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RESEARCH ARTICLE

The Effect of Weathered Layer Thickness and Slope on Potential Areas of Landslides in Gerbosari Village, Samigaluh District, Kulonprogo Regency, Indonesia

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Abstract

Gerbosari Village has a history of landslides with intensity and risk of 56 occurrences over 5 years. Gerbosari Village, Samigaluh District, Kulonprogo Regency is located at geographic coordinates 7◦ 38 '45.33 "- 7◦ 41' 35.24" LS and 100◦ 9 '20.80 "- 110◦ 11' 16.52" BT with topographic conditions at an altitude around 500 - 1000 mdpl. This study aims to determine the subsurface structure of landslide-prone areas in the form of weathered layer thickness and the effect of slope in landslide-prone areas so that it can be used in making micro zonation maps of landslide-prone areas. This study uses 43 microtremor data with a distance between points of 650 m. The microtremor signal was analysed using the horizontal to vertical spectrum ratio (HVSR) method. From the measurement results, it is obtained that the value of the dominant frequency ranges from 1 - 22 Hz, the value of the amplification factor is obtained in the range of 1 - 10.5, the value of the peak ground acceleration ranges from 60 - 300 cm/s^2, the thickness of the weathered layer is obtained in the range of 12 - 22 meters. Based on the results of the slope analysis, the study area is on a slope classified as a bit steep - very steep.

Keywords: landslides, weathered layer thickness, microzonation, HVSR , Gerbosari Village

1. Introduction

Landslides or soil movements are one of the type movements of soil or rock masses, down or out of the slopes due to disturbed soil stability or rock making up the slopes (B). The consequences of landslides are not only casualties but also damage road access so that it can paralyze economic accommodation in the area due to closed main road access in the area. Landslides that occur are caused by several factors, among others, high rainfall, slope, and thickness of the weathered layer.

One area that has a history of high landslide incidents is in Gerbosari Village, Samigaluh District, Kulonprogo Regency where the area has a history of large landslide events of 56 incidents during the last 5 years. So it is necessary to analyse the characteristics of the soil in terms of the thickness of the weathered layer and analysis of the slope that can lead to landslides using the microtremor measurement approach.

Microtremor is a weak vibration on the surface of the earth which occurs continuously due to vibration sources such as earthquakes, human activities, and traffic (Nakamura, 2000). This phenomenon creates a seismic wavefield, where the field is known as the microtremor (Dal Moro, 2015). Microtremors array observation has been used for estimating deep structure (Goto et.al, 2007). Microtremors measurement could be used for landslide susceptibility assessment too (Abdelrahman et.al, 2021).

Signal data from microtremor measurements consist of 3 signals in the form of a vertical component (up and down), a horizontal component (north-south), and a horizontal component (east-west). Then the signal is processed using the HVSR (Horizontal to Vertical Spectral Ratio) method to produce the peak frequency and HVSR amplitude which represent the amplification and frequency of the specific local (Nakamura, 2000).

2. Geology

Samigaluh Subdistrict, Kulonprogo Regency, which is one of the regencies in the Special Region of Yogyakarta (DIY) is located on a tectonic and volcanic route. The northern part of the DIY Province is bordered by the active volcanic Merapi, in the southern part of the DIY Province it is bordered by the Java Trench which is a subduction route of the Indo-Australian-Eurasia plate (Marjuki and Yogafanny, 2008). Rahardjo et al. (1995) described the Kulon Progo stratigraphy as composed of Quaternary volcanic rocks, alluvial deposits accompanied by the presence of a breakthrough rock complex. The rock formations from old to young consist of the Nanggulan Formation, Kebo Butak Formation, Jonggrangan Formation, Sentolo Formation (Husein, et al. 2007). While the research location in Gerbosari Village, Samigaluh District, Kulonprogo Regency consists of the Kebo Butak Formation (Tmok) and Jonggrangan Formation (Tmj).

Gerbosari Village, Samigaluh Subdistrict, Kulonprogo Regency is in The Kebo Butak Formation (Tmok) and the Jonggrangan Formation (Tmj) as shown in Figure 1. The Kebo Butak Formation (Tmok) is a formation that is not aligned above the Gamping-Wungkal Formation and is sediment. The results of volcanic activity are composed of volcanic rocks, either in the form of pyroclastic, plastic, or coherent lava (Bronto et al.).

The constituent rocks of the Kebo Butak Formation consist of andesite breccias, tuffs, tuff lapilli, agglomerates, and clays. Several measurement points are located in the Jonggrangan Formation (Tmj), which overlaps or hovers over it. The rock composition of the Jonggrangan Formation is in the form of conglomerates, marl, tuff, limestone sandstone with lignite inserts, inset limestone, and limestone, while the upper layer consists of bioherm grey limestone interspersed with marl and layered limestone. The thickness of this formation is 2,540 meters and is estimated to be Miocene-Pliocene (Trianda et al, 2018).

