Comparison of Seismic Vulnerability Index Microzonation Using Usgs Vs30 Data and Microtremor Signal Measurements in Prambanan and Gantiwarno Sub-Districts, Klaten Regency

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ARTICLE INFO

Article history:

Received February 23, 2024
Revised March 21, 2024
Accepted April 25, 2024

Keywords:

Microtremor
Vs30
Seismic Vulnerability Index
USGS

ABSTRACT

The May 27, 2006 tectonic earthquake that rocked the Bantul area of Yogyakarta and several areas in Central Java resulted in a lot of damage to buildings and casualties. Earthquake is a disaster that can be minimized by disaster mitigation, one of which is the seismic vulnerability index data of an area. This study aims to compare the microzonation of the seismic susceptibility index (*Kg*) as a result of measurement of microtremor signals by processing data Vs30 USGS. The data used were 30 microtremor signal measurement points and topographic models from the USGS website in Prambanan and Gantiwarno Districts, Klaten Regency. The calculation result of Vs30 USGS shows the value of seismic vulnerability index (*Kg*), which ranges from $0.385\, x\, 10^{-6} s^2/m$ to $0.51\, x\, 10^{-6} s^2/m$. Meanwhile, the seismic vulnerability index value (*Kg*) results from the measurement of the microtremor signal, which ranges from $2.27\, x\, 10^{-6} s^2/m$ to $52.27\, x\, 10^{-6} s^2/m$. Comparative graphs of data from measurements of microtremor signals with the results of processing Vs30 USGS produced R-values square small. This is due to several factors, namely the shift of measurement points with data points Vs30 USGS (longitude and latitude slightly shifted). In addition, the results of calculation of Vs30 USGS are based on the topography of the earth's surface which is limited to a depth of 30 meters so that it does not represent the results of measurement data directly.

Cite Article:

F. Fajarningrum, N. B. Wibowo, "Comparison of Seismic Vulnerability Index Microzonation Using Usgs Vs30 Data and Microtremor Signal Measurements in Prambanan and Gantiwarno Sub-Districts, Klaten Regency," in *Sunan Kalijaga of Journal Physics*, vol. 6, no. 1, pp. 1-10, April, 2024, 10.14421/physics.v6i1.5138.

1. INTRODUCTION

The Special Region of Yogyakarta is one of the provinces located in the southern part of Java Island, directly bordering the Indian Ocean. The tectonic earthquake on May 27, 2006, which struck the Bantul area of Yogyakarta and several regions in Central Java, caused significant damage to buildings and resulted in numerous casualties. This natural disaster was a consequence of Yogyakarta's geographical location, which lies in an active collision zone between the Eurasian Plate and the Indo-Australian Plate. In addition, Yogyakarta is also prone to earthquakes caused by fault activity on land. Physiographically, natural disasters threatening the Special Region of Yogyakarta can be divided into four types: disasters originating from Mount Merapi, landslides and erosion, floods, and earthquakes. Based on historical seismic data, Yogyakarta has experienced major earthquakes in the years 1867, 1943, 1981, and 2006, with maximum intensities ranging from VII to IX on the Modified Mercalli Intensity (MMI) scale [1].

The Bantul tectonic earthquake on May 27, 2006, had a magnitude of 6.3 Mw (Moment Magnitude) and a depth of 12.5 km. It occurred at approximately 05:55 WIB and lasted for 57 seconds. The epicenter was located at 7.961°S – 110.446°E causing much damage and casualties [2]. This earthquake damaged more than 100,000 buildings and killed more than 5,000 people.

Based on 2006 earthquake data, several sub-districts in Klaten Regency suffered significant building damage and casualties due to the May 27, 2006 Bantul earthquake, including Prambanan and Gantiwarno sub-districts. Therefore, the microzonation of seismic vulnerability indices in this area can be used as a reference in the development of urban infrastructure.

The aim of this study is to compare the microzonation of the seismic vulnerability index obtained from microtremor signals measurement with the results of Vs30 data processing obtained from the USGS website in the Prambanan and Gantiwarno sub-districts, Klaten Regency.

