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Identification of Earthquake Hazard Vulnerability in Bengkaung Village, West Lombok Using Geomagnetic Methods

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Abstract: An earthquake disaster is an event that causes various damage and loss of life. This study aims to determine the vulnerability of earthquake hazards in Bengkaung Village, West Lombok Regency. The method used in this research is the geomagnetic method. The results of this: study indicates the value of the magnetic field anomaly in the range of -1100 nT-1500 nT. 2D modeling with 4 paths shows that the study area is dominated by 5 rock layers with a susceptibility range between (0.013 - 6.21)×10^(-3) in SI, which consists of sandstone, clay, fractured andesite lava, fresh andesite lava. and granite. The highest vulnerability to earthquake hazards is in the southern part of Bengkaung Village, due to the presence of a cohesive soil type (like clay) on the surface of the study area, coupled with the presence of intrusions and faults. Meanwhile, the western part of Bengkaung Village and the northern part of the Bengkaung area have a relatively smaller earthquake hazard vulnerability than the southern part. This is because the western and northern parts have the main layer of non-cohesive soil (sandstone) which has high shear strength and becomes a damper in wave propagation when an earthquake occurs.

Keywords: Bengkaung; Earthquake; Geomagnetic; Vulnerability

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Introduction

A natural disaster is the potential occurrence of a natural physical event that can cause loss of life, injury, or other health impacts, as well as damage and loss of property, infrastructure, livelihoods, service provision, and environmental resources (UN ISDR, 2022). Disaster is an event that threatens and disrupts people's lives and livelihoods caused by both natural factors, non-natural factors, and human factors that result in human casualties, environmental damage, and property losses (Mantika et al, 2020). Natural hazard risk assessment is essential for the development and implementation of disaster risk management measures. The hazard characteristics affecting the area are of concern in the risk assessment. Hazard characteristics i.e., expected hazard frequency and intensity, definition of vulnerability of the asset exposed to the hazard (i.e., probability of being damaged), or loss, and the classification of assets in the area (Silva, et.al. 2022).

The description of the characteristics and circumstances of a community, system, or asset that is susceptible to the damaging effects of a hazard is called **Vulnerability**. Within a community and over time Vulnerability varies widely. Physical, social, economic, and environmental factors are part of the many aspects of a vulnerability that may occur. Examples of poor building design and construction, inadequate asset protection, lack of information and public awareness, limited legal recognition of risks and preparedness

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measures, and neglect of prudent environmental management.

Mitigation (disaster and disaster risk) is the reduction of the potential adverse impacts of physical hazards through actions that reduce hazards, exposure, and vulnerability (https://odpm.gov.tt/). Disaster risk reduction (DRR) is all relevant scientific and technical resources and skills covering natural, environmental, social, economic, health, and engineering sciences and scientific capacities (UNISDR, 2013); Boas and Hayden, 2002). It is, therefore necessary to develop a science-policy interface as DRR has been successful so far (UNISDR, 2013). 30 selected innovations for DRR including six approaches: Community Based Disaster Risk Reduction (CBDRR), hazard mapping, assessment, index approach, national platform and native DRR technology) (Weichselgartner and Pigeon, 2015; Zumi, et.al, 2019).

Lombok Island is one of the areas prone to natural disasters (earthquakes) because Lombok Island is located in a subduction zone, namely the Indo-Australian and Eurasian plates. This zone is an area where earthquakes occur very often (Zuhdi et al, 2019). According to BNPB (2011), West Lombok Regency is ranked 17th in the national disaster-prone ranking. The Lombok earthquake in 2018 has proven this. The earthquake caused quite severe damage in the West Lombok Region (Jakandar et al, 2018).

The difference in damage between villages in West Lombok is a strange phenomenon, one of which is the difference in damage in Bengkaung Village with villages in the south. Severe damage occurred in Bengkaung Village, while in villages to the south there was almost no damage, for example in Sandik Village which is directly adjacent to Bengkaung Village, only one damaged house was found (all the roofs collapsed).

From the geological point of view of Lombok, the Bengkaung area is dominated by breccia and lava rocks and there are no indications of fault lines. When viewed from the type of rock/soil, the hazard vulnerability will be higher if the soil conditions in an area are cohesive. This is because cohesive soils have low shear strength. Soil shear strength is the ability of the soil to resist collapse and landslides in the soil (Hardiyatmo, 2002).

To find out the type of soil or subsurface structure of an area, we can take advantage of the magnetic susceptibility of an object in the area. The geomagnetic method is a method that utilizes the magnetic properties of rocks to estimate subsurface geological structures such as faults, folds, igneous rock intrusions, and geothermal reservoirs. Theories and applications governing the earth magnet method have been reported by several researchers. The ground magnetic technique requires measuring the amplitude of the magnetic component at discrete points along a trajectory that is regularly distributed throughout the survey area of interest (Sunmonu, et.al., 2018).

Geomagnetic methods work based on measuring small variations in the intensity of the magnetic field on the earth's surface. This variation is caused by the contrasting magnetic properties between rocks in the earth's crust, giving rise to an inhomogeneous magnetic field of the earth, which is called a magnetic anomaly (Santosa et al, 2012).