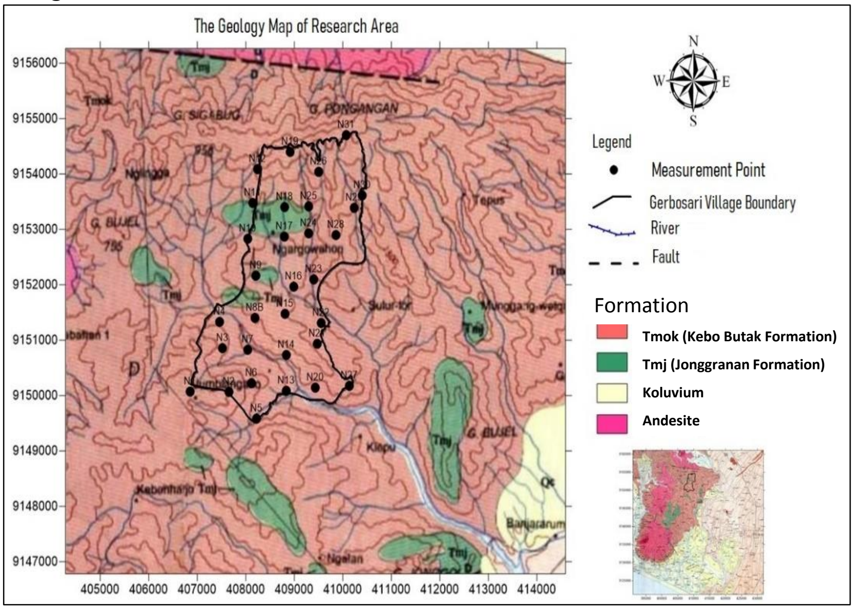

Fig 1. Geological Map of the Research Area (Rahardjo, et al. 1995)

3. Method

3.1 Data Acquisition

Microtremor measurements were carried out around Gerbosari Village, Samigaluh District, Kulonprogo Regency using 31 measurement points with a distance between points of 650 meters using a sampling frequency of 100 Hz with a measurement duration of approximately 45 for each measurement point. Microthermal measurements are based on the terms of the Sesame European Research Project using the HVSR (Horizontal to Vertical Spectral Ratio) method analysis.

The measurement used hardware instruments in the form of a set of Lennarzt 3D/20s Seismometer, Garmin GPS Hand Help, Sesame Log Sheet, and software in the form of DataQ Instrument, Geopsy, Rockwork, and Arcgis.

3.2 HVSR Method (Horizontal to Vertical Spectral Ratio)

The Horizontal to Vertical Spectral Ratio was first introduced by Nogoshi and Iragashi (1970) which states that there is a relationship between the horizontal and vertical component comparisons of microtremor measurements which was later developed by Nakamura (1989). The horizontal-to-vertical (H/V) method has the potential to significantly contribute to site effects evaluation, in particular in urban areas (Bonnefoy-Claudet, 2008). The HVSR equation is stated based on the pattern below:

$$HVSR = \frac{\sqrt{(S_{NS})^2 + (S_{EW})^2}}{S_{VS}} \quad (1)$$

S_{NS} is the horizontal spectrum component in the surface layer in the north-south direction, S_{EW} is the horizontal spectrum component in the west-east surface layer and S_{VS} is the vertical spectrum component on the surface.

3.1 The Dominant Frequency (f_0) and Amplification Factor (A_0)

The dominant frequency is the frequency value that often appears in an area so that it is recognized as the frequency value of the rock layers in that area. It can indicate the characteristics of the rock types that comprise it. The dominant frequency value is related to the depth of the reflected plane subsurface, where the reflected plane is the boundary between loose sediments and hard rock (bedrock). So that if the value of the dominant frequency is small, it comes from the reflection of the wave which shows the deeper of the reflection plane.

The amplification factor is the magnification of the wave acceleration that occurs on the surface due to the type of soil in an area. The magnitude of the amplification value can be estimated from the contrast of the wave propagation parameters, namely the density and velocity of the bedrock and surface sediments (Nakamura, 2000). The greater the difference in these parameters, the greater the amplification value of the wave propagation (Gosar, 2007). If the dominant frequency value (f_0) is high, it means that the subsurface is composed of hard rock. And if the dominant frequency value (f_0) is low, it means that the subsurface is composed of soft rock (sedimentary rock). Dominant frequency (f_0) is influenced by subsurface velocity (V_S) and sediment layer thickness (h) (Mucciarelli M, Gallipoli MR. 2004).

3.2 Inversion of Dispersion Curve

HVSR curve inversion processing was conducted by using Dinver software that a neighbourhood algorithm (Wathelet, 2005). The assumption is that the used microtremor waves are dominated by Rayleigh waves (Molnar et.al, 2022). Processing begins with the HVSR curve which is used as input in the ellipticity curve by providing a limitation of the initial model parameter values including P wave velocity (V_p), S wave velocity (V_s), density (ρ), and Poisson ratio so that the error or mismatch value is obtained (misfit) is lowest (0 ≤ misfits <1).

Some examples of the ground profile appearance of the processing results are shown in Figure 2, which shows the value of shear wave velocity (V_s) and layer depth for each measurement point.