2. METHODS

This study compared the two models of the seismic vulnerability index (Kg) results of measuring microtremor signals with the calculation results of Vs30 USGS in Prambanan and Gantiwarno District, Klaten Regency. The microtremor signal measurements were conducted at 30 research points obtained from a previous study by Zahroh Utami[3], titled *"Analysis of Seismic Vulnerability Index Based on Microtremor Signal Measurements in Prambanan and Gantiwarno Sub-districts, Klaten Regency."*

The measurement used Seismometer equipment of TDV-23S type, Digital Portable Seismograph of TDL 303-S type, compass, GPS, and laptop. Operational standards for measurement based on SESAME with a sampling frequency of 100 Hz for ± 30 minutes. Data processing uses the software Sesarray-Geopsy, MATLAB, Surfer, Global Mapper, and Monost from Xamarin inc. The data obtained from the measurement results are predominant frequency (f_g) and amplification factor (A_g), which were then used to calculate the seismic vulnerability index (Kg) for each measurement point. The calculated Vs30 data were obtained from the USGS website (www.earthquake.usgs.gov). Data points retrieved from the USGS website align with the measurement result data points by selecting the closest longitude and latitude values to obtain the corresponding USGS Vs30 values. These Vs30 values were then processed using the following equation[4] :

$$f_g = \frac{Vs_{30}}{4xh} \tag{1}$$

where f_g is the predominant frequency (Hz), Vs_{30} is the shear wave velocity at a depth of 30 m (m/s), h is the sediment thickness (m) (in this calculation, the sediment thickness is assumed to be at a depth of 30 m).

In addition, the value of Vs30 USGS can also be used to find the value of amplification factors, which refers to the increase in seismic wave amplitude caused by significant contrasts between subsurface layers. The relationship between Vs30 and the amplification factor can be formulated by the following equation

$$log\ (ampv) = 2.367 - 0.852 * log\ (Vs_{30}) \tag{2}$$

where Vs30 is the shear wave velocity at a depth of 30 m/s, and Ampv is the amplification factor.

The seismic vulnerability index (Kg) values of both the Vs30 USGS calculation results and the measurement results are obtained using the following equation [5]:

$$Kg = \frac{{A_g}^2}{f_g} \tag{3}$$

Where Kg is the seismic vulnerability index (s^2/m), A_g is the amplification factor, and f_g is the frequency predominant (Hz)

The values of the predominant frequency (f_g), the amplification factor (A_g), and the seismic vulnerability index (Kg) of the measurement results of the microtremor signal and the data processing result of Vs30 USGS are compared using graphs. Furthermore, the data from microtremor signal measurement and Vs30 data processing were modeled using surfer software to obtain a microzoning map.

The microzoning model is overlayed on the map of Prambanan and Gantiwarno Districts, Klaten Regency.

