Seismic vulnerability analysis in Poso District

M Rusydi1*, M B Cyio2, Rahmawati3 and Ramlan2

1Physics Department, Faculty of Mathematics and Natural Science, Universitas Tadulako, Palu, Indonesia
2Agrotechnology Department, Faculty of Agriculture, Universitas Tadulako, Palu, Indonesia.
3Geography Education Department, Faculty of Teacher Training and Education Universitas Tadulako, Palu, Indonesia

*Email: rusydiutd@gmail.com

Abstract. High seismic activity in Poso District is not supported by information related to earthquake hazard map with detailed scale. This information is very necessary for supporting the government's efforts to reduce the risk of earthquake disasters. Therefore, this study aims to map earthquake-prone zones with detailed scale. The study was conducted by measuring Vs30 using a microtremor on each rock sample using the HVSR method, then these values were used as a reference in correcting the USGS Vs30 data, thus producing a VS30 distribution value, with an interval of 1 km. From the results of the study, it showed that based on the Vs30 ratio in Poso District, it obtained a ratio value > 0.5. This value indicates the difference between the results of microtremor measurements and USGS data which was not different significantly. However, some point showed different values to produce a classification of different types of material, thus affecting the distribution of seismic vulnerability. The results of seismic distribution analysis showed that middle lore has a high level of seismic vulnerability from 19 districts spread across Poso Regency.

1. Introduction

The natural disaster of earthquake often occurs in Indonesia, including in the Poso District, Central Sulawesi Province. Data from the Meteorology Climatology and Geophysics Agency (BMKG) of Palu (2017) noted that an earthquake had occurred in Poso on May 29, 2017, and caused damage to several buildings in Poso City and Napu Valley [1]. This earthquake had a magnitude of 6.6 Mw and its aftershocks were still felt until June 2017. This condition shows that Poso region and the Napu Valley are areas that cannot be separated from the threat of an earthquake disaster. Although during the earthquake in Central Sulawesi was focused more on the Palu-Koro Fault, the incident on May 29, 2017, showed that other faults could potentially generate future earthquake threats in Central Sulawesi Province.

Seismic vulnerability is an indicator in reducing the risk of an earthquake [2], [3]. This indication is important so that the local government can disseminate the territory of a range and the community has a level of knowledge and preparedness in dealing with earthquake disasters. If an earthquake disaster occurs again in the future, it is expected that the level of loss and the fall of the lives can be minimized.

Due to the readiness of vulnerability data, this research has to provide an update data in mapping done by correcting Vs30 sourced from Vs30 Global with Vs30 data from microtremor measurements, the expected outcome is to be able to map the level of seismic vulnerability in all Poso District, given
the topo condition of Poso District which does not allow for overall measurements. In Poso district, it used microtremor. This research has never been done before by other researchers or from the Poso district government.

The parameter often used in predicting shear wave velocity is Vs30 [4], [5]. This parameter is considered to be able to interpret the type of rock that can later be used to design earthquake-resistant buildings [6]–[10]. To find out the effect of earthquake vibrations based on the value of Vs30, one of the classifications referred to describe the type of geological rock is the site class NEHRP (BSSC, 2000). The shear wave classification is shown in table 1 below:

Table 1. Classification of soil by NEHRP

| Site Classes (SC) | Site Natural Period (s) | V₃₀ | NEHRP class |
|------------------|------------------------|-----|-------------|
| SC I : (Rock/Stiff Soil) | Tₑ < 0.2s | V₃₀ > 600 m/s | A + B |
| SC II : (Hard Soil) | 0.2s ≤ Tₑ < 0.4s | 300 < V₃₀ ≤ 600 m/s | C |
| SC III : (Medium Soil) | 0.4s ≤ Tₑ < 0.6s | 200 < V₃₀ ≤ 300 m/s | D |
| SC IV : (Soft soil) | Tₑ ≥ 0.6s | V₃₀ ≤ 200 m/s | E |