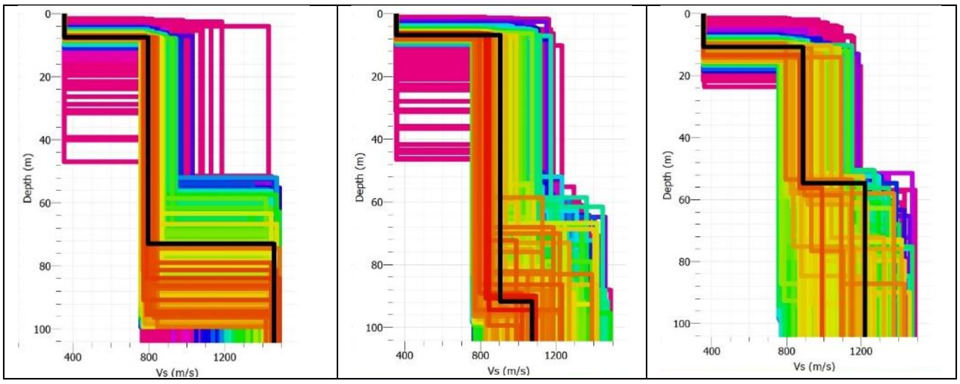

Fig 2. Ground Profile of Inversion Result V_s Value.

4.1 Result and Discussion

4.1. Microzonation Dominant Frequency Value (f_0) and Amplification Factor Value (A_0)

The distribution of the dominant frequency values in the study area has a range of values ranging from 1 – 22 Hz. The measurement results show that almost all research areas have a dominant frequency value that tends to be low which is indicated by the blue colour except at 3 points namely N30, V27, and N8B which have high dominant frequency values which are represented by reddish-orange.

The research area that has a low dominant frequency value shows that the area is an area with a very thick surface sediment thickness with a value range of 1 - 8 Hz. On the contrary, an area that has a high-frequency value indicates that the area has a surface sediment layer that tends to be thin and hard rock shallow with a value range of 15 – 22 Hz. The micro zonation of the dominant frequency values is shown in Figure 3.

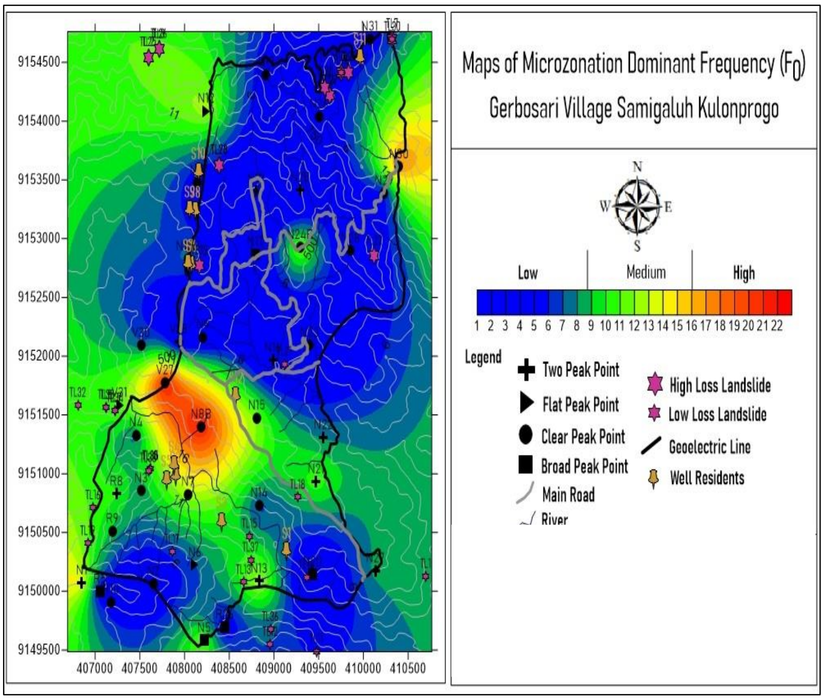

Fig 3. Distribution of the dominant frequency values in the study area.

The distribution pattern of the distribution shows that the north and south sides of the study area with a history of landslides that are seen directly based on field observations during the acquisition are in an area that has a low-frequency value which indicates that the area has a thick enough surface sediment layer and it is indicated that the rock the base is at a fairly deep depth.

Amplification is influenced by shear wave velocity (V_s) which is related to the rock density due to reduced rock density which will cause an increase in the amplification factor value. The level of rock density can reduce the amplification of shocks because the amplitude of the waves propagating in solid rock is relatively small, while in rocks with soft characteristics it will slow down the propagating waves and increase the amplitude of the waves which can cause the potential level of landslide due to shocks originating from large earth shakes. The distribution of the amplification factor value can by seen in Figure 4.

