intrusion	**0.20**	19.76	0.05	CR
Total	1	100		

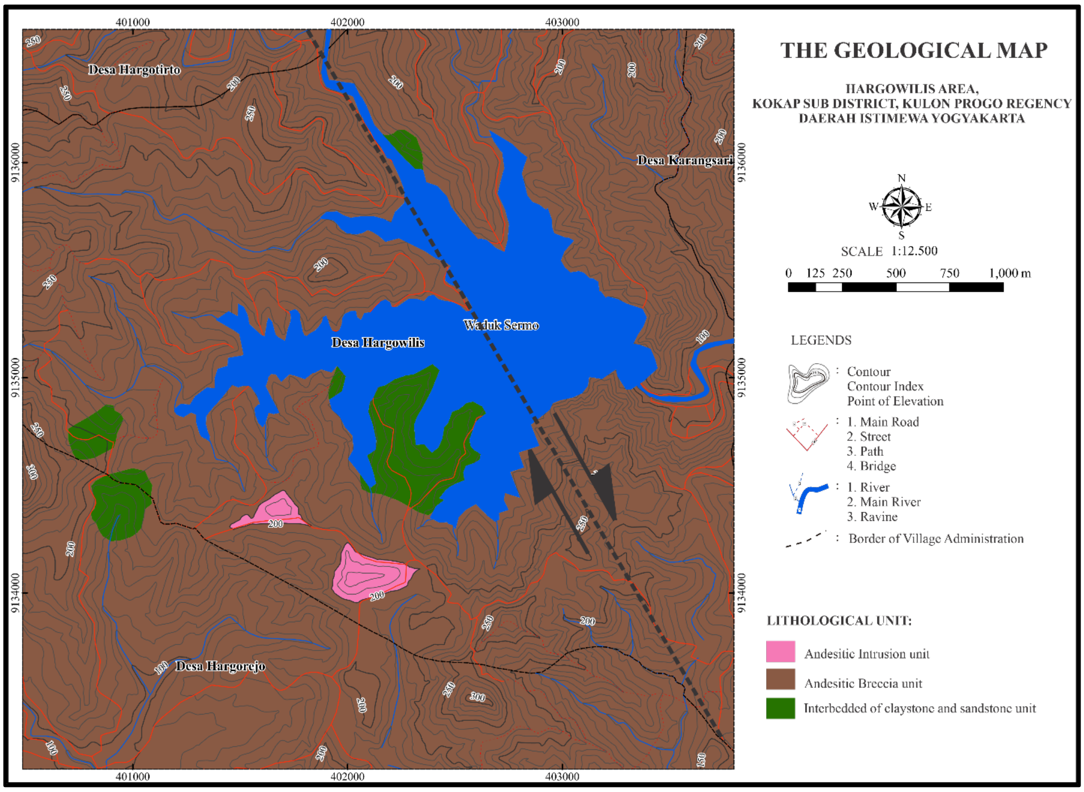

Figure 2. The geological map in research area shows the distribution of rocks

3.3 Land Use of the Research Area

The Hargowilis area is divided into four types; settlements and public places, farms, rice fields, and fields. Settlements and places of activity are the areas most prone to landslides. The cause of vulnerability in this area is because it can take human casualties if there is a landslide. The following parameters are rice fields, farms. The farm is the most resistant to landslides because these areas are resistant to erosion [27].

The comparison matrix for land use results in the number 1 for settlements and rice fields. The Field / Farm has scores of 2 and 0.5 (Table 8). The normalized eigen calculation results in the number 1.33 for settlements and rice fields. The number 0.67 is generated for field/farm (Table 9). The final result of giving the maximum weight is residential land use and rice fields with a value of 2.0 (Table 10).

