ISSN: 2579-5821 (Print)
ISSN: 2579-5546 (Online)
URL address: http://journal.unhas.ac.id/index.php/geocelebes
DOI: 10.20956/geocelebes.v7i2.25476

Jurnal Geocelebes Vol. 7 No. 2, October 2023, 130 – 137

Assessment of Landslide Susceptibility Microzonation using Microtremor Measurements Along Mountain Road in North Bengkulu–Lebong, Bengkulu Province

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Manuscript received: 16 February 2023 ; Received in revised form: 2 March 2023; Accepted: 28 March 2023

Abstract

Based on the geological condition, the research location on the North Bengkulu - Lebong crossing is on the Sumatra fault zone that extends from south to north, which causes this area to have a morphological shape and topography of hills and hills extreme slopes. This research results in landslide-prone micro zonation based on GSS and PGA values obtained from Horizontal-to-Vertical Spectral Ratio (HVSR) method measurements. The research was conducted by measuring 25 research sites. The results of Peak Ground Acceleration (PGA) values processing at the research site, between 0.14 gal - 0.53 gal. Locations with the potential for landslides, shown in blue (0.14-0.29 gal), are located in several spots of the research site. The distribution of Ground Shear Strain (GSS) at the study site is evenly distributed at a value of 10^{-4}, which indicates that the study site is prone to cracking and ground movement. In the distribution of GSS values, it is suspected that the location in the dark red color (10^{-3}) has the highest potential to experience repeated landslides. Based on the results of the calculation of PGA and GSS values on the North Bengkulu - Lebong crossing, the points of landslide-prone locations can be known so that disaster mitigation can be carried out at these locations to reduce the risk that will occur.

Keywords: landslide; microtremor; microzonation; mountain road.

Citation: Nuramadani, U., Halauddin., Suhendra., Fadli, D. I., Panjaitan, A. P., and Sinaga, J. E. E. (2023). Assessment of Landslide Susceptibility Microzonation using Microtremor Measurements Along Mountain Road in North Bengkulu–Lebong, Bengkulu Province. *Jurnal Geocelebes*, 7(2):130–137, doi: 10.20956/geocelebes.v7i2.25476

Introduction

Bengkulu is one of the provinces located on the island of Sumatra, with most of its mountainous territory having a high potential for landslides (BPBD, 2019). One of the areas with a high potential for landslides is the North Bengkulu - Lebong crossing (Ariyanto & Joni, 2019). Based on geological conditions, the North Bengkulu - Lebong crossing is located in the Sumatran fault zone that extends from the south to the north, which causes this area to have a hilly morphological and topographic shape and slopes with high steepness so that it can endanger road users because of the high potential for landslides.

Landslides can occur due to the movement of land masses or can be defined as the displacement of slope-forming materials that move down and out of the slope (Trianda et al., 2018). Apart from that, several human activities can be a triggering factor for landslides, such as logging trees on slopes without reforestation (Nurjanah & Mursalin, 2021), mining of rocks, soil, or other mining goods that cause slope instability (Susanti & Miardini, 2019), the level of soil and rock wetness (Iswahyudi et al., 2021), changes in the slope of the area due to development, and excessive loading from buildings in mountainous areas (Hadi et al., 2021).

Other factors influencing landslides are slip surface or shear surface and high rainfall (Nishimura et al., 2022). The North Bengkulu - Lebong crossing is an important crossing that connects Bengkulu Province with other provinces using land transport. The North Bengkulu - Lebong crossing is one of the most heavily traveled routes, so the resulting vibrations can trigger landslides due to ground movements that change the physical properties of the land surface (Kristie & Budiman, 2021). Landslides that occur on the North Bengkulu - Lebong crossing will have a significant impact on the community because they hamper traffic and have a severe impact on economic problem, for example, landslides that occurred in 2022, causing impacts felt by the community due to disruption of the land transportation system which is covered by landslide material. The preliminary survey results found several locations of the North Bengkulu - Lebong Regency crossing road that experienced landslides, shown in Figure 1.