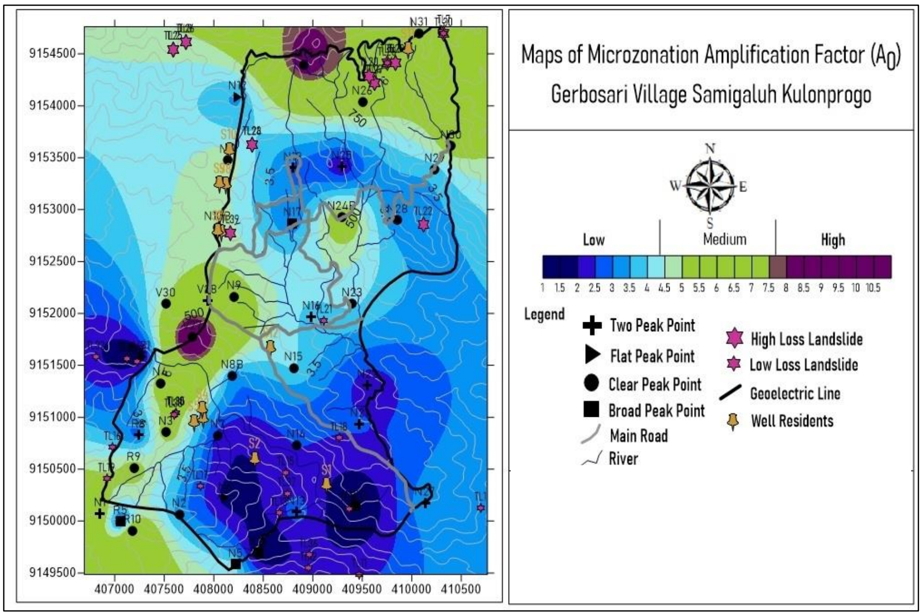

Fig 4. Distribution of the amplification factor value distribution in the study area.

Table 1. Variation of V_s value and layer depth

Name Point	Value of Layer 1 V_s	Value of Layer 2 V_s	Value of Layer 2 V_s	Layer Depth 1	Layer Depth 2	Layer Depth 3
N1	357.05	897.11	1446.24	8.4097	51.002	104.29
N2	353.52	862.10	1431.61	11.222	60.405	104.12
N3	357.08	812.65	1208.58	7.536	58.04	103.647
N4	353.54	1185.01	1322.95	12.52	77.43	104.28
N5	357.05	1094.90	1418.02	7.613	53.07	102.83
N6	357.03	820.26	1432.11	8.928	80.6	102.26
N7	353.37	788.25	1000.48	5.994	56.901	103.29
N8	353.42	952.30	1197.30	4.6287	93.587	104.17
N12	352.55	888.26	1258.75	8.26	76.696	104.31
N13	353.52	812.08	989.63	7.1	55.783	104.14
N14	357.02	888.35	1221.81	10.7847	54.684	104.31
N15	356.96	905.83	1073.09	6.89	91.74	104.06
N16	357.00	796.13	1460.71	7.463	72.975	103.57
N19	357.10	844.98	1445.46	6.949	63.484	102.35
N20	353.52	764.91	1233.88	1.8716	97.381	104.304
N21	353.47	915.12	1446.56	9.666	58.048	106.668
N22	353.5	780.41	1446.35	6.4281	52.546	72.216
N23	353.5	820.3	1489.85	8.493	64.761	104.25
N26	353.38	871.36	1475.52	22.745	72.24	104.29
N27	353.51	888.04	1322.59	9.29	62.234	104.31
N28	353.53	780.58	1490.10	5.113	62.252	104.25
N29	353.49	820.28	845.16	4.769	77.462	108.14
N30	357.03	1127.84	1431.89	7.383	55.383	103.28
N31	353.504	828.59	1460.86	12.645	55.226	102.2
N24	360.68	888.39	1514.66	8.164	55.231	123.21
N25	360.62	780.48	1514.92	5.994	91.744	113.76
N18	353.55	828.55	1545.69	6.756	56.34	137.49
N17	353.52	836.92	1560.77	7.166	57.44	128.71
N11	360.66	780.08	1607.92	7.7176	52.04	137.49
N10	357.01	897.11	1560.64	9.7627	54.14	117.25
N9	353.52	812.76	1530.1	17.558	67.35	110.45

The value of the amplification factor in Gerbosari Village has a range of values from 1 – 10.5 and is classified into 3 classes, namely low with a value range of 1.19 – 3.12 indicated by blue. The areas with moderate amplification values have an amplification factor value range of 3.12 – 6.24 indicated by green and areas with high amplification factor values have a range of values ranging from 6.24 - 10.55 which is indicated by dark purple.

When we see the distribution of the amplification factor value distribution in the study area, it shows a pattern in the form, on the north side and west side the amplification factor value tends to be medium-high which indicates that the area has a large contrast of bedrock and surface sediments. Meanwhile, the western and southern sides of the research area show a low amplification factor value.

4.2 Ground Profile V_s

Ground Profile $\boldsymbol{V_s}$ value is a method that can be used to determine the characteristics of the constituent material so that it can be used to determine subsurface lithology. To obtain parameter values is adjusted to the geological conditions in the study area, namely, the value of $\boldsymbol{V_s}$has a range between 350 – 1500 m/s, the value of $\boldsymbol{V_p}$ has a value range of 250 – 2500 m/s, and the value of σ has a range of values between 0.2 – 0.5 and a density of 1200 – 2800 kg/m^3. It can be assumed that there are 3 layers in the area. And the ground profile identifies 3 layers with varying depths as being shown in Table 1. The first layer has a thickness variation of 1 – 22 meters, the second layer varies in thickness from 51 to 97 meters and the third layer varies in thickness from 72 to 123 meters.