Method

Charles Augustin de Coulomb in 1785 stated that the magnetic force is inversely proportional to the square of the distance between two magnetic charges, which is similar to Newton's law of gravitational force. So, if the two magnetic poles m1 and m2 (Am) of different magnetic monopoles are separated by a distance r (m), then the equation for the magnetic force between the two poles can be expressed as (Reynold, 1995),

$$\vec{F} = \frac{1}{\mu}\frac{m_1 m_2}{r^2}\hat{r} \quad (1)$$

where F is the force acting between the two magnetic poles (Newton), is the permeability of the medium surrounding the two magnetic poles, is the unit vector directed at the two magnetic poles.

Magnetic Field Strength

The strength of the magnetic field $\vec{H}$ at a point which is r from the poles of the magnetic field can be formulated as follows (Murbanendra, 2016):

$$\vec{H} = \frac{1}{\mu}\frac{m_2}{r^2}\hat{r} \quad (2)$$

Rocks Susceptibility

Magnetic susceptibility is used to determine the degree of magnetism of a material (rock). Susceptibility determines the material can be magnetized or referred to as the degree of magnetism of an object (Telford et al, 1990). The magnetization of a magnetic object is determined by the degree of magnetic susceptibility, which can be formulated by the following equation:

$$\mathbf{M} = k\,\mathbf{H} \quad (3)$$

where M is the magnetic field intensity of the rock, k is the magnetic susceptibility of the rock and H is the strength of the magnetic field.

Data Acquisition

The location of data collection is Bengkaung Village, Batu Layar District, West Lombok Regency. Data collection was carried out by measuring the value of the total geomagnetic field in the research area. Field measurement data acquisition was carried out using a closed-loop method. The distance between measuring points is 50 m (depending on field accessibility conditions), and data collection at each point is carried out 5 times, one of which is the center and the other four data are taken at 4 positions about 2 – 5 meters from the data center.

Total geomagnetic anomaly

The total geomagnetic field anomaly value was obtained from the measurement data and corrected for IGRF and daily variations. The existence of a geomagnetic anomaly causes a change in the total magnetic field of the earth and can be written as (Blakely, 1996):

$$HA = HT - \Delta Hr - Hr \quad \text{……………………. (4)}$$

HA is the geomagnetic field anomaly in nT units, HT is the total magnetic field value in nT, Hr is the daily variation value in nT and Hr is the IGRF value in nT.

The data processing of the measurement results in the field using a closed-loop technique is the total magnetic field data of the research area. Therefore, it is necessary to make various corrections (Daily Correction and IGRF Correction) to obtain the value of the magnetic field anomaly. Magnetic field anomaly is the value from the calculation of the total magnetic field with the regional magnetic field or IGRF as well as the daily correction value from the external magnetic field (Blakely, 1996). After the total anomaly is obtained, the reduction to the poles is carried out and the residual anomaly is separated from the regional anomaly using an upward continuation technique. The residual anomaly obtained was then carried out by inversion modeling of the 2D model to estimate the subsurface structure of the study area. In this research, the results of 2D modeling are classified into cohesive and non-cohesive soil types to determine the potential vulnerability to earthquake hazards.

Results and Discussion

Total Magnetic Field Anomaly

After correcting for daily variations and IGRF, the final result is the total geomagnetic anomaly value. This total anomaly value is still a combination of regional anomalies and residual anomalies. So that information about deep and shallow rock layers is still difficult to interpret. The value of the total geomagnetic anomaly in the study area (Figure 1), it can be explained that the anomalous value of the magnetic field ranges from minus 1100 nT to positive 1500 nT. High anomaly is indicated by purple color and the low anomaly is indicated by blue color. High-value anomalies indicate that there are magnetic objects that have high magnetic susceptibility values and vice versa. Magnetic anomaly values that show low values are thought to be caused by anomalous objects below the surface that have small magnetic susceptibility values.

Reduction To Pole

Reduction to pole (RTP: Reduction To Pole) aims to place the area with the maximum anomaly just above the object causing the anomaly. Reduction to the poles is done by changing the parameters of the earth's magnetic field in the study area. The magnetic field of the study area has an average declination value of 0.971^0 and a slope angle of -328690^0, changed to conditions at the poles with a declination value of 0^0 and an inclination of 90^0.Thus, the direction of the magnetic field which was originally a dipole becomes a monopole right above the object causing the anomaly. The magnetic field anomaly data that has been reduced to the poles is shown in Figure 2. The value of the total magnetic anomaly appears to have changed its range from before and after the RTP process. The total magnetic anomaly value before the RTP process ranged from minus 1100 nT to positive 1500 nT (Figure 1) and after the RTP process the magnetic anomaly value changed to minus 1000 nT to positive 1700 nT. The area of high anomaly and moderate anomaly was reduced while the area of negative anomaly became wider (Figure 2).

Separation Anomaly of Upward Continuation Method

The geomagnetic anomaly map that was reduced to the poles is still a combination of regional and residual anomalies in the research area. To facilitate the interpretation process, it is necessary to separate regional and residual anomalies. The anomaly separation method used is Upward Continuation and the result is a regional anomaly value (Long wavelength). These regional anomalies are related to deep sources of anomalies such as basements. Furthermore, the residual anomaly value is calculated from the result of subtracting the total anomaly value that has been reduced to the poles with regional anomalies.