The impact of landslides can be minimized by conducting disaster mitigation and management efforts (Zulfa et al., 2022). One of the disaster mitigation efforts can be made using the Horizontal-to-Vertical Spectral Ratio (HVSR) method (Hartantyo et al., 2020). The HVSR method can be used to determine complex geological structures and determine the thickness of sedimentary layers obtained from data in the form of natural vibrations originating from natural sources and human activities (Silitonga, 2022). The HVSR method has two important methods obtained from the processing results: dominant frequency (f_0) and amplification (A_0). In addition, microtremor data can be used to find seismic susceptibility index, sediment layer thickness, Peak Ground Acceleration (PGA), and Ground Shear Strain (GSS), which are used as parameters for analysis in identifying potential landslide areas (Refrizon et al., 2013). The landslide-prone zonation areas can be mapped based on the PGA and GSS values obtained from the HVSR method.

Figure 1. Documentation of the location of the North Bengkulu - Lebong crossing road that experienced a landslide on 26 March 2022.

A landslide investigation using the HVSR method has been conducted (Natasya et al., 2022) on the Bengkulu - Kepahiang causeway. The interpretation results showed that in the Bengkulu - Kepahiang causeway area, the average value obtained is relatively medium-high, so it is less likely if a landslide occurs at a depth of 0 to 30 meters. However, at a depth of 0 to 5 meters, the average value is relatively low-medium, so the area is prone to landslides. Therefore, the HVSR method is often used in case studies of landslides and earthquakes (Hadi et al., 2018).

Local Geology Setting

The Barisan Mountains dominate the geology of the Bengkulu sheet, the corner is part of the South Sumatra Basin, and the west is part of the Bengkulu Basin. The study area is a plateau located around the

Sumatra fault zone, associated with the Musi-Keruh and Ketaun faults and covered by a mixture of Quaternary alluvium and volcanic materials. Plio-Plistocene volcanic rocks cover the plateau. Elevation on this plateau is up to 500 meters above the MSL. The oldest unit exposed is the Seblat Formation which includes marine sediments derived from clastic volcanic rocks of the Barisan Mountains and locally inserted limestone. The Simpangaur Formation consists of shallow marine to muddy freshwater sediments and lignite coal. The Plio-Plistocene-aged Bintunan Formation taxonomically overlies the Simpangaur Formation. Based on the geological map of the Bengkulu sheet on the North Bengkulu - Lebong cross-section, there are also Bintunan Formation and Andesite-Basalt volcanic rocks, which can be seen in Figure (2). This lane forms the Barisan volcanic chain that stretches along the western part and is parallel to the long axis of the island of Sumatra. It is an area of magmatic activity during the Tertiary and Quaternary, which may indicate the maturity of the volcanic arc (Gafoer et al., 2007).