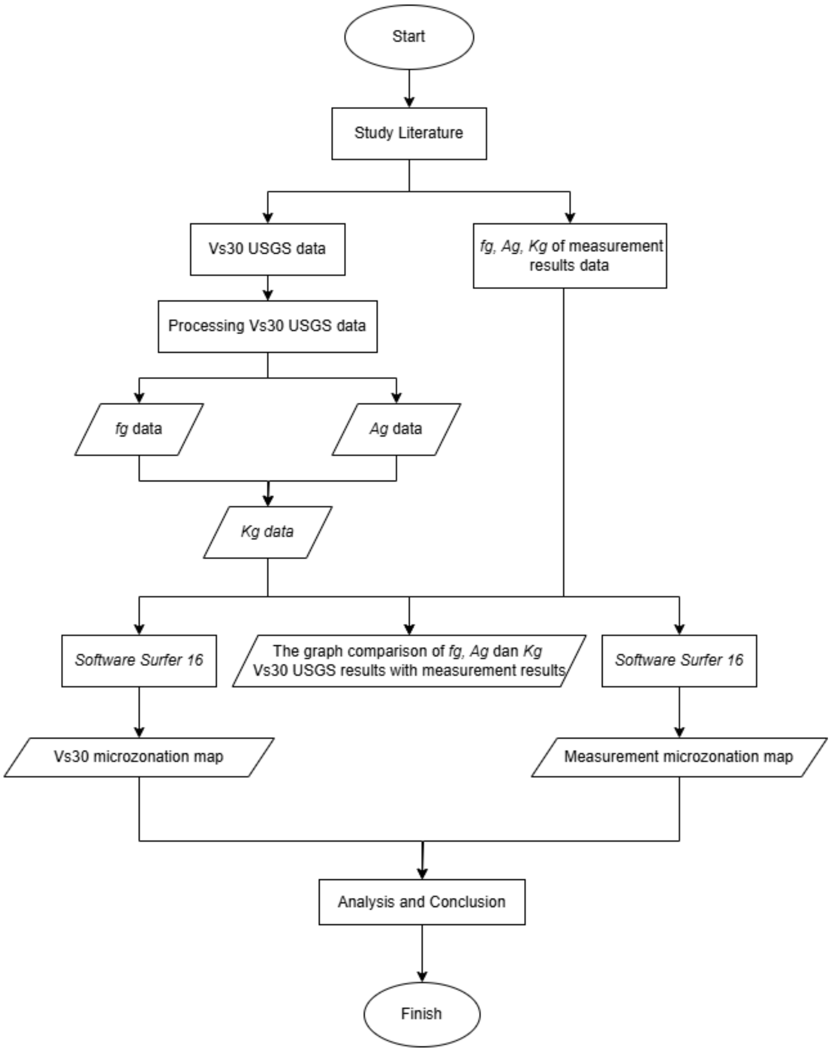


Figure 1. Flow Chart of Research

3. RESULTS AND DISCUSSION

The distribution of the predominant frequency value (f_g) indicates the physical characteristics of the soil, particularly the thickness of sediment layers in an area. The microzonation map derived from Vs30 USGS data processing shows a frequency range of 2.6 Hz to 3.3 Hz. Meanwhile, the microzonation map based on field measurements shows a wider range, from 0.5 Hz to 9.5 Hz. The microzonation of predominant frequency (f_g) based on Vs30 USGS data is shown in Figure 2.

The microzonation map of the Vs30 USGS processing results shows that the Prambanan and Gantiwarno sub-districts have a predominant frequency value varying with a minimum value of 2.6 Hz in the east of Gentan Village and a maximum value of 3.3 Hz in the west of Kokosan Village, Bugisan, Tlogo, Kebon Dalem Kidul, Pereng in the west.

Based on Kanai’s classification [6], the distribution of predominant frequency between 2.6 Hz and 3.3 Hz corresponds to Soil Type III, an alluvial rock that is almost the same as type II soil, distinguished only by an unknown formation with a depth of 10–30 m. This area is categorized as thick sediment. Meanwhile, the microzonation map of predominant frequency (f_g) based on field measurements is shown in Figure 3.