Source: [11]

The analysis used in this study used the HVSR method to see the soil profile at the subsurface [12]–[18]. This method will show the horizontal-to-vertical spectrum ratio (HVSR) so that later it can predict the value of Vs (wave velocity) [19]. This value will then be used to predict Vs30. In the related field measurement, Vs30 will be measured in each different rock. The measurement results will be used as a reference for correcting the Vs30-USGS value, where the interpolation results are carried out at 1 km intervals. The distribution of the Vs30 value will then be analyzed spatially so that the seismic vulnerability level in Poso district will be obtained.

The geological condition of the study area and its characteristics are different from other regions in Central Sulawesi because this region has a large lake. Based on the regional geological map of Poso sheets [20] the location of the study is in the Molasses Celebes Sarasin and Saracin. Lithology materials commonly found in the location are sandstones, conglomerates, claystone, limestone, and alluvium units in the form of coastal sediments such as gravel, gravel material coarse sand, and loam. From the results of surface geological observations at the study site, there were weathered granites which were bedrock. The granite has almost resembled sand or decomposed rocks, thus making the surrounding rocks or the burden on weathered rocks easily released so it occurs [21].

2. Material and methods
The Vs30 data from the USGS was corrected to the microtremor data from field measurements at 5 sample points, using a portable microtremor device consisting of a Portable Digital Seismograph with 3 components, 1 vertical component and 2 horizontal components: EW-NS [22], [23]. A short period of the Taurus brand (Canada) with a DS-4A type of Feedback Short Period Seismometer sensor and equipped with a digitizer (Datalogger) [24]–[26].

Data analysis was carried out by field acquisition, to obtain more detailed results. After that, it was continued by the acquisition of a microtremor in accordance to the previously designed stages. The resulting data will then be processed to obtain natural frequencies along with their implied values. The results obtained using the HVSR method will show the value of Vs30 [27], [28]. Data processing of wave propagation records was done using the SeisImager program which was divided into 2 stages, where the first stage used the Surface Wave Analysis Wizard software to obtain disperse curves.

Microtremor data processing began with windowing using a window length of 30 seconds. Next was the spectrum calculation Fourier with FFT (Fast Fourier Transform) for each window. This calculation was performed on each component U-D, N-S, and E-W. Then, the refinement or smoothing of the Fourier spectrum employed Konno-Ohmachi method [29]–[31].
The magnitude of seismic waves due to the elasticity of the material is important to know in the design of earthquake-resistant buildings [18]. This is because, in soft rocks, the amplification of seismic waves occurs during an earthquake [32–34]. The VS30 value was obtained from the following equation:

\[
V_{s30} = \frac{30}{\sum_{i=1}^{N} \left( \frac{d_i}{v_i} \right)}
\]

where:
- \(d_i\) is the thickness of the sedimentary layer (m)
- \(v_i\) is the shear wave velocity (m/s)
- \(N\) is the number of layers above a depth of 30 m.

3. Results and discussion

The microtremor refraction method is a geophysical method that uses a passive source of near-surface noise. Retrieval of data was done in a passive way that was by using sources of interference from nature as an energy source. Then, the data that has been obtained was the result of a geophone recording. Records of seismic data in the time and distance domains were then transformed into the frequency domain with respect to Phase velocity.

Based on observations of rocks in the field, precisely on the avalanche wall, there are outcrops of coarse sand, conglomerates, and weathered granite with a fairly steep slope > 40°. It appeared that the lowest rock position was granite which is considered to act as weathered rocks which can act as a sliding field at the study site. In interpreting subsurface models, geological information (rocks) in the field would be used as control data.

![Figure 1. Share wave velocity profile at line 1](image)

Based on the figure, the velocity profile of the shear waves at Line-1 shows that the shear wave velocity values range from 350 - 610 m/s and the average shear wave velocity at a depth of 30 m is 349 m/s. Based on these data, the first to fifth layers are dominated by the type of sand material/saturated (Figure 1).