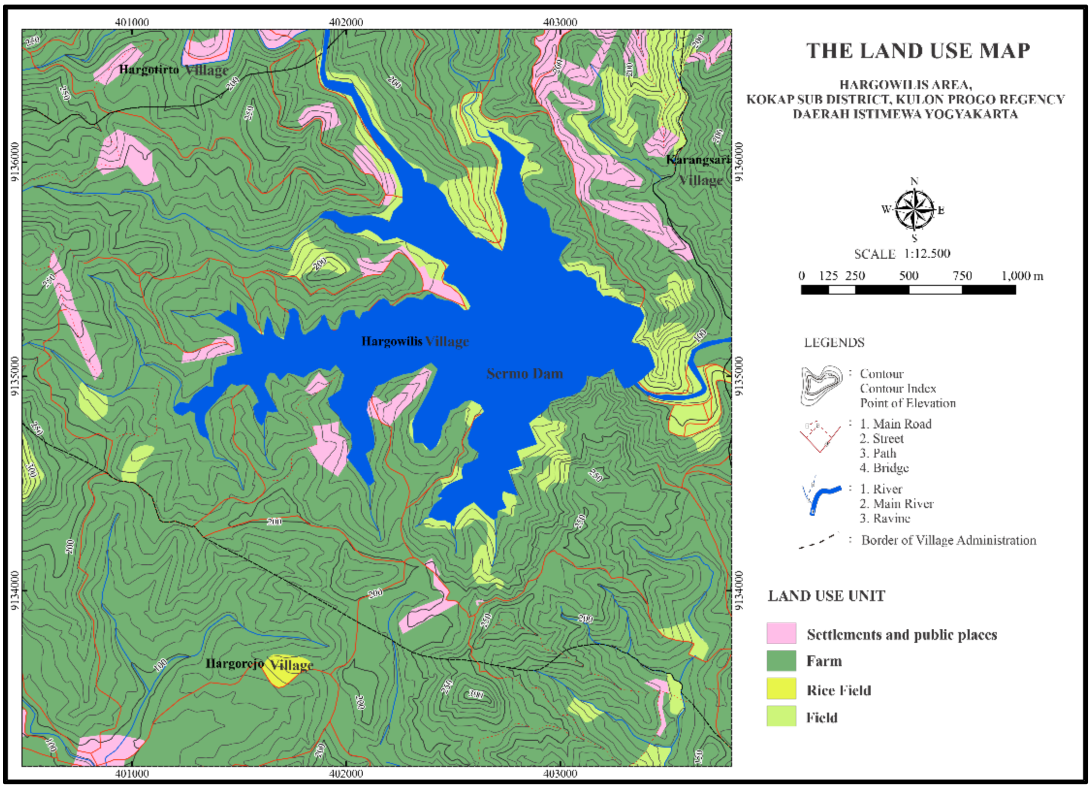

Figure 3. The land use map in research area

Table 8. The land use class comparison matrix

Parameter	Settlements / Rice Field	Field / Farm
Settlements / Rice Field	1	2
Field / Farm	0.5	1
Total	1.5	3

Table 9. Eigen calculation for lithology class normalization

Normalization	Settlements / Rice Field	Field / Farm	Total
Settlements / Rice Field	0.67	0.67	1.33
Field / Farm	0.33	0.33	0.67
Total	1	1	2

Table 10. Calculation of weights and priority of land use classes

Parameter	Weighting	Percentage (%)	Correction	
Settlements / Rice Field	**0.667**	66.67	2.000	max
Field / Farm	**0.333**	33.33		
Total	1	100		

3.4 Rainfall in the Research Area

Rainfall data in the Hargowilis area were taken from monthly weather observations during 2018 - 2020 from the weather observation station in Kokap District. The rainfall data were obtained from the Meteorological, Climatological, and Geophysical Agency (BMKG). The figure shows that the highest rainfall levels are in January, March and December (Figure 4). The rainfall weighting class uses rainfall intensity classification [28] (Table 11).