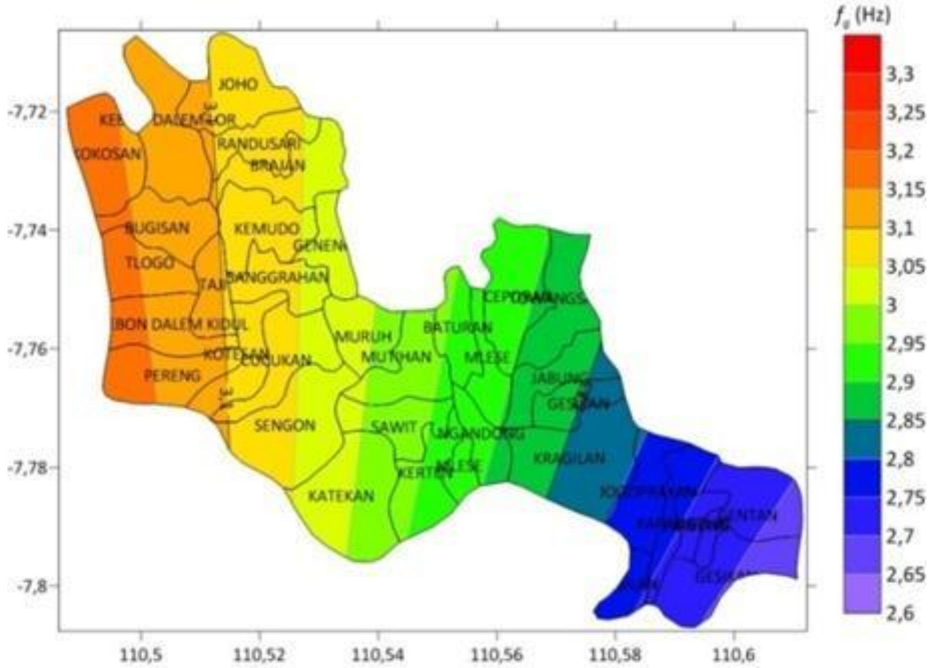


Figure 2. The microzonation of predominant frequency (f_g) based on Vs30 USGS

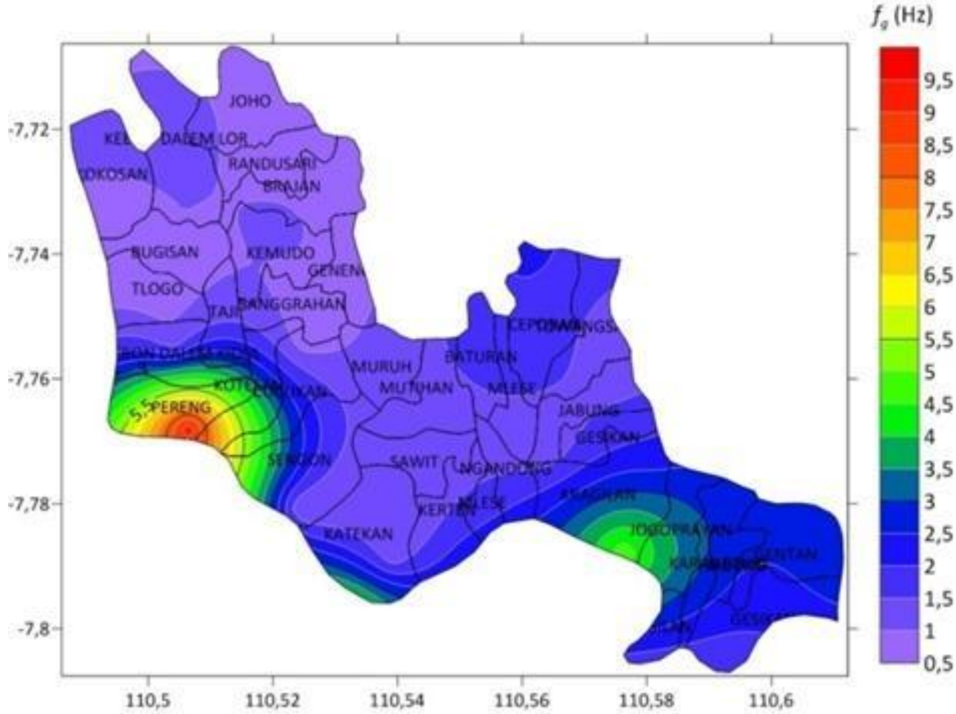


Figure 3. The microzonation map of predominant frequency (f_g) based on field measurements

The microzonation map of the measurement results shows that the Prambanan and Gantiwarno sub-districts have more predominant frequency values with a minimum value of 0.5 Hz around Joho Village, Randusari Village, Brajan Village, Genen Village, Sanggrahan Village, Bugisan Village, and Tlogo Village. The maximum predominant frequency value is 9.5 Hz located in Pereng Village. Based on Kanai's classification [6], the predominant frequency distribution between 0.5 Hz to 2.5 Hz indicates classification of type IV soil, i.e. alluvial rocks formed by sedimentation of delta, topsoil, mud with a depth of 30 m. Areas with type IV soil classification are distributed throughout most of the area. Predominant frequency values ranging from 2.5 Hz to 4 Hz, which is an alluvial rock that is almost the same as type II soil, are distinguished only by the presence of unknown formations, spread across Jogoprayan and Kotesan villages. Meanwhile, the higher predominant frequency values, ranging from 4 to 6.67 Hz, indicate alluvial rocks with a thickness of approximately 5 meters, consisting of gravelly sand, hard clayey sand, clay, and silt. Areas with these higher frequency values are found in Kotesan, Sengon, and Pereng Villages.

Furthermore, a linear plotting of the result of the graph comparison of the predominant frequency value (f_g) of the measurement result with the predominant frequency (f_g) of the data processing result Vs30 USGS. The graph shows a small R-Square magnitude of 0.08308.

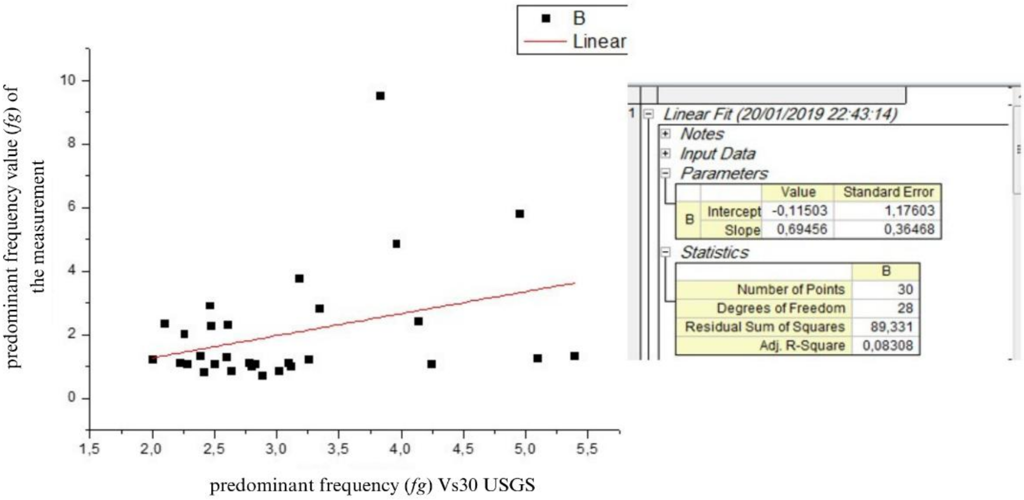


Figure 4. The graph comparison of the predominant frequency value (f_g) of the measurement result with the predominant frequency (f_g) of the Vs30 USGS