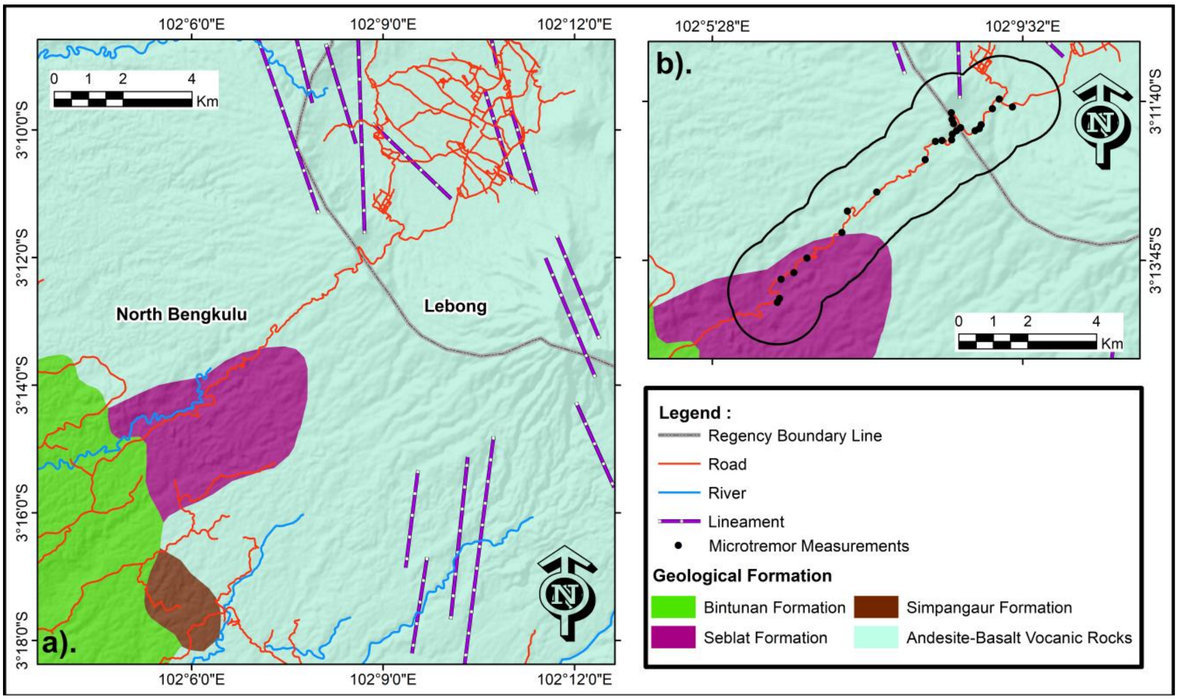

Figure 2. a). Research geological map (modified from Gafoer et al. (2007); b). HVSR site measurements.

Materials and Methods

The research was conducted in the mountainous area of the North Bengkulu - Lebong Regency of Bengkulu Province measurements using microtremor as many as 25 measurement points along the research location road. Data were collected for 30 minutes at each measurement point with a sampling frequency of 100 Hz. The structure of subsurface rock layers can be described by variations in shear wave velocity obtained from forward computation and HVSR inversion of microtremor data. Rocks with complex properties, like igneous rocks, will have low landslide-prone factor values. On the other hand, soft rocks like clay and silt have high landslide-prone factor values (Sugianto & Refrizon, 2021).

The dominant frequency (f_0) and amplification (A_0) values obtained from HVSR analysis are used as input data to calculate the seismic susceptibility index (K_g). The seismic susceptibility index is an index that describes the level of susceptibility of the surface soil layer to deformation during an earthquake (Tanjung et al., 2019). The seismic susceptibility index can be calculated using the following Equation (1) (Asnawi et al., 2020):

$$Kg = \frac{Ag^2}{fg}\frac{1}{\pi^2 vb} \tag{1}$$

Based on the seismic vulnerability index obtained, the soil structure or subsurface rock condition at the research location can be known.

Peak Ground Acceleration (PGA) value is calculated using earthquake parameters with the most significant magnitude at the epicenter distance closest to the research location (Prakoso, 2018). The PGA formula is as follows Equation (2) (Douglas, 2021):

$$\alpha_g = \frac{5}{\sqrt{T_g}} 10^{(0,6\,M)-\left(1,6+\frac{3,6}{R}\right)\log R + 0,167 - \frac{1,8}{R}} \tag{2}$$

The Ground Shear Strain (GSS) value describes the geological conditions at a location (Sugianto et al., 2021). GSS is one of the physical parameters that shows the level of rock susceptibility to stretching or shifting from its equilibrium point due to earthquakes. GSS is often used to describe the characteristics of soil layers or the potential for liquefaction and landslides at a location. The GSS value is obtained by multiplying the seismic susceptibility index with the PGA because the relationship is directly proportional. The greater the value of the seismic vulnerability index and PGA, the greater the GSS value and will cause the soil layer to deform (Gemintang et al., 2022). The GSS formula is as follows Equation (3) (Nakamura, 2008):

$$\boldsymbol{\gamma} = Kg \times (10^{-6}) \times \alpha \tag{3}$$

Results and Discussion

The measurement results at this research location are data from vibration signals analyzed using Sesaray Geopsy for signal filtering without noise. The results of signal filtering were analyzed using the HVSR method, resulting in H/V curves, predominant frequency values (f_0), and amplification factors (A_0). The value of the predominant period is used as a parameter to determine the Peak Ground Acceleration (PGA) value, which is calculated using Equation (2). The PGA values at the 25 research points were inputted in the PGA map shown in Figure 3. The results of processing the PGA values in the surface layer show PGA values between 0.14 g - 0.53 g.

Low PGA values are shown in dark blue with values of 0.14 g - 0.19 g, medium PGA values in green with values of 0.34 g - 0.39 g, and high PGA values in dark brown with values of 0.48 g - 0.53 g. The PGA value is directly proportional to the dominant frequency value. This parameter shows that areas with low PGA values have low dominant frequency values. Areas with low PGA values have thick sedimentary layers and a small density of constituent rocks. Areas with small PGA values have seismic wave velocities that propagate through the rock layers resulting in significant amplification and seismic wave vibrations that travel below the ground surface for a long time, which can cause more significant damage.