Table 11. Calculation of weights of rainfall

Rain fall Intensity	Parameter	Weighting
< 2.000	Dry	1
2.000 – 2.500	Moderate	2
2.500 – 3.000	Wet	3
>3.000	Very Wet	4

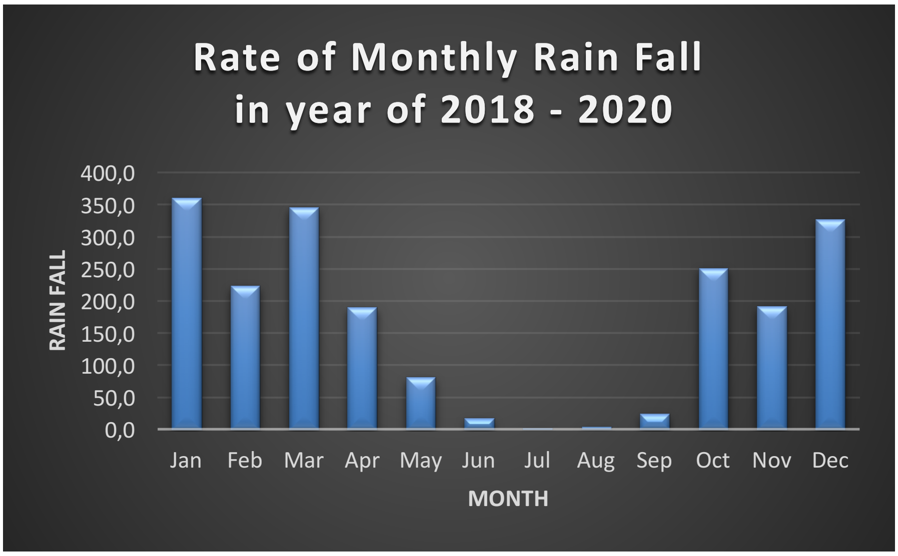

Figure 4. The rainfall data in research area; the highest rain fall is January and the lowest rainfall is July and August

3.5 Weighting and Making a Map of Landslide Susceptibility

The weighting of parameters and variables that affect landslide disasters is carried out using the AHP method. The Analytical Hierarchy Process (AHP) method collects slope parameters, lithology, land use, and rainfall. This weighting process is carried out based on the level of influence on landslides. The higher the weight value indicates the great influence of these parameters on the landslide disaster. The parameter comparison matrix produces a data value of 2.5, slope with a value of 4, land use of 5.5 and rainfall with a value of 8 (Table 12 and 13).

To determine the consistency level of the resulting weights, the consistency index (CI) and consistency ratio (CR) values were calculated. The index consistency value generated in the Cinomati area is 0.1 and the consistency ratio value in the research area is 0.1. (Table 14). This value indicates that the weight value obtained is considered consistent because it meets the AHP requirements.

Table 12. Parameter class comparison matrix

Parameters	**Lithology**	**Slope**	**Land Use**	**Rain fall**
Lithology	1	2	2	2
Slope	0.5	1	2	3
Land Use	0.5	0.5	1	2
Rain Fall	0.5	0.33	0.50	1
Total	2.5	4	5.5	8

Table 13. Eigen calculation for each parameter class normalization

Normalization	**Lithology**	**Slope**	**Land Use**	**Rain fall**	Total
Lithology	0.4	0.5	0.4	0.3	1.5
Slope	0.2	0.3	0.4	0.4	1.2
Land Use	0.2	0.1	0.2	0.3	0.8
Rain Fall	0.2	0.1	0.1	0.1	0.5
TOTAL	1.000	1.000	1.000	1.000	4.000

Table 14. Calculation of weights and priority of each parameter class

Normalization	weighting	Percentage	Correction	
Lithology	0.384	38.4	4.2	max
Slope	0.300	30.0	0.1	CI
Land Use	0.191	19.1	0.1	CR
Rain Fall	0.126	12.6		
Total	1	100.000		

3.6 Landslide Prone Areas

The landslide susceptibility map is obtained by *overlaying the* seven parameters that affect landslides using a GIS application. The result of the intersection of each variable is multiplied by the weight obtained in the table. The multiplication results are then added together to get the landslide susceptibility index value. The lowest landslide hazard value is 0.1 and the highest vulnerability value is 4.2. 22/PRT/M/2007 is divided into three classes of vulnerability, namely low (1.28-2.24), medium (2.25-3.19), and high (3.20-4.14). The vulnerability class is divided into 5 classes in the research area, namely very low, low, medium, high and very high (Figure 4).