4.3 Microzonation of Weathered Layer Thickness Value

Based on the inversion results, the coating value for each point as shown in Table 1 can be used to microzone the weathered layer thickness value in the area by using the thickness value in the first layer as being shown in Figure 5.

Based on the results of microzonation in Figure 3, it can be seen that most of the research areas have a high enough thickness value of the sediment layer on the Northeast side, the middle side of the research area, and the southern part of the study area with a value range between 12-22 meters which is shown by green and red colour. Thick weathered layers are around points N31, N26, N23, N16, N12, N11, N10B, and N9 with thicknesses of 12.6, 22.7, 8.4, 7.4, 8.2, 7.7, 9.7, and 17.5 meters. Meanwhile, the areas with thin weathered layer thickness characteristics have values ranging from 4.6 - 7.3 meters which are indicated by the blue colour.

4.4 Analysis of Slopes

The slope of an area that has the potential for landslides is a major factor, especially in areas with a slope of more than 15°. The slope in an area is the main controlling factor that causes landslides. A steep slope or cliff will increase the driving force. And when the driving force of a rock on a slope is greater than the bearing force, a landslide will occur.

The determination of value of the slope is determined by using height data from DEMNAS, the classification of slopes is divided into 7 classes regarding the slope classification by (Sitanala,1989) as shown is in Figure 6.

Based on Figure 6, the slope of Gerbosari Village is dominated by a rather steep and very steep classification on the north and south sides with a history of landslides that are quite frequent. This shows that this side of the area has a high enough potential due to the effect of the slope. Besides the slope, the north side has a weathered layer thickness with a high classification with a value of 16-22 meters. The soil characteristics in the area are at a frequency value of 1 - 5 Hz which indicates that the area has soft soil types.

Meanwhile, on the middle side, it shows the slope with a slightly sloping rather steep classification and it is can be known that the area has the potential for landslides which is quite low when compared to the north and south sides.

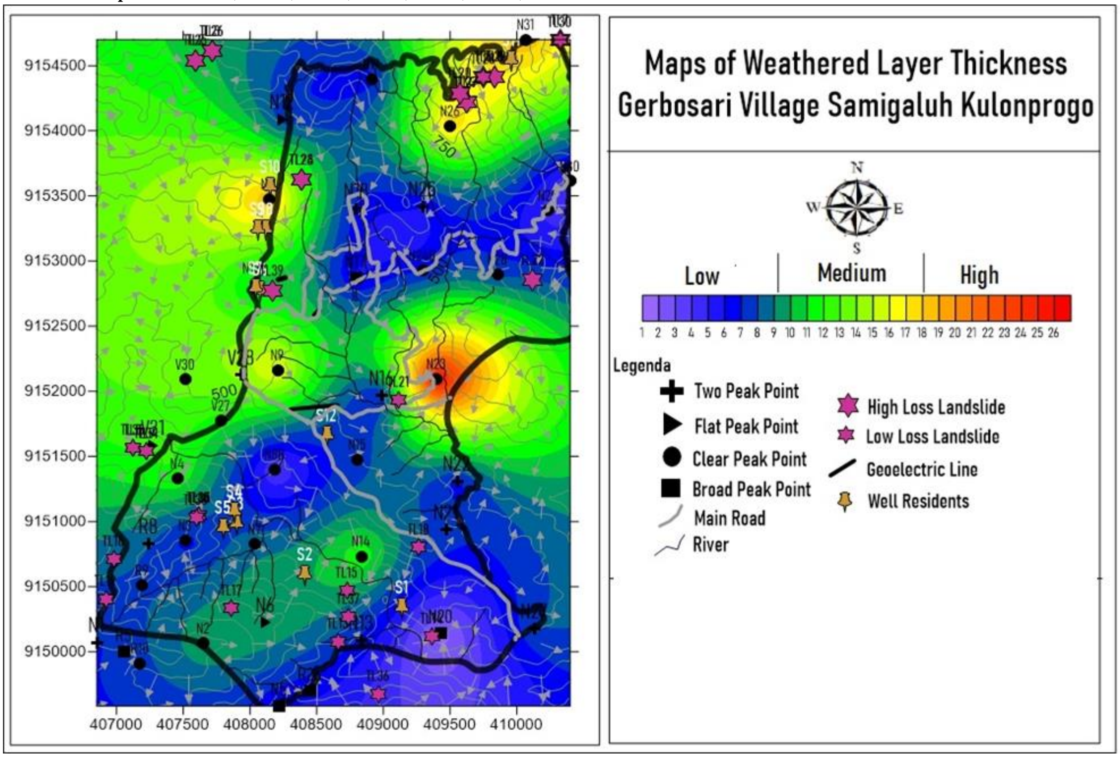

Fig 5. Microzonation of weathered layer thickness values in Gerbosari Village.