Line 2 shows that the shear wave velocity value ranges from 300 - 900 m/s and the average shear wave velocity at a depth of 30 m is 422.7 m/s (Figure 2). Based on these data, the first to fifth layers are dominated by alluvium material types. In line 3, it is obtained that the shear wave velocity values range from 180 - 320 m/s and the average shear wave velocity at a depth of 30 m is 240.4 m/s.
Based on this data, the first to fifth layers are dominated by the type of sand material (not saturated).

**Figure 2.** Share wave velocity profile at line 2

**Figure 3.** Share wave velocity profile at line 3

Line 4 shows that the shear wave velocity value ranges from 190 - 1350 m/s and the average shear wave velocity at a depth of 30 m is 375.6 m / s (Figure 4). Based on these data, the first to fifth layers are dominated by alluvium material types, and line 5 shows that the shear wave velocity value ranges from 310 - 780 m / s and the average shear wave velocity at a depth of 30 m is 304.5 m / s. Based on these data, the first to fifth layers are dominated by the type of sand material/saturated (Figure 5).

From the HVSR analysis, the natural frequency of the soil and the amplification at 5 measurement points in the Poso Regency area were converted to get the VS value, then used to calculate the VS30 value. The value of the natural soil frequency ranges from 0-15 Hz. From the inversion of the HVSR curve, the distribution of the S wave velocity (VS) value distribution at each acquisition point has been obtained. Based on body waves of the HVSR curve, the inversion was carried out using the Model HVSR software. The VS distribution value at the research location was obtained with the lowest Vs value around 180-320 m/s and the highest Vs ranging from 300-900 m/s. This indicates that most of the areas in Poso Regency are classified as massive, hard, compact and dense rock (bedrock). The VS30 estimation is generated from VS above 30 meters depth resulting from the inversion of the
HVSR curve for each microtremor data acquisition point which is then mapped in Figure 1. The VS30 map is an important parameter for local effects research. From the VS30 micro-zonation map obtained and referring to Table 1 regarding soil classification, Poso Regency is classified as soil type C which spreads in almost the entire study area except for the center to the north which has VS soil type D.

![Figure 4. Share wave velocity profile at line 4](image)

Based on Global Vs30-USGS data, the value of Vs30 in Poso Regency ranges from 192 to 900 m/sec. The varied Vs30 values can be classified by site based on the NEHRP classification, so that the results obtained as shown in Figure 7 The distribution obtained shows that the study site has a type of soft soil (SC IV) to Rock (SC I). Soft soil type (SC IV) is only around the south Poso lake with an area of 86 Ha. The medium soil type (SC III) is dominant in the valley, coastal areas of Tomini Bay and Poso Lake. The classification results also show that the Poso area is dominated by hard lands (SC II) and Rocks (SC I) which are located along the mountains in Poso District.

To obtain more accurate information related to the distribution of Vs30, the USGS data should be corrected by using microtremor data. The results obtained indicated that soft-land is not only located
in the Poso Lake but also spread evenly in the lowlands and coastal areas of Poso District. The comparison of areas based on the NEHRP classification can be seen in Table 1.

The comparison between Vs30 data from USGS and corrected Vs30 shows that the corrected Vs30 distribution model is almost close to the facts on the ground during the earthquake in 2017 compared to the Vs30-USGS distribution model. When the magnitude 6.6 earthquake occurred in the Napu Valley, many residents' houses in the area were damaged. These casualties are supported by information on the distribution model Vs30 corrected that in the Napu Valley is soft soil. During the earthquake, an amplification occurred resulting in damage in many residential buildings (Figure 6). Meanwhile, the Vs30-USGS distribution model identified that the Napu valley was on moderate soil with a relatively low possibility of building damage due to earthquake, this is inversely proportional to the conditions in the field during an earthquake.

