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RESEARCH ARTICLE

Application of HVSR Method on Microtremor Data for Analysis of Earthquake Potential in Candipuro District, Lumajang, Indonesia

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Abstract

The Earthquake of 6.1 magnitude occurred on April 10, 2021, in Lumajang district. One affected area suffered building losses, road damage, and casualties in Candipuro District, Lumajang Regency, East Java. Then the research was conducted to determine the strength of the soil against the potential earthquake by micro zoning the area in Candipuro District. This research uses the microtremor method with HVSR (Horizontal to Vertical Spectral Ratio) analysis. Analysis of earthquake potential includes parameters of Ground Amplification (A_0), Dominant Frequency (f_0), Ground Vulnerability Index (Kg), and Ground Shear Strain (GSS).

The acquisition was completed with 16 measurement points in Supiturang Village with 500 meters between points using the Portable Seismograph TDS - 303. The results obtained in Supiturang Village have the results of the amplification value factor which is classified as medium-high (2.7 - 8.7), low dominant frequency value (0.5 - 1.4 Hz), medium-high soil susceptibility index (10 - 90), V_{S30} value which includes medium - hard soil (187.81 - 548.38) m/s, and GSS value which shows the response of cracks and soil subsidence to shaking (2×10^{-5} - 2×10^{-4}).

Keywords: Microtremor, HVSR, GSS, Earthquake.

1. Introduction

1.1 Sub Introduction

East Java is one of the areas in Indonesia that is relatively vulnerable to earthquake disasters. East Java's geographical proximity to earthquake-causing sources increases the risk of earthquake disasters. (Permana & Faisal, 2023). Earthquakes are vibrations that originate from within the earth, sourced within the earth which then propagate to the earth's surface due to earth fractures breaking and displacing hard.

On April 10, 2021, an earthquake with a magnitude of 6.1 occurred in the Lumajang Regency area. One affected area suffered building losses, road damage, and casualties in Candipuro sub-district, Lumajang district, East Java (Anonymous, 2021).

The tectonic tremors can be utilized to mitigate disasters by making maps of potential earthquakes using the microtremor method.

Microtremor is a natural harmonic vibration in the ground in the rock sediment layer and undergoes reflection due to the existence of a boundary between layers that has a constant frequency due to the presence of a micro vibration below the ground surface (Nurwidyanto et al., 2023). HVSR analysis can then be conducted to produce earthquake vulnerability levels.

The HVSR method is a method of comparing the spectrum of the horizontal component to the vertical component of microtremor waves. Microtremors consist of a basic variety of Rayleigh waves, it is assumed that the peak period of the microtremor H/V ratio provides the basis of the S wave period (Arifin et al., 2014).

2. Geology

The geological condition of the Supiturang Village area has several formations formed by the volcanic activity of Mount Semeru. In Supiturang Village are Semeru 2 Lahar Deposits, Semeru 2 Pyroclastica Fall Deposits, and Semeru 3 Lava Flow. The unit in this village has a layer dominated by ash (tuff) and passive breccia (Fig. 1) (S. Sutawidjaja Igan, et al. 1996).

3. Methodology

3.1. Data Acquisition

The data were acquired from July 31 to August 14, 2022 in Supiturang Village, Lumajang Regency, East Java Province. Measurements were carried out with a minimum duration of 30 minutes at each point which has a lot area of 2 km2 and the distance between microtremor measurement points is 500 meters.

3.2. Horizontal to Vertical Spectral Ratio (HVSR)

Microtremor is a geophysical method that can describe the susceptibility of the surface soil layer to deformation during an earthquake (Nakamura, 2008). The HVSR method assumes that the ratio of the horizontal and vertical spectra of the surface vibration is a function of displacement (Rochman et al., 2023). It also shows that the dynamic characteristics of the surface layer can be roughly understood at the observed point (Nakamura, 1989). HVSR has a formula as in equation (1).

$$HVSR = T_{SITE} = \frac{\sqrt{[(S_{North-South})^2 + (S_{East-West})^2]}}{S_{VS}} \quad (1)$$

3.3. Natural frequency (f_0)

Natural frequency is the frequency value that appears frequently, recognized as the natural frequency value of a measurement area. The dominant frequency value can indicate the type and characteristics of rocks in an area (Haerudin, N, et al, 2019). The dominant frequency value is related to the depth of the reflected layer in the subsurface, which is the boundary between the sedimentary layer and the bedrock so that it can describe the thickness of the sedimentary layer composed of the sedimentary layer (Hariansyah et al., 2020). The sediment layer can be known by applying equation (2).