The amplification factor is inversely proportional to the shear wave velocity, the smaller the wave velocity, the greater the amplification factor [7]. The speed of the waves is affected by the density of the rocks of the area. The decreasing density of the rock of an area causes waves passing through it to have a small speed and to have a large amplification factor. This causes amplification factors to also be affected by rock density [8]. The higher the value of the amplification factor indicates that the ground shaking will be more intense, which increases the risk of damage in a given area. The microzonation of the amplification factor (A_g) in the Prambanan and Gantiwarno sub-districts of the USGS results is shown in Figure 5.

Based on the results of the Vs30 USGS processing, the value of the amplification factor (A_g) was found to vary from 1.22 to 1.33. The minimum amplification factor value of 1.22 is spread in Gesikan Village and Silan Village. The more to the west, the greater the amplification factor value with a maximum value of 1.33 located in the Kokosan Village area.

According to Ratdomopurbo [9], the classification of amplification factors between 1.22 to 1.33 falls under the category of low classification.

Based on the measurement results, it was found that the amplification factor (A_g) values varied between 1.5 to 9.0. The minimum amplification factor value of 1.5 is located in Joho Village, while the maximum amplification factor value of 9.0 is located in Kragilan Village. According to Ratdomopurbo [9], the amplification factor classification of measurement results (Figure 6.) between 1.5 to 3.0 is in the category of low classification, spread over the northern and southern parts of the country. Amplification factor values between 3.0 to 6.0 belong to a moderate category, scattered over most of the region. The value of the amplification factor 6.0 to 9.0 is included in the high category spread in the areas of Gesikan Village, Kragilan Village, Ngandong Village, and Klese Village.