![Building damage due to an earthquake with a magnitude of 6.6 in 2017 in the Napu Valley, Poso District](image)

Figure 6. Building damage due to an earthquake with a magnitude of 6.6 in 2017 in the Napu Valley, Poso District

The Vs30 ratio in this study shows a comparison of the Vs30 microtremor value and the Vs30 USGS. In general, the Vs30 ratio in Poso District was > 0.5, which indicated that the difference between the results of microtremor measurements and USGS data was not different significantly. However, some point shows different values to produce a different classification of material types. This shows that in soft soil the USGS Vs30 value is less accurate than the Vs30 value in hard soil and rocks.

To see the extent of the existing seismic vulnerability, a value conversion was performed where SCI is an area with a high level of seismic vulnerability, SC II is an area with a moderate level of seismic vulnerability and Site Class III and IV have a low level of vulnerability. Referring to the classification, the seismic vulnerability distribution map can be seen in Figure 7.

Based on the map of seismic vulnerability distribution, it can be seen that low seismic vulnerability is more dominant in Poso district, while for high seismic vulnerability is in a low category. However, many residential areas were scattered in areas that have a high seismic vulnerability. So, this region has a high level of risk if an earthquake occurs. The distribution of seismic vulnerability in each district can be seen in Table 2.
Figure 7. Distribution Vs30-corrected in Poso District

Table 2. Distribution of seismic vulnerability in each district

| No | District                   | Vulnerability Seismic |
|----|----------------------------|-----------------------|
| 1  | Poso Kota                 | High                  |
| 2  | Poso Kota Utara           | Medium                |
| 3  | Poso Kota Selatan         | High                  |
| 4  | Lage                      | Medium                |
| 5  | Lore Barat                | Low                   |
| 6  | Lore Selatan              | High                  |
| 7  | Lore Tengah               | High                  |
| 8  | Lore Timur                | High                  |
| 9  | Lore Utara                | Medium                |
| 10 | Lore Pore                 | High                  |
| 11 | Pamona Barat              | Medium                |
| 12 | Pamona Puselemba          | Medium                |
| 13 | Pamona Selatan            | High                  |
| 14 | Pamona Tenggara           | Medium                |
| 15 | Pamona Timur              | High                  |
| 16 | Pamona Utara              | Medium                |
| 17 | Poso PESISIR              | High                  |
| 18 | Poso Pesisir Selatan      | Low                   |
| 19 | Poso Pesisir Utara        | Medium                |

From Table 2, It can be seen that based on the area of vulnerability, the middle lore sub-district has the highest level of seismic vulnerability while the lowest is in Poso sub-district. However, if seen based on the existing population based on data from the Central Statistics Agency [35], it shows that
Poso City has a population of 28,831 people (the most populous population in all Poso districts), while in Central Lore sub-district it has a population of 4,033 people. This shows that when an earthquake occurs, Poso Subdistrict of the city becomes the area that has the highest risk compared to other districts.

4. Conclusion
Poso District is one area that has a high earthquake hazard. Based on the Vs30 ratio in Poso District, a ratio value of > 0.5 was obtained. This shows that the difference between the results of microtremor measurements and USGS data was not different significantly. However, some point shows differences in values to produce a classification of different types of material, thus affecting the distribution of seismic vulnerability. The results of the seismic distribution analysis showed that the middle Lore had a high level of seismic vulnerability from 19 sub-districts scattered in Poso District.

Acknowledgement
Thank you to the DRPM (Indonesian Republic's Ministry of Research, Technology and Higher Education) for funding this research. Thank you also to the Faculty of Mathematics and Natural Sciences who have helped facilitate the laboratory.