The area with high landslide susceptibility is in the exact center of Hargowilis Village right around the Sermo reservoir shown in red in Figure 5. The high landslide susceptibility in this area is caused by the moderate to steep slope (8°-16°) which results in a force. The gravity force acting on the material on the slope is greater. In general, this area is in the form of rice fields included in the andesite breccia unit in the form of volcanic rock so that it is easy to erode and rockfall can occur at any time. Landslides are more likely to occur in the Nanggulan claystone unit because the rock is less resistant. The effects of landslide parameters from the highest to the lowest are lithology (38.384%), slope (29.988%), land use (19.056%), and rainfall (12.572%) (Table 15). On the other hand, Areas traversed by geological structures such as faults can also be prone to landslides [28].

Table 15. Recapitulation of Level Calculation for Landslide Susceptibility

No.	Parameter	Class	Weighting	Total weighting	Total (%)	% Per parameter
1	**Lithology**	Claystone	0.490	0.188	18.827	38.384
		Andesitic Breccia	0.312	0.120	11.972	
		Andesitic Intrusion	0.198	0.076	7.585	
2	**Slope**	>16°	0.426	0.128	12.774	29.988
		8°-16°	0.268	0.080	8.024	
		4°-8°	0.156	0.047	4.684	
		2°-4°	0.091	0.027	2.743	
		0°-2°	0.059	0.018	1.763	
3	**Land Use**	Settlements / Rice Field	0.667	0.127	12.704	19.056
		Field / Farm	0.333	0.064	6.352	
4	**Rain fall**	Dry	1.000	0.126	12.572	12.572
Total			4.000	1	100.000	100.000