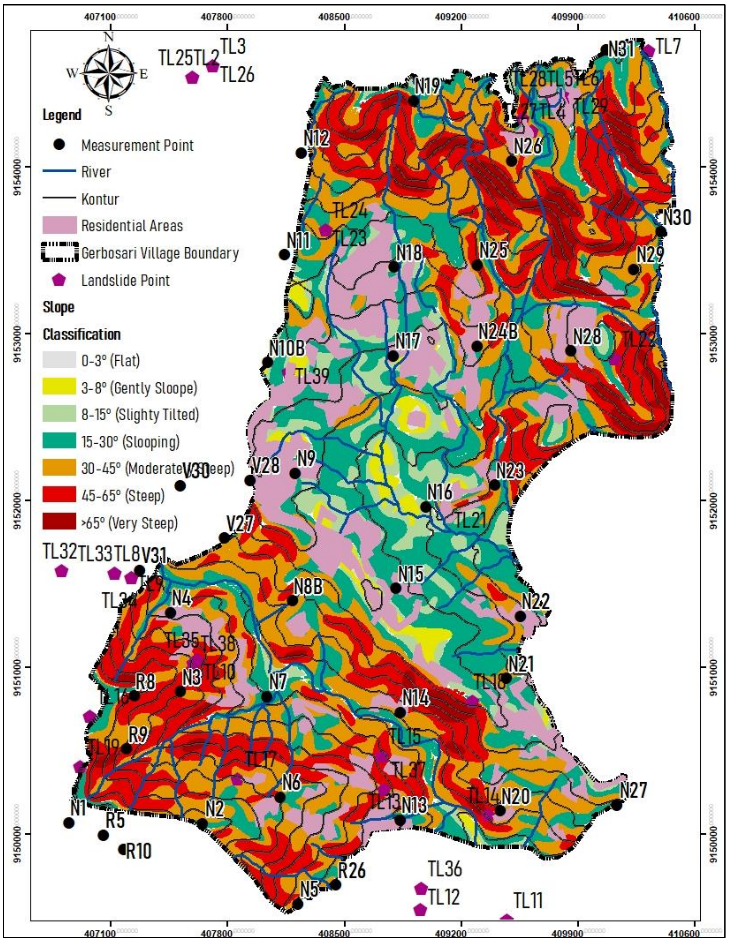

Fig 6. Map of the slope of the village of Gerbosari slopes.

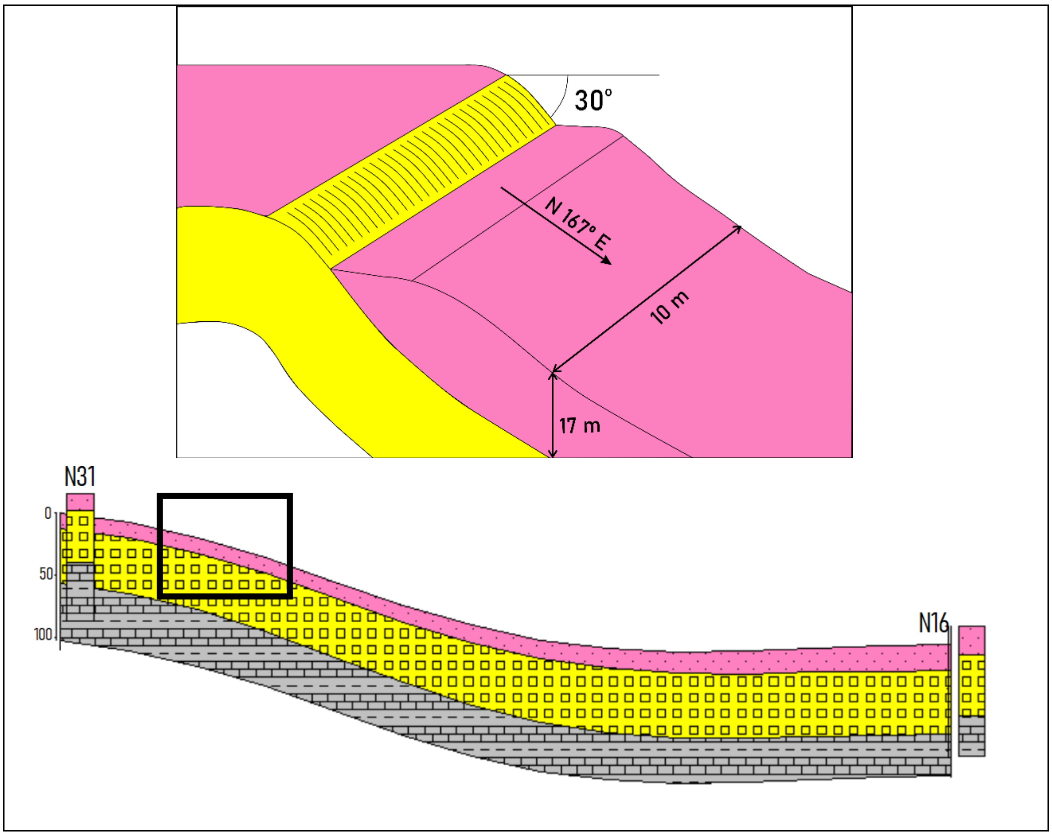

Fig 7. The layer of weathered thickness around the N30 and N26 points.