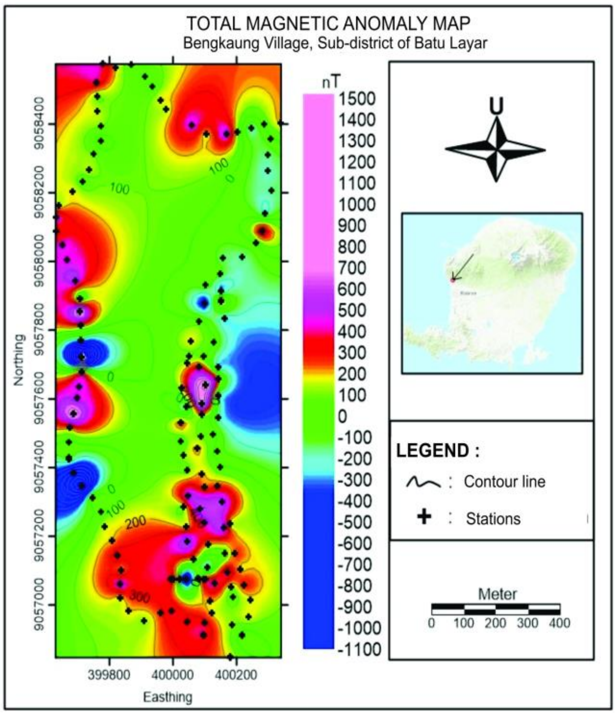

Figure 1. Contour of the total magnetic anomaly before being reduced to the poles

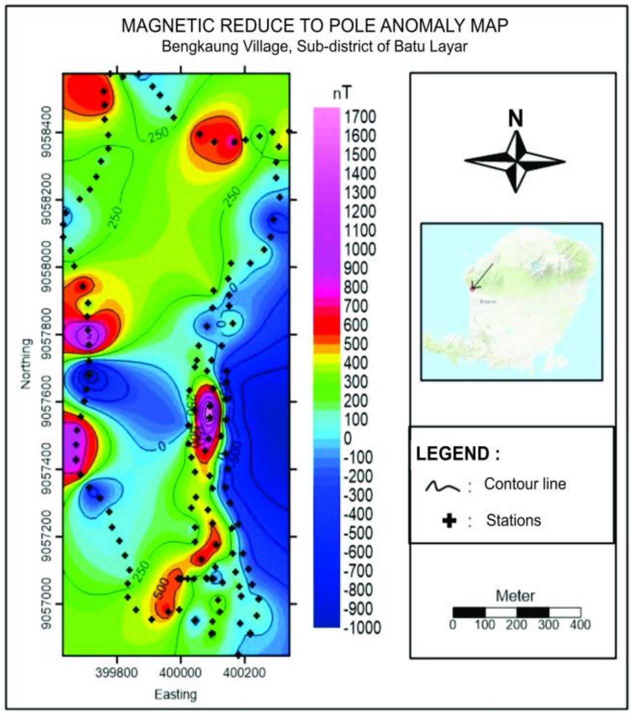

Figure 2. Total anomaly after being reduced to the poles

In this study, the upward continuation process is carried out by changing the altitude so that the regional anomaly value is stable at a certain elevation. In this study, the stable regional anomaly value was obtained at an altitude of 400 m above sea level (masl). At an altitude of 400 meters above sea level, a long-wave anomaly lineament pattern can be seen which describes a regional anomaly, without any local noise and residual anomaly.

Furthermore, the residual anomaly value is calculated by subtracting the total anomaly value that has been reduced to the poles with the regional anomaly value. Figure 3 is the contour of the residual anomaly. This residual anomaly value is a local/shallow geomagnetic response from within the earth. Residual anomalies describe the magnetic response of various rock types with variations in magnetic susceptibility in the study area. We group this residual anomaly into three groups, namely low anomaly with values between minus 1200 nT to minus 300 nT (blue color). Medium anomaly (green color) with a value range between minus 300 nT to positive 300 nT, and high anomaly values (yellow to red) with a value range of 300 nT to 1650 nT.

The group of low anomaly values above can be seen in the east and west of the study site (blue). Low anomalies are associated with low susceptibility values of rocks or sedimentary rocks, rocks resulting from weathering of breccias and lava, such as clay, sandstone, and so on. The low anomaly locations on both sides of the research site are hills whose surface is covered by layers of clay, pumice (lapilli) and volcanic breccia sand. These thin layers cover the underlying clay layer and are thought to be ancient topography, namely before the eruption of Mount Samalas in 1257 (Hiden et al, 2017).

Anomalies are dominating the research area, especially the central to northern parts. Moderate anomalies are related to rocks that have moderate susceptibility values or metamorphic rocks, such as phyllites, gneiss, and others. In accordance with direct observations in the field, the northern and central parts of the research location are generally covered by alternating layers of clay sand with clay, silty pumice and lapilli pumice, and volcanic breccia sand. High anomaly values indicate rocks that have high susceptibility values or igneous rocks such as granite, andesite lava, and others. This is in accordance with the local geological formations, namely the Kalibabak Formation and Alluvium (Haikal, 2021) which contain these rocks.

High anomaly (red to a brownish color with anomaly 300 nT to 1650 nT), we interpret as an intrusion that is trending from south to north in the middle of the location, while in the west and north the intrusion is in the form of spots. To explain in detail the rock layers in this research area, 2D residual anomaly modeling was carried out. Residual anomaly (Figure 3) is used as a target for 2D modeling to analyze the structure/strata of rock layers in the study area which are local and shallow.