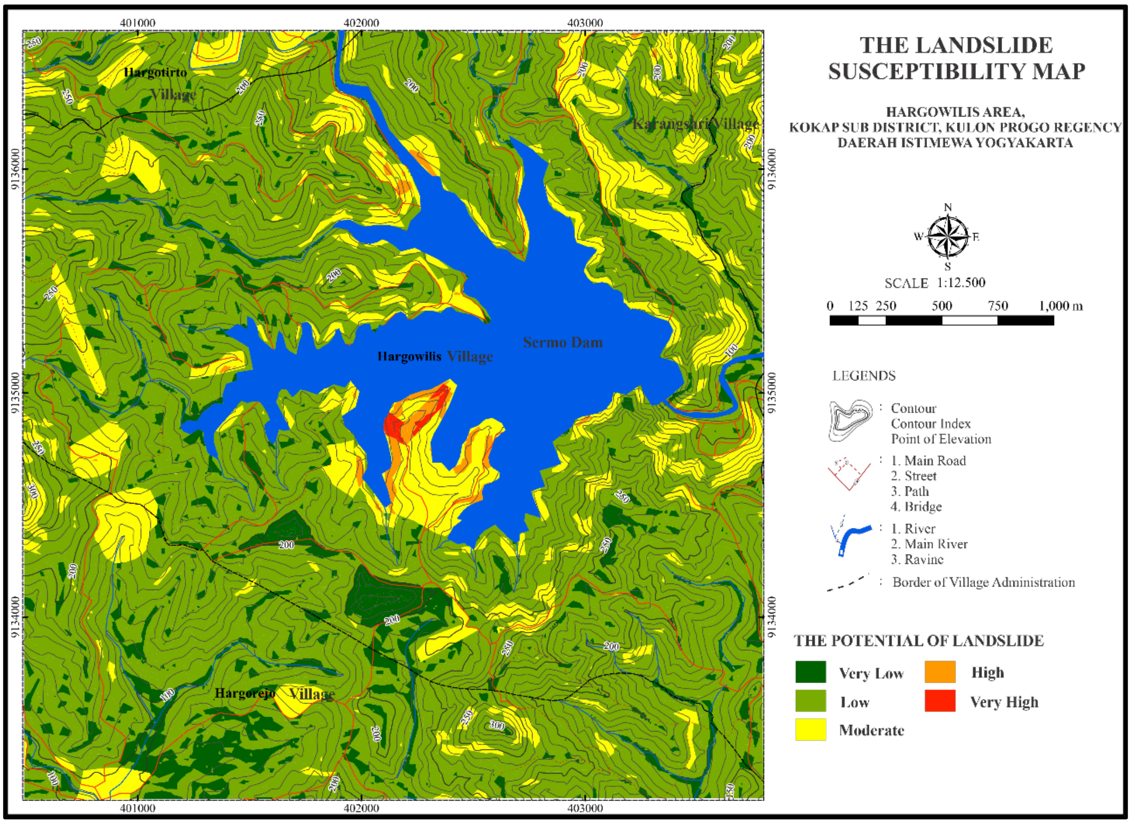

Figure 4. The Map of Landslide Susceptibility in research area

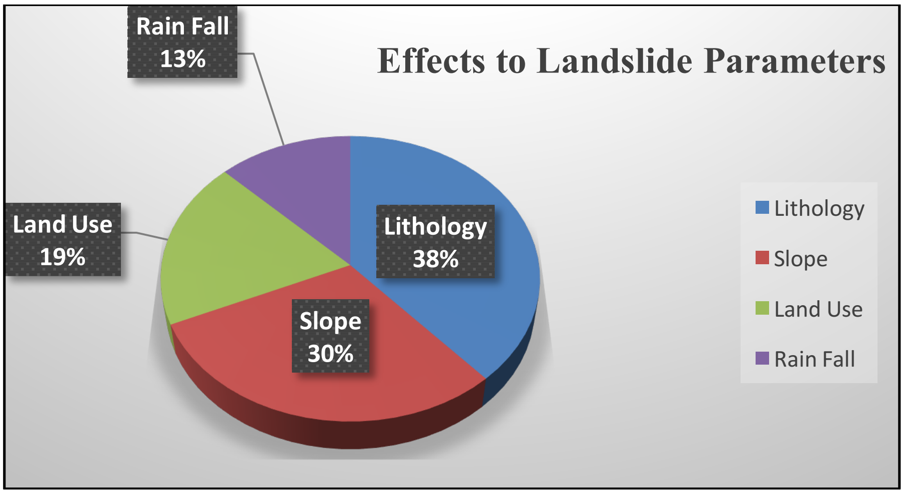

Figure 5. Distribution of Effect for Landslide Parameters

4. CONCLUSION

The research area is classified as a flat topography to a steep topography composed of claystone lithology, andesite breccia, and andesite intrusion. Results Mapping of Landslide Susceptibility in the research area using the Analytical Hierarchy Process (AHP) method gives an assessment and weight for 4 parameters; slope, lithology, land use, and rainfall. The level of influence of the most significant parameter is the lithology that composes the research area. The weighting and the Landslide Susceptibility Map determine that there are five classes of landslide susceptibility, namely very low, low, moderate, high and very high classes. Areas prone to landslides are Hargowilis Village in the south and southwest of the Sermo Reservoir which is composed of Nanggulan Claystone lithology. This claystone is distributed in spots in several places.