4.5 Landslide Potential Analysis

Based on the history of landslides that often occur in Gerbosari Village, landslides often occur on the north side of the research area and are around points N30 and N26. The results of the analysis show that the area is on a rather steep slope as shown in Figure 6. Based on the results of the inversion and a cross-section of the incision was performed to determine the thickness of the weathered layer in the area as shown in Figure 7.

Figure 7 shows, the area is on a slope of 30 ° with a weathered layer thickness of 17m as the driving factor. The existence of a driving factor disrupts slope stability, especially on steep slopes, which can cause landslides to occur. Landslides in this area are also caused by the influence of high rainfall intensity. Where the slope instability is due to periodic rain which causes the water in the soil to flow laterally so that the degree of saturation of the soil increases and reduces the pore water pressure resulting in decreased shear strength. This decrease in soil shear strength and increase in shear stress causes landslides to occur.

5. Conclusions

The result of microtremor measurement shows that the dominant frequency is in the range of 1 - 22 Hz. In the research area, the dominant frequency value tends to be in a low class which indicates that the area has soft soil characteristics. The amplification value in the study area shows the pattern on the north and west sides of the study area have a high enough value which indicates that the area has a small rock density which causes a high magnification of waves. The value of the amplification factor in Gerbosari Village has a range of values from 1 - 10.5.

The study area is in a condition with a slope classification that is rather steep - very steep with a slope of 30-> 65 °. The north and south sides, of the study area, have a very steep slope classification where in this area, there is a history of previous landslides. Then, based on the inversion results for each point, the value of each layer is obtained where the layer which is assumed to be weathered is used for the analysis of the thickness of the weathered layer as a driving factor for landslides in steep areas. So, the area that has the most landslide history is on a rather steep slope - very steep with a thick weathered layer thickness. This is what causes landslides.

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References

Abdelrahman, K., Al-Otaibi, N., Ibrahim, E., and Binsadoon, A., 2021, Landslide susceptibility assessment and their disastrous impact on Makkah Al-Mukarramah urban Expansion, Saudi Arabia, using microtremor measurements, *Journal of King Saud University – Science* 33, 1-12.

Bonnefoy-Claudet, S., Kohler, A., Cornou, C., Wathelet, M and Bard, P., 2008. Effects of Love Waves on Microtremor H/V Ratio, *Bulletin of the Seismological Society of America* 98(1), 288–300.

Bronto, S., Mulyaningsih S., Hartono G., Astuti B., 2008. Gunung Api Purba Watuadeg: Sumber Erupsi dan Posisi Stratigrafi, *Jurnal Geologi Indonesia* 3, 117-128.

Dal Moro, G., 2015, Surface Waves Analysis for Near Surface Applications, *Elsevier*, Amsterdam.

Farazi, A.H., Mia, A.J., Mahmud, M.I., 2018. A Case Study Based Slope Stability Analysis at Chittagong City, Bangladesh*, Journal of Geoscience, Engineering, Environment, and Technology* 3(3), 164-173.

Faris, F. and Fathani, F., 2013. A coupled hydrology/slope kinematics model for developing early warning criteria in the Kalitlaga Landslide, Banjarnegara, Indonesia. In *Progress of Geo-Disaster Mitigation Technology in Asia* (pp. 453-467). Springer, Berlin, Heidelberg.

Fathani, T.F., Karnawati, D., Wilopo, W. and Crowley, K., 2016. An integrated methodology to develop a standard for landslide early warning systems.*Natural Hazards & Earth System Sciences* 16(9).

Gosar, A., 2007, Microtremor HVSR Study for Assessing Site Effects in the Bovec Basin (NW Slovenia) Related to 1998 Mw 5.6 and 2004 Mw 5.2 Earthquake, Elsevier, *Engineering Geology* 91, 178-193.

Goto, H., Takahashi, C., Ishi, Y., Ling, Su-Qun, Miyakoshi, K., Morikawa, H, Sato, Y., Sawada, S., Shingaki, Y., Suzuki, Y., Takabatake, D., and Joshima, M., 2007. Deep subsurface structure estimated by Microtremors array observations and gravity surveys in kashiwazaki area, japan, *Soils And Foundations, Japanese Geotechnical Society* 49(4), 651–659.

Husein S., Karnawati D., Pramumijoyo S., Ratdomopurbo A., 2007. Kontrol Geologi Terhadap Respon Lahan dalam Gempa Bumi Yogyakarta 27 Mei 2006: Upaya Pembuatan Peta Zonas Mikro di Daerah Bantul, Yogyakarta, Universitas Gadjah Mada.

Islam, M.S., Islam, M.S., Ahmed, A.S.D., Karim, S.U., Hossain, M., Hoque, F., 2015. Seismic induced landslide vulnerability in the Chittagong City, Bangladesh. *Journal of Geotechnical Engineering (JoGE)* 2(1), 1-13.

Islam, M.S., Hussain, M.A., Khan, Y.A., Chowdhury, M.A.I., Haque M.B., 2014. Slope Stability Problem in the Chittagong City, Bangladesh*. Journal of Geotechnical Engineering (JoGE*) 1(3), 13-25.