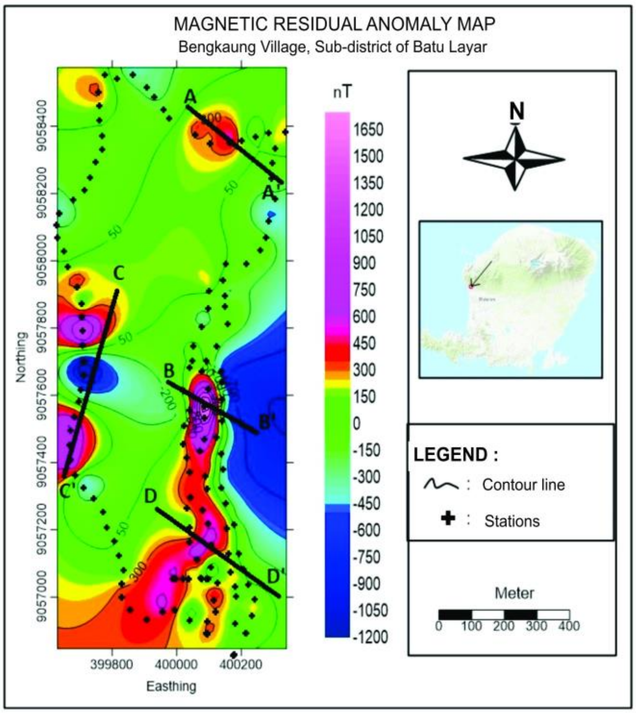

Figure 3. The contour of residual anomalies in Bengkaung

2D Geomagnetic Structure Modeling

Based on the residual anomaly map in Figure 3, it is clear that there is a clear contrast between low (blue) and high (red) anomalies between moderate anomalies (green). It is very interesting to study more deeply what the subsurface structure looks like? Is it related to the level of damage at the site?

Slice AA'

One way to find out the structure or strata of the subsurface layer is to do 2D modeling based on survey data. The 2D modeling refers to the geological references of the research area and from the results of previous studies related to the research location. 2D modeling is made from several incisions with the aim of knowing whether there are geological structures such as faults, folds, or intrusions in the study area. 2D modeling is done by trial and error method, namely by changing the model parameters such as the susceptibility value, width, and depth of the 2D model. The first AA' profile (Figure 4) was taken to the northeast of the site by intersecting the high anomaly between the medium anomaly. The following are the results of 2D modeling on the AA' profile.

From the AA' profile (Figure 4), a subsurface strata model is built with a depth of up to 85 meters. AA's profile length is 450 m. The results of the AA' incision modeling show the presence of 5 rock layers. The first layer has a susceptibility value of 0.014×10^{-3} in SI which is a sandstone layer, this layer is obtained from a depth of 0 m - 56 m, the second layer has a susceptibility value of 0.210×10^{-3} in SI which is a clay layer resulting from weathering of breccia rocks. These rocks are at a depth of 4 m - 70 m. The third layer has a susceptibility value of 0.400×10^{-3} in SI which is fractured andesite lava rock at a depth of 10 m - 78 m, the fourth layer is a fresh andesite lava layer with a susceptibility value of 0.490×10^{-3} in SI at a depth of 35 m - 81 m and the fifth layer has a susceptibility value of 0.700×10^{-3} in SI which is estimated to be granite at a depth of 68 m - 81 m. Granite rock (Igneous Volcanic Rock) is estimated to be the result of the cooling down process of magma or lava (Lolong, 2016). The rock types above are in accordance with direct observations in the field and research by Ferro et al., (2015) in the Batu Layar sub-district.

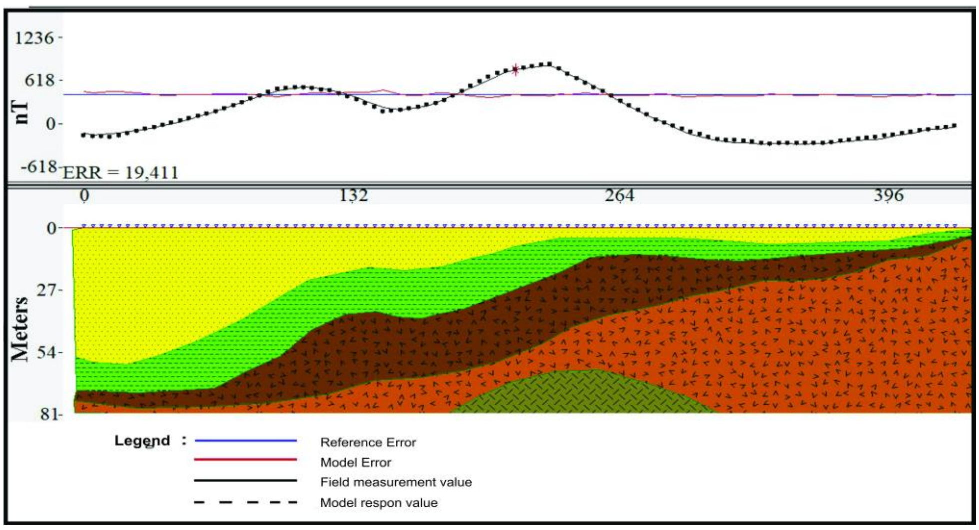

Figure 4. Results of 2D modeling of the AA' trajectory

Figure 5. Sandstone outcrop near line AA'

Direct observations in the field (figure 6 and figure 8) show the presence of layers of sandstone and clay. This is in accordance with Ferro et al, (2015) that geological formations in Batu Layar Village, Batu Layar District (south of Bengkaung Village) consist of: volcanic sandstone (layer 1), weathered breccia (layer 2), andesite lava fractures (layer 3). and fresh andesite lava (layer 4). According to Brotodihartdjo (1990) in Zakaria et al (2007) said that the results of weathering of breccia rocks are dominated by clay.