The PGA value in this study was used to find the Ground Shear Strain (GSS) value. GSS value is a parameter related to the dynamic nature of the soil. If an area has a high GSS value, then the area is prone to stretching or shifting movements. The stretching and shifting will cause the rock structure to deform and experience landslides. However, if the GSS value is smaller, the soil layer will be difficult to deform.

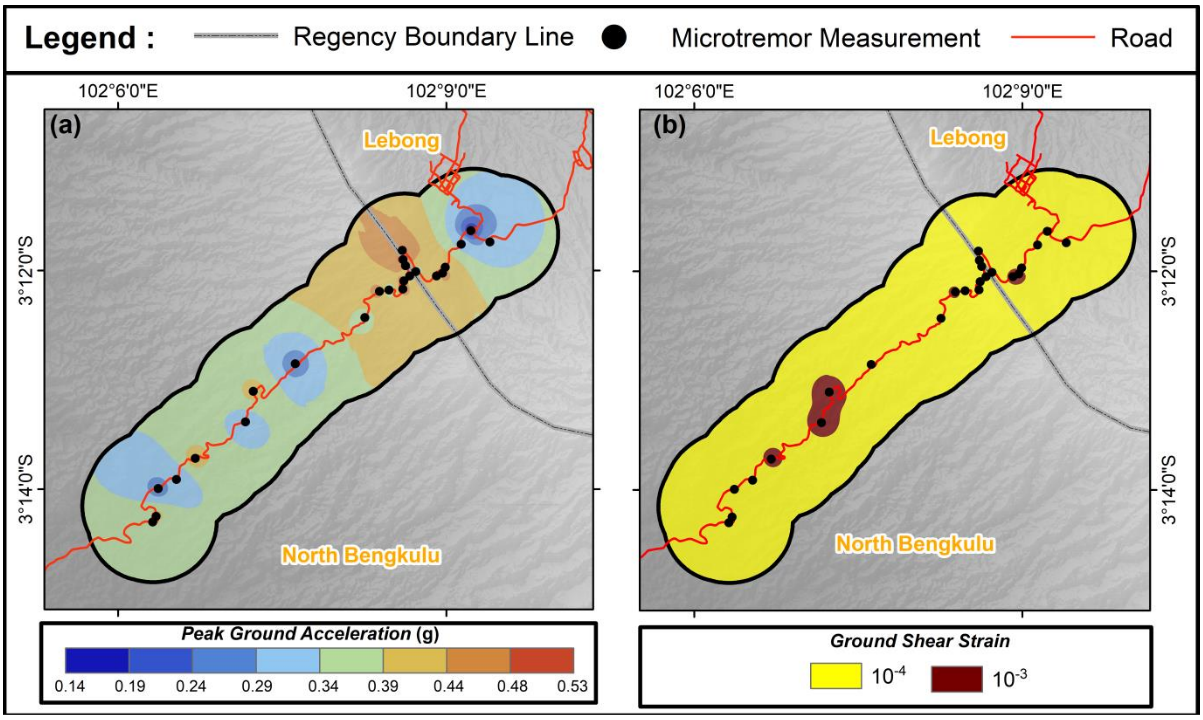

Figure 3. a). Peak Ground Acceleration (PGA) distribution map; b). Ground Shear Strain (GSS) distribution map.

Based on the distribution map of GSS values, the research site has elastic-plastic soil dynamics when looking at the relationship between GSS values and the nature of soil dynamics. Therefore, cracks and subsidence can occur if the nature of soil dynamics is elastic-plastic. Judging from the results of the GSS distribution map overlay, areas with high GSS values are shown in dark red. The even distribution of GSS values at 10^{-4} indicates that the study site is prone to cracking and ground movement. The rock structure is susceptible to seismic vibrations and mechanical vibrations caused by transport vehicles, changing the physical properties of the rock. The triggering factor for ground movement at the study site can be cracking and landslide collapse. The GSS 10^{-4} values evenly distributed along the North Bengkulu-Lebong mountain road are not all susceptible to landslides. The research location with a high susceptibility to landslides is in the area with a GSS value of 10^{-3}. This condition causes some areas along the mountain road to experience landslides with a small volume of material. The factor that causes the size of the landslide can be caused by the angle of the slope on the side of the road. The North Bengkulu-Lebong crossroad is located between regencies that are mountainous areas with steep slopes and a high potential for landslides.