References
[1] BMKG 2007 Berita Gempa
[2] Vicente R, Parodi S, Lagomarsino S, Varum H and Silva J A R M 2011 Bull. Earthq. Eng 9(4), 1067-1096
[3] Lagomarsino S and Cattari S 2013 Seismic Vulnerability of Structures 1-62
[4] Kuo C H, Chen C T, Lin C M, Wen K L, Huang J Y and Chang S C 2016 J. Asian Earth Sci 128 27-41
[5] Rusydi M, Efendi R, Sandra and Rahmawati 2018 Journal of Physics: Conference Series
[6] Bonilla L F, Steidl J H, Lindley G T, Tumarkin A G and Archuleta R J 1997 Bull. Seismol. Soc Am
[7] Elnashai A S and Di Sarno L 2008 Fundamentals of Earthquake Engineering: From Source to Fragility
[8] Hatheway A W 1996 Eng. Geol 1(43) 81-82
[9] Hatheway A W and Kiersch G A 2017 Handbook of Physical Properties of Rocks
[10] Pelekis P C and Athanasopoulos G A 2013 Soil Dyn. Earthq. Eng
[11] Mahajan A K 2009 Eng. Geol 104(3-4) 232-240
[12] Castellaro S, Mulargia F and P. L. Rossi 2008 Seismol. Res. Lett
[13] Gallipoli M R and Mucciarelli M 2009 Bull. Seismol. Soc. Am
[14] Harutoonian P 2012 Soil Dyn. Earthq. Eng
[15] Leyton F, Ruiz S, Sepúlveda S A, Contreras J P, Rebolledo S and Astroza M 2013 Eng. Geol
[16] Lunedei E and Albarello D 2010 Geophys. J. Int 181(2) 1093-1108
[17] Picozzi M, Parolai S and Albarello 2005 Bull. Seismol. Soc. Am
[18] Rusydi H, Effendi R and Rahmawati 2017 Int. J. Sci. Appl. Sci. Conf. Ser
[19] Boxberger T, Picozzi M and Parolai S 2011 J. Appl. Geophys 75(2) 345-354
[20] Sukamto R 1973 Peta Geologi Tinjau Lembar Palu Sulawesi
[21] Kieffer H H, Mullins K F, and MacKinnon D J 2008 Photogramm. Eng. Remote Sensing
[22] Zheng Y, Ma H S, Lu J, Ni S D, Li Y C and Wei S J 2009 Sci. China, Ser. D Earth Sci
[23] Refrizon, Arif I H, Kurnia L and Tria O 2013 Prosiding Semirata FMIPA Universitas Lampung
[24] Bignardi S, Yezzi A J, Fusselllo S and Comelli A 2018 Comput. Geosci 120 10-20
[25] Kawase H, Nagashima F, Matsushima S and Sánchez-Sesma F J 2014 NCEE 2014 - 10th U.S. National Conference on Earthquake Engineering: Frontiers of Earthquake Engineering
[26] Tian B, Xu P, Ling S, Du J, Xu X and Pang Z 2017 J. Geophys. Eng 14(5) 1283-1289
[27] Holzer T L, Padovani A C, Bennett M J, Noce T E and Tinsley J C 2005 Earthq. Spectra
[28] Ozcep F, Tezel O and Asci M 2010 *Int. J. Phys. Sci* 5(1) 47-56
[29] Mucciarelli M and Gallipoli M R 2001 *Bollettino di Geofisica Teorica ed Applicata*
[30] Okada H and Suto K 2003 *The Microtremor Survey Method*
[31] Warnana D D, Soemitro R A A and Utama W 2011 *Int. J. Basic Appl. Sci. IJBAS-IJENS*
[32] Aydan O, Ulusay R and Atak V O 2008 *Environ. Geol* 54(1) 165
[33] Ghofrani H, Atkinson G M and Molnar S 2017 *Front. Built Environ*
[34] Mohammed M A, Abudeif A M, Omar K A and Attia M M 2018 *Arab. J. Geosci* 11(2) 16
[35] Poso B K 2019 *Kabupaten Poso dalam Angka 2018*