BB's profile

Based on the results of 2D modeling for the BB' slice (Figure 6), it can also be seen that there are 5 layers with a line length of 300 m. The first layer has a susceptibility value of 0.023×10^{-3} in SI which is a sandstone layer, this layer fills a depth of 0 m - 10 m below the earth's surface. The second layer with a susceptibility value of 0.230×10^{-3} in SI, is a layer of clay resulting from weathering of breccia rocks. These rocks are at a depth of 2 m – 40 m. The third layer has a susceptibility value of 0.390×10^{-3} in SI which is an andesitic lava rock fracture located at a depth of 8 m - 63 m. The fourth layer has a susceptibility value of 0.44×10^{-3} in SI which is fresh andesite lava rock at a depth of 34 m - 80 m. Finally, the fifth layer has a susceptibility value of 6.21×10^{-3} in SI which is the volcanic igneous rock in the form of granite at a depth of 70 m - 80 m. This is in accordance with the results of the field survey which showed the alternation of layers of pumice, lapilli, and volcanic breccias right at the location of the BB' trajectory (see Figure 7).

Direct observation in the field showed that many houses were heavily damaged (Figure 10) around the BB' and CC' lines. This is thought to be related to the loose nature of the soil at this location.

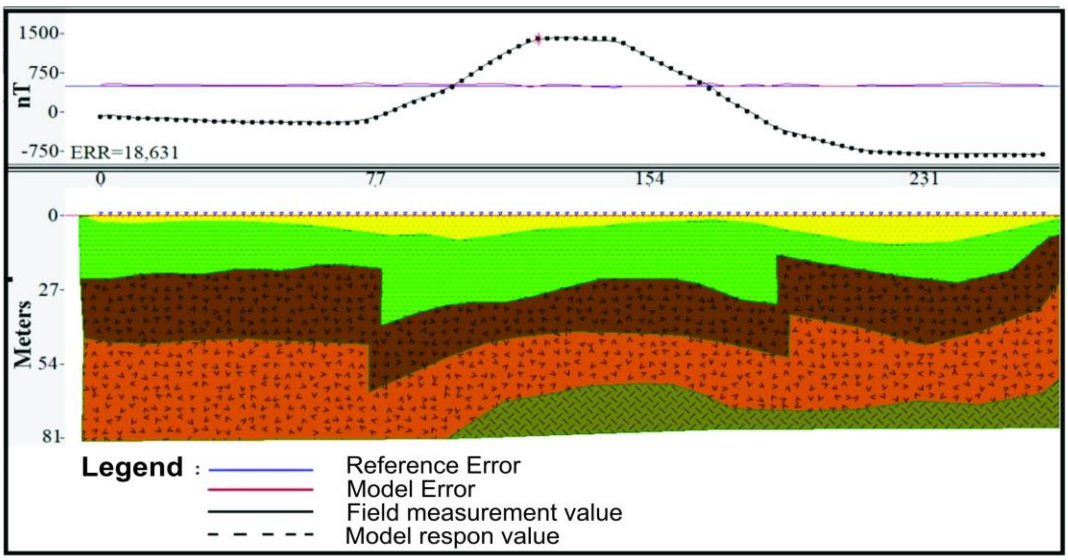

Figure 6. 2D Model of the Geomagnetic Anomaly Structure of the BB' trajectory

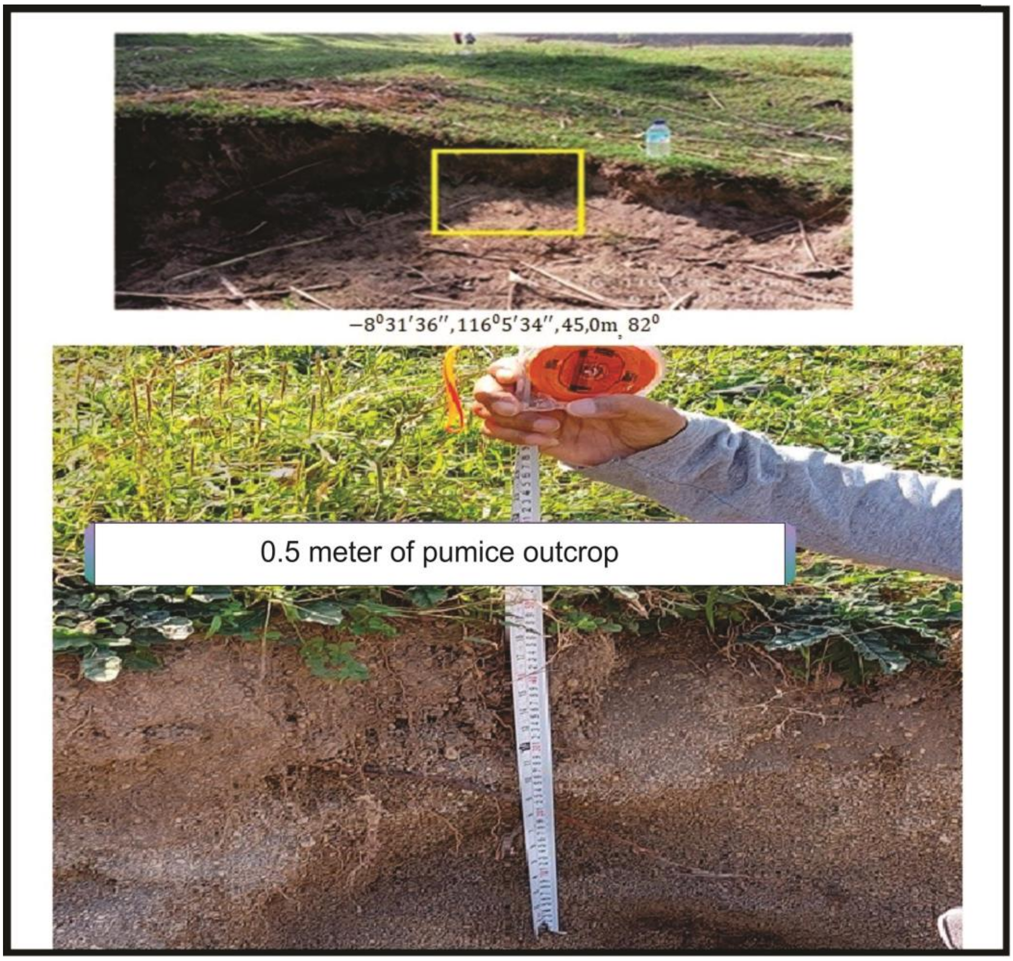

Figure 7. Outcrop) Lapilli pumice and volcanic breccia sand (left),
Interspersed layers of lapilli pumice and volcanic breccia at the BB' track location (right)

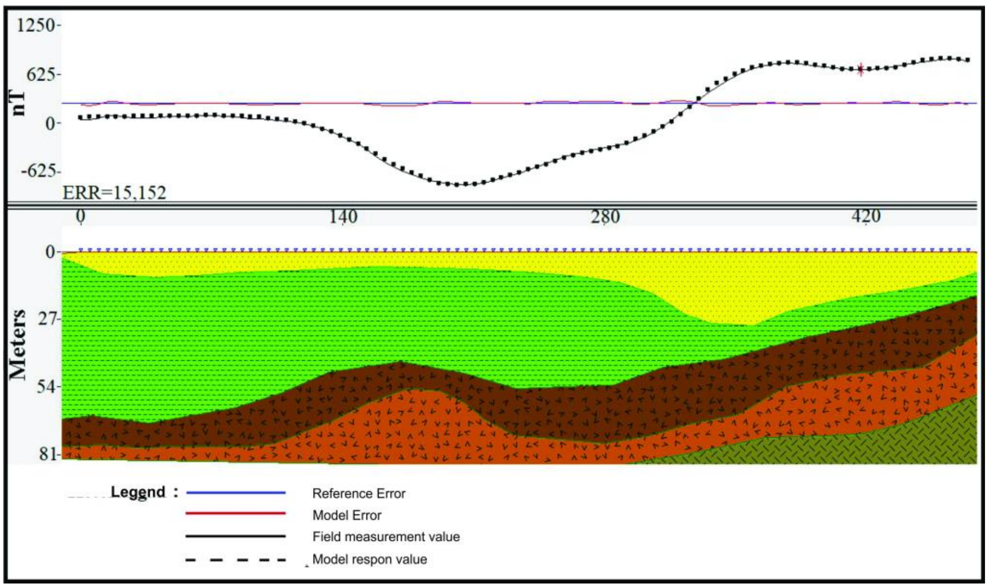

Figure 8. 2D Model of CC' Trajectory Geomagnetic Anomaly Structure