Conclusion

The distribution of PGA values in the research location is dominated by green color, which has a landslide risk if no disaster management is done. In addition, some dark blue colored points show a high risk of landslides. Meanwhile, based on the distribution map of GSS in the study area, several dark red colored points show the potential severe danger of landslides. Therefore, based on the distribution map of PGA and GSS on the North Bengkulu - Lebong crossing, it is possible to identify locations prone to landslides so that disaster mitigation can be carried out at those locations to reduce the risk.

Acknowledgements

The authors thank the Research Institutions and Community Service

(LPPM), University of Bengkulu, for the grant for Research Fundamentals 2007/UN30.15/PP/2022 to support this work financially. The author also thanks the Physics Laboratory of the University of Bengkulu for providing equipment for this work. Finally, we thank the anonymous reviewers and academic editors who took the time and effort to review the manuscript. We appreciate all valuable comments and suggestions that improve the manuscript's quality.

Author Contribution

Conceptualization, U.N., H., S., and D.I.F.; Methodology, D.I.F, S., and H.; Software, D.I.F; Investigation, and Data Acquisition, A.P.P., and S.; Writing – Original Draft Preparation, U.N., D.I.F, and J.E.E.S.; Writing – Review & Editing, H., and S.; Visualization, D.I.F.; Supervision, H., and S.; Project Administration, H., and S.; and Funding Acquisition, H., and S.

Conflict of Interest

The authors declare no conflict of interest.

References

Ariyanto, S. V., & Joni, I. (2019). Zone Landslide Analysis Using Geophysical Method and Analysis of Soil Type for Disaster Mitigation In Waru Pamekasan. *Indonesian Journal of Applied Physics*, 9(02), 68–75. https://doi.org/10.13057/ijap.v9i2.34520

Asnawi, Y., Simanjuntak, A. V. H., Umar, M., Rizal, S., & Syukri, M. (2020). A Microtremor Survey to Identify Seismic Vulnerability Around Banda Aceh Using HVSR Analysis. *Elkawnie: Journal of Islamic Science and Technology*, 6(2), 342–358. https://doi.org/10.22373/ekw.v6i2.7886

BPBD. (2019). *Badan Penanggulangan Bencana Daerah Provinsi Bengkulu*.

Douglas, J. (2021). *Ground Motion Prediction Equations 1964–2021*. Department of Civil & Environmental Engineering Imperial College London.

Gafoer, S., Amin, T. C., & Pardede. (2007). *Peta Geologi Lembar Bengkulu, Sumatera*. Pusat Penelitian dan Pengembangan Geologi. Pusat Penelitian dan Pengembangan Geologi.

Gemintang, K. N., Hanatha, F. D., Indriatmoko, T. W., Qurrotu'aeni, W. S., Azis, B. N. L., & Hamdalah, H. (2022). Identifikasi Zona Rawan Amblesan Berdasarkan Parameter Hvsr Dan Ground Shear Strain Di Daerah Gua Pindul. *Jurnal Geosaintek*, 8(3), 232–241. https://doi.org/10.12962/j25023659.v8i3.14395

Hadi, A. I., Brotopuspito, K. S., Pramumijoyo, S., & Hardiyatmo, H. C. (2018). Regional landslide potential mapping in earthquake-prone areas of kepahiang regency, Bengkulu Province, Indonesia. *Geosciences (Switzerland)*, 8(6), 219. https://doi.org/10.3390/geosciences8060219

Hadi, A. I., Brotopuspito, K. S., Pramumijoyo, S., & Hardiyatmo, H. C. (2021). Determination of Weathered Layer Thickness around the Landslide Zone using the Seismic Refraction Method. *IOP Conference Series: Earth and Environmental Science*, 830(1), 012022. https://doi.org/10.1088/1755-1315/830/1/012022

Hartantyo, E., Khayati, N. N., Nur, R., & Novita, S. (2020). Kajian Nilai Percepatan Puncak di Daerah Kulon Progo Utara, Yogyakarta, Indonesia, Berbasis Peta Gempa Nasional 2017 dan Pengukuran Mikrotremor. *Positron*, 10(2), 148–154. https://doi.org/10.26418/positron.v10i2.43310

Iswahyudi, S., Widagdo, A., & Laksono,

F. A. T. (2021). Sosialisasi Analisis Penyebab Bencana Longsor Desa Sirau, Karangmoncol, Purbalingga. *Jurnal Dharma Bakti-LPPM IST AKPRIND*, 4(1), 7–17.