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REFERENCES

[1] Rahardjo, W., Sukandarrumidi, dan H.M.D. Rosidi (1995) Peta Geologi Lembar Yogyakarta, Jawa, edisi ke-2, Pusat Penelitian dan Pengembangan Geologi, Bandung.
[2] Widagdo, A., Pramumijoyo, S., & Harijoko, A. (2018, December). Tectonostratigraphy-volcanic of Gajah-Ijo-Menoreh Tertiary volcanic formations in Kulon Progo mountain area, Yogyakarta-Indonesia. In *IOP Conference Series: Earth and Environmental Science* (Vol. 212, No. 1, p. 012052). IOP Publishing.
[3] Pambudi, S. (2016). KONFIGURASI CEKUNGAN PURBA FORMASI NANGGULAN DI DAERAH NANGGULAN, KULONPROGO, DAERAH ISTIMEWA YOGYAKARTA. *ReTII.*
[4] Sasongko, W., Doli, F. B., & Mahendra, F. H. M. (2018). KAJIAN HUBUNGAN DIAGENESIS DAN SIKUEN STRATIGRAFI FORMASI NANGGULAN BERDASARKAN ANALISIS PETROGRAFI BATUPASIR. *KURVATEK*, *3*(1), 71-82.
[5] NURAINI, S. (2017). *Geometri Perlapisan Batupasir Konglomeratan Sebagai Sisipan pada Formasi Nanggulan di Kali Watupuru dan Kali Songgo, Pegunungan Kulon Progo, Yogyakarta* (Doctoral dissertation, sekolah tinggi teknologi nasional yogyakarta).
[6] NURAINI, S. (2018). *PERBANDINGAN INTENSITAS ANTARA ARUS PASANG-SURUT DENGAN PENGARUH GELOMBANG TERHADAP PENGENDAPAN DELTA NANGGULAN DI KALI WATUPURU DAN KALI SONGGO, PEGUNUNGAN KULON PROGO, YOGYAKARTA* (Doctoral dissertation, institut teknologI nasional yogyakarta).
[7] Nuraini, S. (2019). Fenomena Hard Ground Pada Batu Lempung Kaya Gampingan Formasi Nanggulan, Di Sungai Watupuru, Pegunungan Kulon Progo, Yogyakarta. *KURVATEK*, *4*(1), 95-102.
[8] Nur'aini, S. Lapisan condensed section pada batulempung gampingan Nanggulan, Pegunungan Kulonprogo, DIY.

[9] Hani, D. S. N., & Pandita, H. (2020). Analisis Litofasies dan Lingkungan Pengendapan Formasi Nanggulan Lintasan Kali Songgo, Kabupaten Kulon Progo. *ReTII*, 298-309.

[10] Nugrahini, R. A., Hartono, H. G., & RA, T. L. (2020). PALEOMORFOGENESIS BENTANG ALAM KOMPLEKS GUNUNG IJO, KULONPROGO. *KURVATEK*, *5*(2), 1-8.

[11] Harjanto, A., 2011. *Vulkanostratigrafi di Daerah Kulon Progo dan Sekitarnya, Daerah Istimewa Yogyakarta*, Jurnal Ilmiah MTG, Vol.4, No.2, Juli 2011.

[12] Rahardjo, W., Sukandarrumidi, &Rosidi, H.M.D. 2012. *Geological Map of the Yogyakarta Sheet 1:1 00,000*. Center for Geological Survei, Geological Agency.

[13] Maryanto, S., & Hasan, R. (2011). Korelasi-Regresi Antar parameter Petrofisika Batuan Beku dan Batugamping dari Daerah Pegunungan Kulonprogo, Daerah Istimewa Yogyakarta. *Jurnal Geologi Indonesia*, *6*(4), 203-2ll.

[14] Irzon, R., & Permanadewi, S. (2010). Elements Study of Igneous and Altered Rocks in Kulonprogo and Its Surrounding Using ICP-MS. *Proceeding PIT IAGI, Lombok*, 1-10.

[15] Rizqi, A.F (2019). IDENTIFIKASI STRUKTUR GEOLOGI DAN IMPLIKASINYA TERHADAP PENYEBARAN BATUAN FORMASI ANDESIT TUA–SENTOLO DI SUNGAI NITEN, GIRIPURWO, KULON PROGO. *Angkasa: Jurnal Ilmiah Bidang Teknologi*, *11*(2), 152-163.