Figure 9. Damage to houses in the study area around the line BB′ and CC′

CC Profile'

Profil and 2D model of the CC' geomagnetic structure (Figure 8) with a track length of 480 m, consisting of five layers. The first layer with a susceptibility value of 0.015×10^{-3} in SI is thought to be a sandstone layer. This layer is at a depth of 0 m - 32 m. The second layer has a susceptibility value of 0.014×10^{-3} in SI which is interpreted as a clay layer at a depth of 6 m - 68 m. The 3rd and 4th layers are andesitic lava rock with susceptibility values of 0.400×10^{-3} and 0.380×10^{-3} in SI. The third layer is fractured andesite lava with a depth of 35 m - 76 m. Layer 4th is fresh andesite lava located at a depth of 37 m - 80 m. The 5th layer with susceptibility of 0.980×10^{-3} in SI is interpreted as granite and occupies a depth of 69 m - 81 m.

DD' profile

The modeling results on the DD' section (Figure 10) show the same number of rock layers as the previous path, namely 5 layers with a profile length of 450 m. The first layer has a susceptibility value of 0.130×10^{-3} in SI which is a sandstone layer, this layer occupies a depth of 0 m - 50 m. The second layer having a susceptibility value of 0.240×10^{-3} in SI is thought to be a clay layer, the result of weathering of breccia rocks. These rocks are at a depth of 4 m 50 m. The third layer has a susceptibility value of 0.440×10^{-3} in SI which is a fractured andesite lava rock at a depth of 4 m - 72 m. The fourth layer has a susceptibility value of 0.390×10^{-3} in SI which is fresh andesite lava rock at a depth of 25 m - 82 m and the fifth layer is estimated to be granite with a susceptibility value of 0.980×10^{-3} in SI at a depth of 68 m - 82 m.