Izzati, F.N., Laksmana, Z.S., Marcelina, B., Hutabarat, S.S. and Widodo, 2017, July. Identifying potential ground movement as a landslide mitigation approach using resistivity method. In *AIP Conference Proceedings* (1861(1), 030046). AIP Publishing LLC.

Kusnadi, S., 2017. Slope Stability Analysis Based on Type, Physical and Mechanical Properties Rock In Teluk Pandan District, East Kutai Regency, East Kalimantan Province, Indonesia, *Journal of Geoscience, Engineering, Environment, and Technology*, 2(4), 272-277.

Marani, M.I.R., Najib, N., Ali, R.K., 2018. Penentuan Zona Gerakan Tanah dan Analisis Kemantapan Lereng di Kecamatan Klego, Kabupaten Boyolali, Jawa Tengah. *J. Geosains dan Teknol.* 1, 89-98.

Marjuki, B., Yogafanny E., 2008, Profil Kebencanaan Provinsi Daerah Istimewa Yogyakarta, *BAPPEDA DIY*, Yogyakarta.

Martono, Hasria, Asfar, S., Azzaman, MA., Ngkoimani, L.O., Okto, A., Hamimu, L., Irawati, Sawaludin, 2022.

Morphotectonic Control of Land Movements at Wundulako Region, Kolaka Regency, Southeast Sulawesi Province, Indonesia, *Journal of Geoscience, Engineering, Environment, and Technology*, 7(2), 81-86.

Mia, A.J.M., Farazi, A.H., Mahmud, M.I., 2017. Factors Affecting Slope Stability for Triggering Rainfall Induced Landslide at Chittagong City: A Case Study on 2007 and 2008 Landslides. *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)* 14(4), 43-48.

Monar, S., Sirohey, A., Assaf, J., Bard, P.Y., Castellaru, S., Cornou, C., Cox, B., Guillier, B., Hassani, B., Kawase, H., Matsushima, S., Sanchez-Sesma, F.J., and Yong., A., 2022. A review of the microtremor horizontal-to-vertical spectral ratio (MHVSR) method, *Journal of Seismology*, Springer.

Mulyasari, R., Brahmantyo, B., Supartoyo, S., 2017. Kuantitatif Aktivitas Tektonik Relatif di Pegunungan Baturagung Jawa Tengah. *Bull. Geol*. 1, 40–53. https://doi.org/10.5614/bull.geol.2017.1.1.3

Mucciarelli, M., Gallipoli, M.R. 2004. The HVSR technique from microtremor to strong motion: empirical and statistical considerations. In: *Proc. Of 13th World Conference of Earthquake Engineering*, Vancouver, BC, Canada, 45.

Nogoshi, M., dan Igarashi, T., 1970, On The Propagation Characteristics Estimations of Subsurface Using Micro tremors on The Ground Surface, *J. Seism. Soc. Japan* 23, 264–280.

Nakamura, Y., 1989, A Method for Dynamic Characteristics Estimation of Subsurface using Microtremor on Ground Surface, *Quarterly Report of Railway Technical Research Institute (RTRI)* 30(1).

Nakamura, Y., 2000, Clear Identification of Fundamental Idea of Nakamura's Technique and Its Applications, *System and Data Research*, Japan.

Prabowo, U.N, 2021. The Soft Layer Thickness Estimation using Microtremor Measurement to Identify Landside Potential in Watukumpul, Central Java, Indonesia, *Journal of Geoscience, Engineering, Environment, and Technology* 6(1), 16-23.

Puspitasari, P. and Herdiansyah, H., 2019. December. Landslide Vulnerability in Residential Areas for Disaster Mitigation in Sawangan District, Depok City. In *Journal of Physics: Conference Series*(Vol. 1339, No. 1, p. 012091). IOP Publishing

Putra, Y.A., Ismail, N., Faisal, 2015. Analisis Penentuan Faktor Penyebab Gerakan Tanah di Kabupaten Aceh Tengah, Provinsi Aceh. *J. Ilmu Kebencanaan (JIKA),Pascasarj. Univ. Syiah Kuala* 2, 96–103.

Samodra, G.,Chen, G., Sartohadi, J. and Kasama, K., 2018. Generating landslide inventory by participatory mapping: an example in Purwosari Area, Yogyakarta, Java.*Geomorphology* 306, 306-313.

Trianda, O., Prastowo, R., Sely, N., 2018. Identifikasi Ketebalan Lapisan Lapuk di Daerah Kalirejo, Kulonprogo Berdasarkan Pengukuran Mikrotremor dalam Upaya Mitigasi Tanah Longsor, *ReTII* (pp. 246-253).

Wahyudi, Donny R., Sumaryono, Emi Sukiyah, Dicky Muslim, A.R.D., 2015. Morphotectonic Control towards Land Movement in Malalak Region, West Sumatra. *J. Lingkung. dan Bencana Geol.* 6, 229–240.

Zamroni, A., Kurniati, A.C., Prasetya, H.N.E., 2020. The assessment of landslides disaster mitigation in Java Island, Indonesia: a review, *Journal of Geoscience, Engineering, Environment, and Technology* 5(3), 124-128.