[16] Nugroho, N. E., & Kristanto, W. A. D. (2020). Kajian Tingkat Risiko Tanah Longsor Desa Hargomulyo, Kecamatan Kokap, Kabupaten Kulonprogo. *Jurnal Ilmiah Lingkungan Kebumian (JILK)*, *1*(2), 9-25.

[17] Sari, S. N., & Prastowo, R. (2019). Peta Potensi Kerusakan Bangunan Akibat Kerentanan Gerakan Tanah Di Daerah Kalirejo Kulonprogo Yogyakarta. *ReTII*, 435-441.

[18] Wibowo, N. B., & Niyartama, T. F. (2015). Mikrozonasi Multidisaster Daerah Sekitar Waduk Sermo Berbasis Analisis Keputusan Multikriteria Simple Addtive Weight (SAW) Berdasarkan Pengukuran Mikrotremor. *Jurnal Dialog dan Penanggulangan Bencana*, *6*(1), 1-11

[19] Amalia, N. R., Indrawan, I., & Warmada, I. W. (2018, December). Pengaruh Alterasi Hidrotermal terhadap Tingkat Kerentanan Longsor di Daerah Kalirejo dan Sekitarnya, Kabupaten Kulon Progo dan Purworejo. In *PROCEEDING, SEMINAR NASIONAL KEBUMIAN KE-11 PERSPEKTIF ILMU KEBUMIAN DALAM KAJIAN BENCANA GEOLOGI DI INDONESIA 5–6 SEPTEMBER 2018*. Departemen Teknik Geologi.

[20] Saaty, T. L. (1991). *Some mathematical concepts of the analytic hierarchy process*. Behaviormetrika, 18(29), 1-9.

[21] Makkasau, K. (2013). Penggunaan metode Analytic Hierarchy Process (AHP) dalam penentuan prioritas program kesehatan (studi kasus program Promosi Kesehatan). *J@ ti Undip: Jurnal Teknik Industri*, *7*(2), 105-112.

[22] He, H., Hu, D., Sun, Q., Zhu, L. and Liu, Y., (2019). *A landslide susceptibility assessment method based on GIS technology and an AHP-weighted information content method*: A case study of southern Anhui, China. *ISPRS International Journal of Geo-Information*, *8*(6), p.266.

[23] Peraturan Menteri Pekerjaan Umum Nomor 22/PRT/M/2007 Tahun 2007. Pedoman Penataan Ruang Kawasan Rawan Bencana Longsor.

[24] Van Zuidam, R. A. (1983). Guide to Geomorphologic Aerial Photographic Interpretation and Mapping. *International Institute for Geo-Information Science and Earth Observation, Enschede, The Netherlands*, *325*.

[25] Pramudianti, E. and Hadmoko, D.S., (2013). Analisis Stabilitas Lereng Menggunakan Model Deterministik untuk Zonasi Rawan Longsorlahandi Sub-das Gintung, Kab. Purworejo. Jurnal Bumi Indonesia, 1(3).

[26] Pramumijoyo, S., Widjajanti, N., & Widagdo, A. (2021). Optimal design of the Sermo Fault deformation monitoring network using sensitivity criteria based on geological information. *Arabian Journal of Geosciences*, *14*(20), 1-9.

[27] Karnawati, D., (2005), *Bencana Alam Gerakan Massa Tanah di Indonesia dan Upaya Penaggulangannya*, Penerbit Jurusan Teknik Geologi FT Universitas Gadjah Mada, Jogjakarta.

[28] Prasetya, H. N. E., Aditama, T., Sastrawiguna, G. I., Rizqi, A. F., & Zamroni, A. (2021, June). Analytical landslides prone area by using Sentinel-2 Satellite Imagery and geological data in Google Earth Engine (a case study of Cinomati Street, Bantul Regency, Daerah Istimewa Yogyakarta Province, Indonesia). In *IOP Conference Series: Earth and Environmental Science* (Vol. 782, No. 2, p. 022025). IOP Publishing.