Based on the results of the 2D inversion modeling (Figure 10) above, it is known that one of the subsurface layers is a clay layer. Clay is a type of cohesive soil while other layers such as pumice, sandstone, and andesite lava are non-cohesive soil types. Based on the classification (cohesive and non-cohesive), the layer most vulnerable to the risk of earthquake disaster is the clay layer. This is because clay is a cohesive soil that has low shear strength (Mayasari, 2015). According to Desmonda and Adjie (2014) clay is most vulnerable to the risk of earthquake hazards compared to sandstone, and andesite rocks have the lowest value to vulnerability to tectonic earthquake hazards. This is in line with Satria et al (2020) who showed that the zone with high vulnerability was dominated by alluvial composed of claystone and silt. Clay also has the potential for landslides caused by the dissolution of salt in the clay layer, by rainwater infiltration, or groundwater flow which reduces its shear strength (Hardiyatmo, 2006).

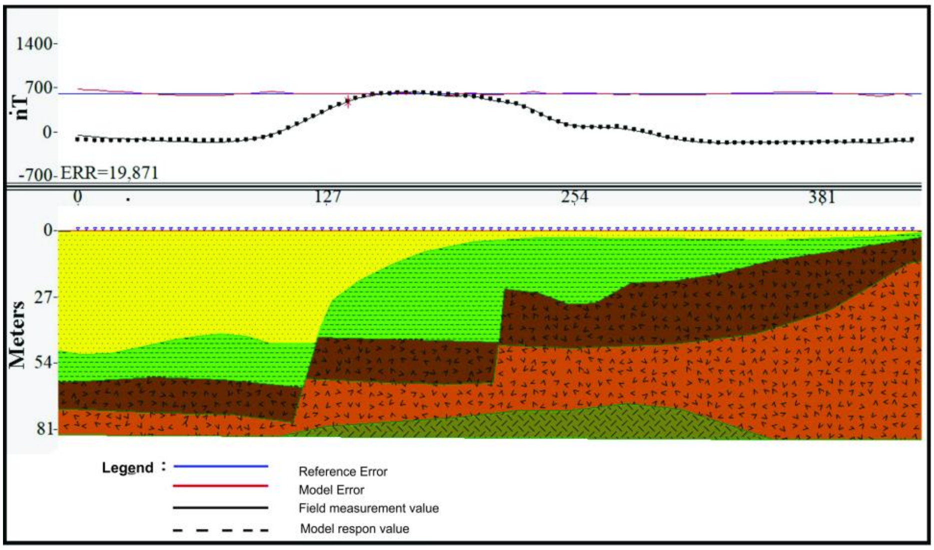

Figure 10. Results of 2D modeling of the DD' trajectory

The southern part of Bengkaung Village is generally covered with a layer of clay to a depth of 15 m, other than that from the modeling results it appears that there is a north-south trending fault. These two structures and strata are closely related to the potential vulnerability to earthquake hazards. This potential vulnerability, we have verified with the level of damage (Figure 10) at the site. Based on direct observations in the field, the level of severe damage to people's houses, generally found in the southern part of the village. This is in accordance with West Lombok BPBD data (Septeriansyah, 2018) that the damage that occurred in Bengkaung village was, 271 lightly damaged, 207 moderately damaged, and 328 heavily damaged. The pattern of damage is generally south to north.

Conclusion

The rock structure and subsurface soil strata of the study area have a range of susceptibility values from 0.013 to 6.21 in SI units. The strata of susceptibility values were interpreted respectively: sandstone, clay, andesite lava fracture, fresh andesite lava, and granite from the local soil surface. The faults are indicated on the BB' profile on the east side of the site and on the CC' line on the west side of the study site. The area that is most vulnerable to the risk of earthquake hazard in Bengkaung Village is in the south, which is dominated by cohesive soil in the form of clay, on the other hand, the west and north have a relatively low vulnerability to earthquake hazards. This area is dominated by non-cohesive soil in the form of breccia sand and pumice stone, both of which have high shear strength.

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References

Blakely, R.J. (1996) *Potential Theory in Gravity and Magnetic Applications*. Edinburgh: Cambridge University Press. https://doi.org/10.1017/CBO9780511549816.

BNPB. (2011). *Indeks Rawan Bencana Indonesia*. Jakarta.

Boaz, A., & Hayden, C. (2002). Pro-active Evaluators: Enabling Research to Be Useful, Usable and Used. *Evaluation*, *8*(4), 440–453. https://doi.org/10.1177/13563890260620630

Brotodihardjo, A.P.P. (1990). *Masalah Geoteknik di Sekitar Rencana Terowongan/Saluran Irigasi Karedok Kanan, DAS Cimanuk*, Diresentasikan Pada Pertemuan Ilmiah Tahunan IAGI XIX 11-13 Desember 1990.

Desmonda, N. I., & Pamungkas, A. (2014). Penentuan Zona Kerentanan Bencana Gempa Bumi Tektonik di KAbupaten Malang Wilayah Selatan. *Jurnal Teknik ITS*. 3(2). 132-142. http://dx.doi.org/10.12962/j23373539.v3i2.7232

Ferro R. A., Joko, M., Anwar, J., Rully, M., & Erman, K. (2015). *Laporan Teknis Kestabilan Lereng Dengan Metode Resistivity Sounding di Desa Batulayar Barat.* Tim Bidang Geologi Dan Sumberdaya Dinas Pertambangan Dan Energi Kabupaten Lombok Barat.

Hardiyatmo, H.C. (2002). *Mekanika Tanah 1*. Gajah Mada University Press. Yogyakarta.