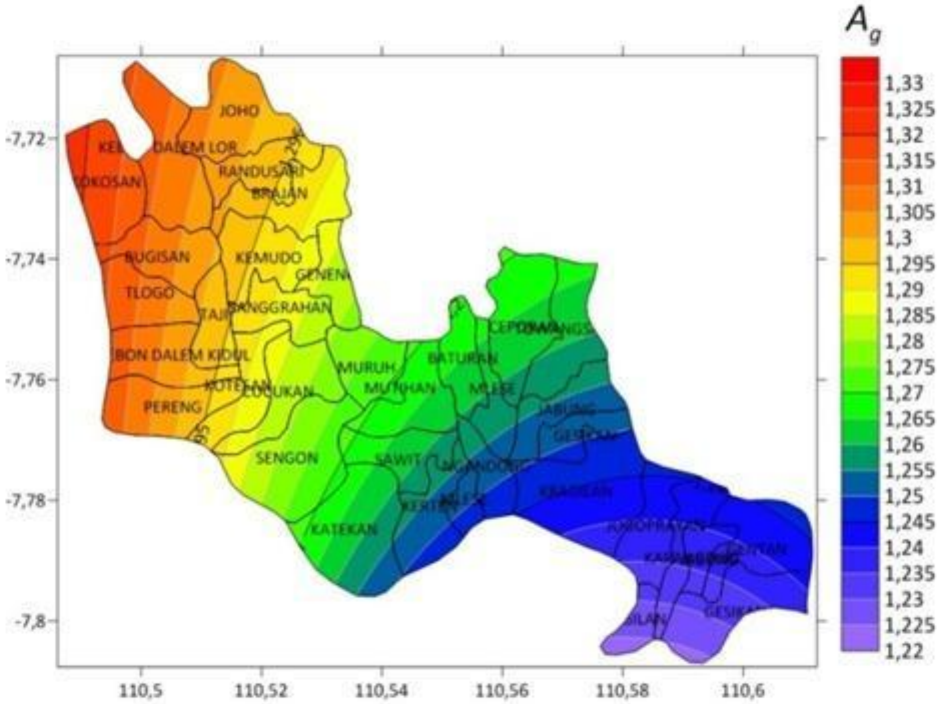


Figure 5. The microzonation of the amplification factor (A_g) based on Vs30 USGS

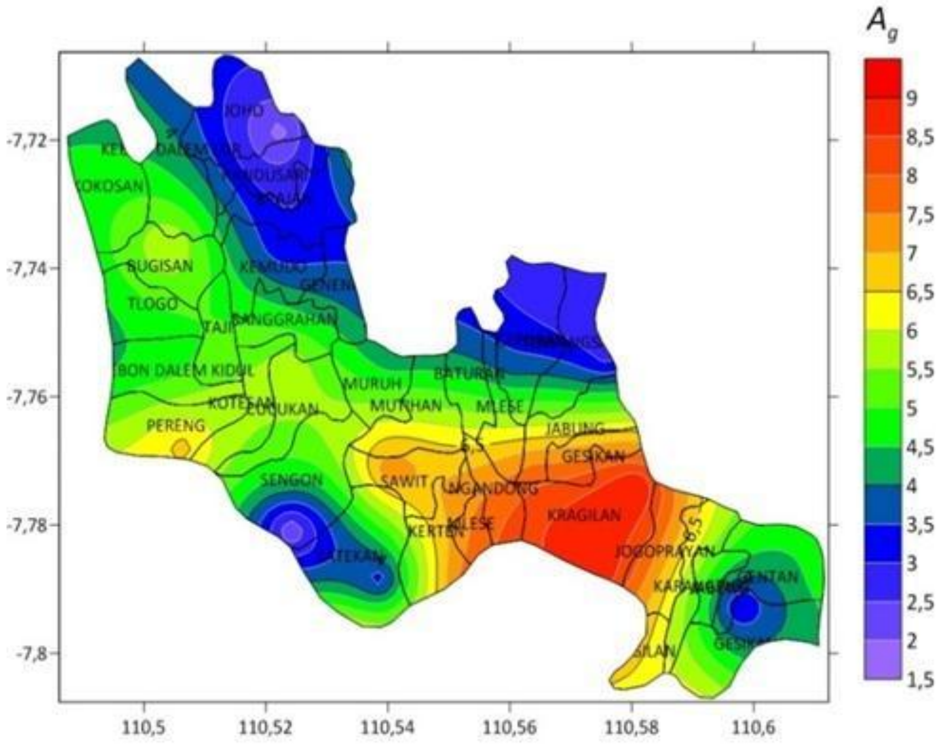


Figure 6. The microzonation of the amplification factor (A_g) based on field measurements

Linear plotting of the relationship between the Vs30 USGS amplification factor and the linear plotting of the measurement result. The results showed a small R-square value of 0.15761.

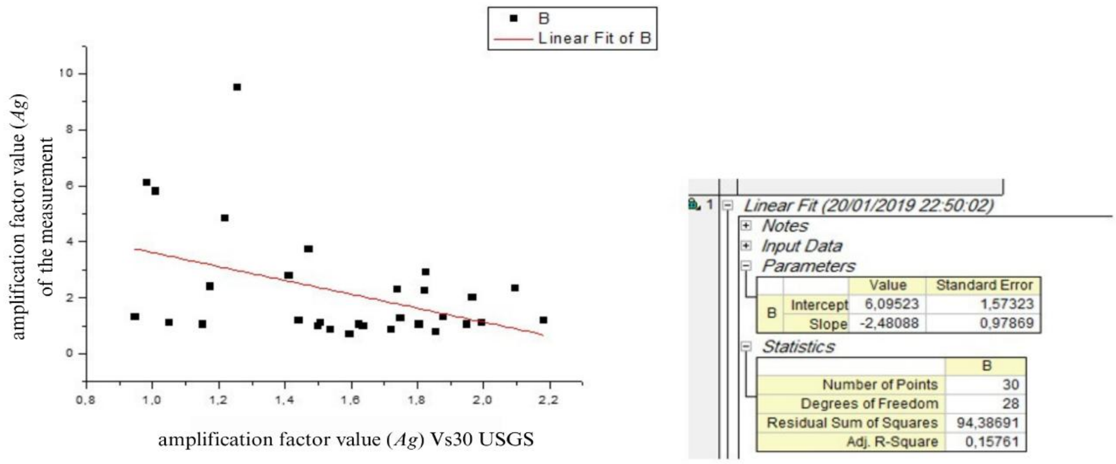


Figure 7. The graph comparison of the amplification factor (A_g) of the measurement result with the amplification factor (A_g) of the Vs30 USGS

The seismic vulnerability index is an index that represents the degree of vulnerability of surface soil layers to soil deformation during an earthquake [10]. Information about seismic vulnerability indices can be used to determine the high or low potential for damage to an area caused by an earthquake. Figure 8 shows the microzoning of the seismic vulnerability index of the results of the Vs30 USGS data processing. The microzonation map shows the seismic vulnerability index values of USGS results vary, with a minimum value of $0.385\ x\ 10^{-6} s^2/m$ located in the Silan Village area and a maximum value of $0.51\ x\ 10^{-6} s^2/m$ located to the west. Seismic vulnerability index values based on Vs30 USGS data processing results indicate low vulnerability scales. Meanwhile, the seismic vulnerability index of the measurement results showed different values from the Vs30 USGS results. The microzonation map of the seismic vulnerability index (Kg) of the study results is as follows.