Kristie, H. J., & Budiman, A. (2021). Karakteristik Sifat Fisis Tanah Daerah Potensi Longsor di Jalan Raya Sumbar Riau Nagari Koto Alam, Sumatera Barat. *Jurnal Fisika Unand*, 10(1), 123–129. https://doi.org/https://doi.org/10.25077/jfu.10.1.123-129.2021

Nakamura, Y. (2008). On the H/V spectrum. *The 14th World Conference on Earthquake Engineering*, 1–10.

Natasya, I. D., Puspa, M., Elona, L., Gatra, G., & Refrizon, P. (2022). Upaya Mitigasi Bencana Longsor Jalan Lintas Bengkulu-Kepahiang Berdasarkan Kecepatan Gelombang Geser (Vs). *Newton-Maxwell Journal of Physics*, 3(1), 33–37. https://doi.org/https://doi.org/10.33369/nmj.v3i1.21243

Nishimura, I., Noguchi, T., Ono, Y., & Kohno, M. (2022). Subsurface Structures Based on Microtremor Observations in Landslide Area of Tandikat , West Sumatra, Indonesia. *GEOMATE Journal*, 22(90), 57–62.

Nurjanah, S., & Mursalin, E. (2021). Pentingya Mitigasi Bencana Alam Longsor Lahan: Studi Persepsi Mahasiswa. *Jurnal Basicedu*, 6(1), 515–523. https://doi.org/10.31004/basicedu.v6i1.1937

Prakoso, B. A. (2018). *Analisis Tingkat Risiko Tanah Longsor Berdasarkan Nilai* Peak Ground Acceleration *(PGA) di Desa Purwosari Kecamatan Girimulyo Kabupaten Kulon Progo*. Universitas Negeri Yogyakarta.

Refrizon, Arif, I. H., Kurnia, L., & Tria, O. (2013). Analisis Percepatan Getaran Tanah Maksimum dan Tingkat Kerentanan Seismik Daerah Ratu Agung Kota Bengkulu. *Prosiding Semirata FMIPA Universitas Lampung*, 323–328.

Silitonga, B. (2022). Pengukuran Seismik Dengan Metode HVSR Untuk Pendugaan Bencana Gempa Bumi. *Jurnal Rekayasa Konstruksi Mekanika Sipil (JRKMS)*, *5*(2), 103–111. https://doi.org/10.54367/jrkms.v5i2.2184

Sugianto, N., & Refrizon. (2021). Struktur Kecepatan Gelombang Geser (Vs) di Daerah Rawan Gerakan Tanah (Longsor) Jalan Lintas Kabupaten Bengkulu Tengah-Kepahiang. *Indonesian Journal of Applied Physics*, 11(2), 134–142. https://doi.org/https://doi.org/10.13057/ijap.v11i2.41699

Sugianto, N., Refrizon, Mase, L. Z., & Anggeraini, S. (2021). The updated zonation of seismic vulnerability index and ground shear strain at Bengkulu City, Indonesia. *AIP Conference Proceedings*, 2320, 040022. https://doi.org/10.1063/5.0037597

Susanti, P. D., & Miardini, A. (2019). Identifikasi Karakteristik dan Faktor Pengaruh pada Berbagai Tipe Longsor. *AgriTECH*, 39(2), 97–107. https://doi.org/10.22146/agritech.40562

Tanjung, N. A. F., Yuniarto, H. P., & Widyawarman, D. (2019). Analisis Amplifikasi Dan Indeks Kerentanan Seismik Di Kawasan Fmipa Ugm Menggunakan Metode HVSR. *Jurnal Geosaintek*, 5(2), 60–67. https://doi.org/10.12962/j25023659.v5i2.5726

Trianda, O., Prastowo, R., & Novitasari, S. (2018). Identifikasi Ketebalan Lapisan Lapuk di Daerah Kalirejo, Kulonprogo Berdasarkan Pengukuran Mikrotremor dalam Upaya Mitigasi Tanah Longsor. *Prosiding Seminar Nasional ReTII ke-13 2018*, 246–253. https://journal.itny.ac.id/index.php/ReTII/article/view/892

Zulfa, V. A., Widyasamratri, H., &

Kautsary, J. (2022). Mitigasi Bencana Berdasarkan Tingkat Risiko Bencana Tanah Longsor. *Jurnal Kajian Ruang*, 2(2), 154–169. https://doi.org/http://dx.doi.org/10.30659/jkr.v2i2.26532