Hardiyatmo, H C. (2006). *Penanganan Tanah Longsor dan Erosi*. Yogyakarta: Gajah Mada University Press.

Hiden, H., Brotopuspito, K. S., Sri Hadmoko, D., Lavigne, F., Airaksinen, K. B., Mutaqin, B. W., Hananto, N. D., Handayani, L., Sudrajat, Y., & Suryanto, W. (2017). The Isopach Mapping of Volcanic Deposits of Mount Samalas 1257 AD Based on the Values of Resistivity and Physical Properties. In *Geosciences* (Vol. 7, Issue 3). https://doi.org/10.3390/geosciences7030067

Jakandar, L. I. E. (2018). Dampak Gempa Bumi Lombok Terhadap Kondisi Sosial Ekonomi Masyarakat Di Desa Kekait Kecamatan Gunung Sari Kabupaten Lombok Barat, *Sophist: Jurnal Sosial Politik Kajian Islam dan Tafsir*, *1*(2), 210-227. https://doi.org/10.20414/sophist.v1i2.772.

Lolong, S.P., & Wibowo, H. T. (2016). *Geologi dan Petrogenesa Batuan Andesit Desa Sumbertangkil Dan Sekitarnya Kecamatan Tirtoyudo Kabupaten Malang Provinsi Jawa Timur*. Diresentasikan Pada Seminar Seminar Nasional Sains dan Teknologi Terapan, Malang, Oktober 2016.

Mantika, N. J., Hidayati, S. R., & Fathurrohmah, S. (20200. Identifikasi Tingkat Kerentanan Bencana Di Kabupaten Gunungkidul, *Matra*, *1*(1), 59-70. Retrieved from https://journal.itny.ac.id/index.php/matra/article/view/1254

Mayasari, W. A. (2015). *Analisis Jenis Tanah Dengan Menggunakan Metode Geolistrik Resistivitas 3d Dan Uji Geser Langsung Di Perumahan Istana Tidar Regency Kecamatan Sumbersari Kabupaten Jember*, Program Studi Fisika, Fakultas Matematika dan Ilmu Pengetahuan Alam, Universitas Jember.

Reynold, J.M. (1995). *An Introduction to Applied and Environmental Geophysics*. Mold, Clwyd, North Wales, United Kingdom.

Santosa, B. J., Mashuri, M., Sutrisno, W. T., Wafi, A., Salim, R., &Armi, R. (2012). Interpretasi Metode Magnetik untuk Penentuan Struktur Bawah Permukaan di Sekitar Gunung Kelud Kabupaten Kediri. *Jurnal Penelitian Fisika dan Aplikasinya (JPFA)*, *2*(1), 7-14, https://doi.org/10.26740/jpfa.v2n1.p7-14.

Satria, A., Resta, I.L., dan Muchtar, N. (2020). Analisis Ketebalan Lapisan Sedimen dan Indeks Kerentanan Seismik Kota Jambi Bagian Timur. *Jurnal Geofisika Eksplorasi*: 6(1). 18-30 https://doi.org/10.23960/jge.v6il.58

Septeriansyah, I.M. (2010. *Data Kerusakan Rumah akibat gempa bumi 2018 di Desa Bengkaung Kec. Batu Layar, Kab. Lombok Barat*

Silva, V., Brzev, S., Scawthorn, C., Yepes, C., Dabbeek, J., & Crowley, H. (2022). A Building Classification System for Multi-hazard Risk Assessment. *International Journal of Disaster Risk Science*. https://doi.org/10.1007/s13753-022-00400-x

Sunmonu, L.A., Adagunodo, T.A., Adeniji, A.A., Ajani, O.O. (2018). Geoimaging of subsurface fabric in Awgbagba, Southwestern Nigeria using geomagnetic and geoelectrical techniques, *Malaysian Journal of Fundamental and Applied Sciences* 14(2). 312-324

Telford, W.M., Geldart L.P., & Sherrif, R.E. (1990). *Applied Geophysics, Second edition*, Cambridge university press, London, https://doi.org/10.1017/CBO9781139167932

United Nations (UN) International Strategy for Disaster Reduction Offices of Disaster Prepardness and managmenet, **(ISDR)** https://www.odpm.gov.tt/

UNISDR. (2013). *Using science for disaster risk reduction: report of the UNISDR scientific and technology Advisory group 2013*

Zakaria, Z., Yuniardi, Y., dan Sophian, I. (2006). Karakteristik Keteknikan Tanah Dan Hubungannya Dengan Pengembangan Wilayah Di Kawasan Pengembangan Terpadu Jatinangor, Kabupaten Sumedang, Jawa Barat. *Bulletin of scientific contribution: 5(1).* https://doi.org/10.24198/bsc%20geology.v5i1.8131

Zuhdi, M., Makhrus, M., Sutrio, S., & Wahyudi, W. (2019). Sosialisasi Tentang Mitigasi Bencana Tsunami Dan Gempa Lombok Di Jempong Baru, Sekarbela, Mataram. *Jurnal Pengabdian Magister Pendidikan IPA*, 2(2). https://doi.org/10.29303/jpmpi.v2i1.316

Weichselgartner, J., & Pigeon, P. (2015). The Role of Knowledge in Disaster Risk Reduction. *International Journal of Disaster Risk Science*, *6*(2), 107–116. https://doi.org/10.1007/s13753-015-0052-7