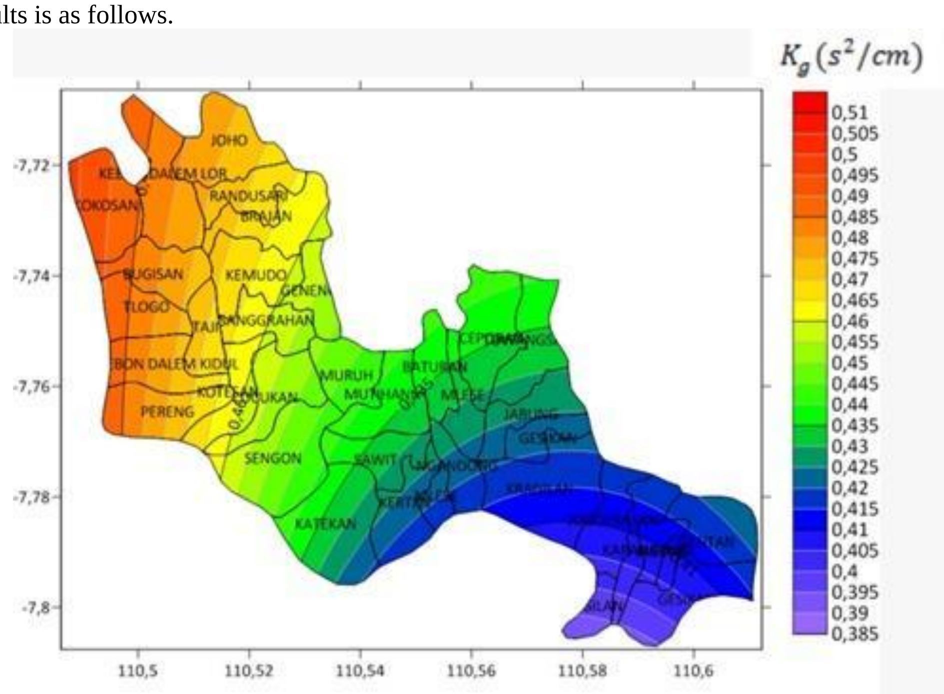


Figure 8. the microzoning of the seismic vulnerability index based on Vs30 USGS

Based on data analysis, the seismic vulnerability index values obtained from measurements are more varied than those derived from the USGS Vs30 data. According to the microzonation map, the seismic vulnerability index ranges from $2.27\ x\ 10^{-6} s^2/m$ to $52.27\ x\ 10^{-6} s^2/m$. The lowest seismic vulnerability index values, ranging from $2.27\ x\ 10^{-6}s^2/m$ to $10.27\ x\ 10^{-6}s^2/m$, are spread across the eastern area, parts of the northern area, and parts of the western area. The medium seismic vulnerability index values, ranging from $10.28\ x\ 10^{-6}s^2/m$ to $34.27\ x\ 10^{-6}s^2/m$, are concentrated in the central region. Meanwhile, the high seismic vulnerability index values, ranging from $35.27\ x\ 10^{-6}s^2/m$ to $52.27\ x\ 10^{-6}s^2/m$, are found in Ngandong Village, Sawit Village, Tlogo Village, and Bugisan Village.

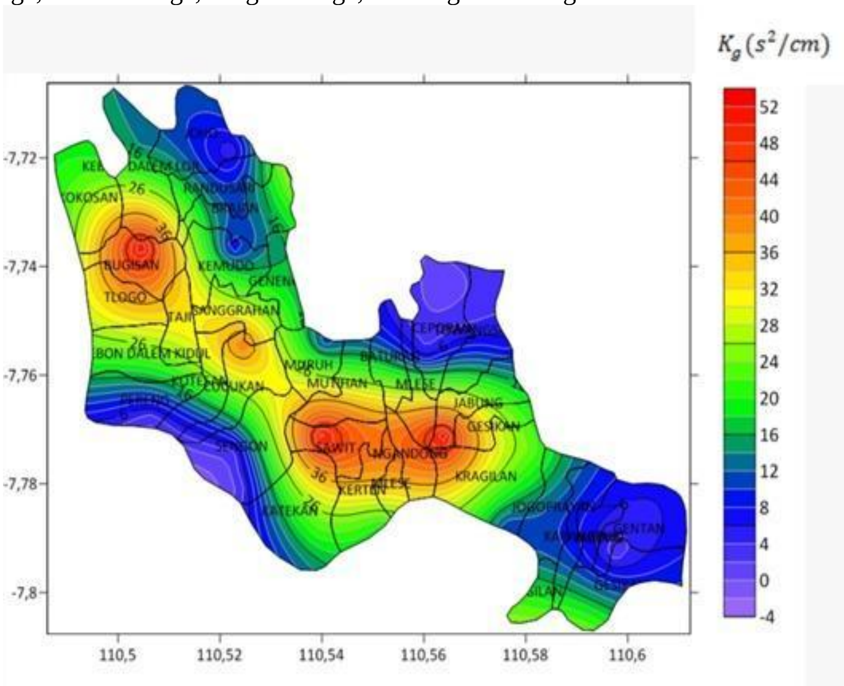
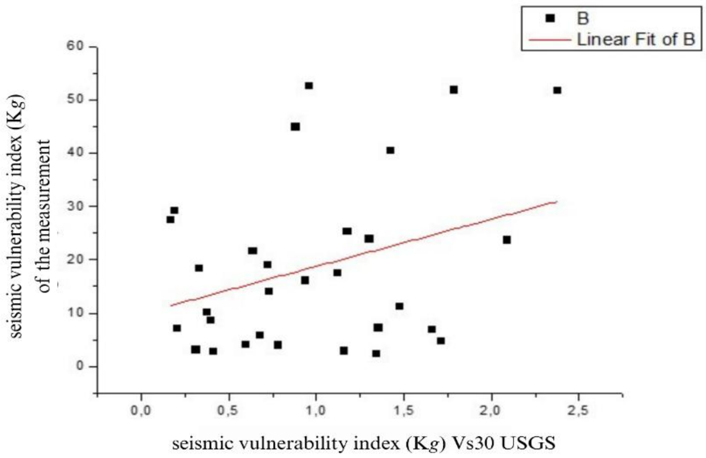


Figure 9. The microzoning of the seismic vulnerability index based on field measurement

The comparison graph of the measured and USGS seismic vulnerability indices (Kg) is as follows. Based on the data points obtained, linear plotting resulted in a small R-square value of 0.07691.



		Value	Standard Error
B	Intercept	9,938	5,44328
	Slope	8,85774	4,79241

	B
Number of Points	30
Degrees of Freedom	28
Residual Sum of Squares	6473,66861
Adj. R-Square	0,07691

Figure 10. The graph comparison of the seismic vulnerability index of the measurement result with the seismic vulnerability index of the Vs30 USGS

4. CONCLUSION

Based on the experiments in the research that has been done, it can be concluded that:

1. The Predominant frequency (f_g) value of the Vs30 USGS data processing of Vs30 USGS processing result is 2.6 Hz to 3.3 Hz, while the Predominant frequency (f_g) value of the data measurement is 0.5 Hz to 9.5 Hz. The value of amplification factor of data processing of Vs30 USGS is 1.22 to 1.33, while the value of the amplification factor (Ag) of the research result is 1.5 to 9.0
2. The seismic vulnerability index value (*Kg*) of USGS results is $0.385\,x\,10^{-6}s^2/m$ to $0.51\,x\,10^{-6}s^2/m$, while the seismic vulnerability index value (*Kg*) of measurement results is $2.27\,x\,10^{-6}s^2/m$ to $52.27\,x\,10^{-6}s^2/m$.
3. The comparison graph of the microtremor signal measurement results with the Vs30 USGS data processing results in a small R-square value with the data point Vs30 USGS (longitude and latitude slightly shifted). In addition, the calculation result of Vs30 USGS based on the topography of the earth's surface which is limited to a depth of 30 meters so that it does not represent the results of measurement data directly in the field.

DECLARATION

Author Contribution

Conceptualization, Fitri Fajarningrum.; methodology, Fitri Fajarningrum. and Nugroho Budi Wibowo.; software, Nugroho Budi Wibowo.; validation, Fitri Fajarningrum. and Nugroho Budi Wibowo.; formal analysis, Nugroho Budi Wibowo.; investigation, Fitri Fajarningrum.; resources, Nugroho Budi Wibowo.; data curation, Fitri Fajarningrum.; writing—original draft preparation, Nugroho Budi Wibowo.; writing—review and editing, Fitri Fajarningrum. and Nugroho Budi Wibowo.; supervision, Fitri Fajarningrum.; project administration, Nugroho Budi Wibowo. All authors have read and agreed to the published version of the manuscript.

Funding

Our thanks go to Yogyakarta State University and BMKG for their full support in carrying out this community service activity.

Acknowledgments

The authors would like to thank all parties who supported the completion of this research, including colleagues and institutions involved in data collection and analysis.

Conflict of Interest

The authors declare no conflict of interest.

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