$$f_0 = \frac{v_s}{4H} \quad (2)$$

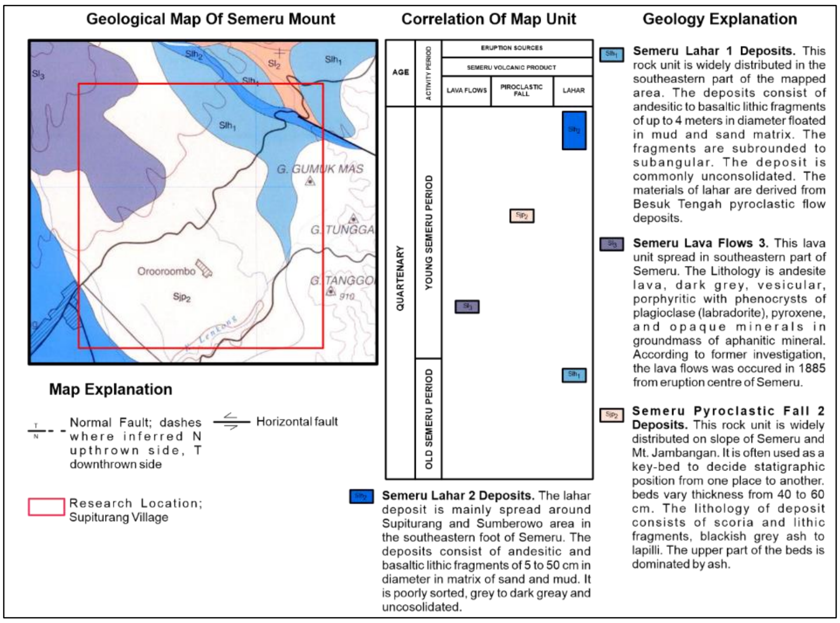

Fig 1. Local Geological Map of Semeru Mount (S. Sutawidjaja Igan, et al. 1996)

3.4. Amplification (A_0)

Amplification is the magnification of seismic waves originating from large variations in layer density (Risa et al., 2023). Amplification describes the magnitude of wave amplification as it passes through a particular medium. Amplification is the magnification of seismic waves that occurs due to significant differences between layers. The amplification factor will also increase if the rock passed by the seismic wave has been deformed in the form of weathering, folding, or displacement that can change the nature of the rock (Fadhilah et al., 2017). In the same rock, the amplification value may vary according to the degree of deformation in the weathering of the rock body. Based on this understanding, the amplification can be written in equation (3).

$$A = \frac{\rho_b v_b}{\rho_s v_s} \quad (3)$$

3.5. Shear Wave Velocity (Vs)

Soil dynamic characteristics such as estimating Vs values for multi-dimensional soil depths are conventionally used by borehole geophysical methods for seismic micro zonation (Mufida et al., 2013). Estimation of Vs and estimation of earthquake damage distribution can be used for earthquake mitigation and determination of earthquake-resistant building standards. Therefore, the Vs information from the subsurface is directly related to the stiffness property of the material.

3.5. Soil Vulnerability Index (Kg)

The seismic vulnerability index is a parameter that is strongly related to the level of vulnerability of an area from the threat of earthquake risk (Fauzatun Wachidah & Ninik Agustin, 2021). Some of the factors that affect the seismic vulnerability index include the dominant frequency value, which indicates the thickness of the sediment, and the amplification factor value, which indicates the contrast in density of the layers (Syahputri & Sismanto, 2020). The magnitude of the seismic vulnerability index (Kg) can be written with equation (4).

$$K_g = \frac{{A_0}^2}{f_0} \quad (4)$$

3.6. Ground Shear Strain (GSS)

The Ground Shear Strain (GSS) is the ability of a soil layer material to stretch and shift during an earthquake (Fatimah et al., 2019). This definition means that GSS values can be used to characterize the impact of earthquake disasters, such as ground cracks, landslides, liquefaction, subsidence, and ground shaking. According to Nakamura (2000), there is an empirical approach to determine the GSS value by using the PGA parameter with the soil susceptibility index parameter formulated in equation (5).

$$\gamma = Kg \cdot (10^{-6}) \cdot a \quad (5)$$

4. Result and Discussion

4.1. Distribution of Amplification Factors (A_0)

The amplification factor value (A_0) is the value of wave amplification due to the difference in strength or contrast between layers of different compactness. The amplification value can be influenced by several layer deformation factors such as folding, weathering, and displacement. In the same layer, there will be an amplification value if the rock is deformed. Figure 2 is a map of the distribution of amplification values in Supiturang Village. The map was created in ArcGIS 10.8 software using IDW (Inverse Distance Weighting) interpolation.

Figure 2 is an administrative map correlated with the distribution of amplification values (A_0) at 16 measurement points (indicated by black dots with codes TB1 to TB16). Each of the scattered points has a spacing between points of 400 - 500 meters. The map has a scale of 1: 204 meters with a plot area of 3 km2. Administratively, there are 4 hamlets included in the measurement location, namely Supiturang, Gemukmas, Curahkoboan, and Sumberwuluh Hamlets.

Supiturang Village has a lithological constituent in the form of passive breccia and thick tuff breccia, this is known from the

VES results obtained. The microtremor measurement results obtained in Supiturang show amplification values that vary from low to high with values of 2.76 to 8.7. This value shows the difference in contrast between bedrock and soft rock which has different density values when a layer with a large difference in density value due to being passed by waves will produce a high amplification factor value in Supiturang Village. so that it can be interpreted that the constituent layers are not compact or weathered layers. The measurement results obtained response values located in each hamlet in Table 1.

Table 1 shows that the hamlets in Supiturang Village have low and high amplification level classifications. The low level is in Dusun Gemukmas and Curahkoboan, this low value indicates that the magnification or strengthening of waves will be moderate. So that when a shock or earthquake occurs, it will produce moderate vibrations. In Supiturang and Sumberwuluh Hamlets have a high amplification value classification, high values indicate a high level of wave amplification as well. So when an earthquake or shock occurs, it will cause a large wave strength. Based on the micro zonation carried out with the classification according to S.S Arifin, the hamlets in Supiturang Village show a large level of wave amplification. Therefore, this condition has the potential for a fairly high hazard level in the event of an earthquake or shaking.

Table 1. Distribution of A_0 Value of Supiturang Village

No	Hamlets	A_0 Value	Description
1	Supiturang	6 – 8,7	High
2	Gemukmas	2,7 – 5	Medium
3	Curahkoboan	2,7 – 5	Medium
4	Sumberwuluh	4 – 8	High

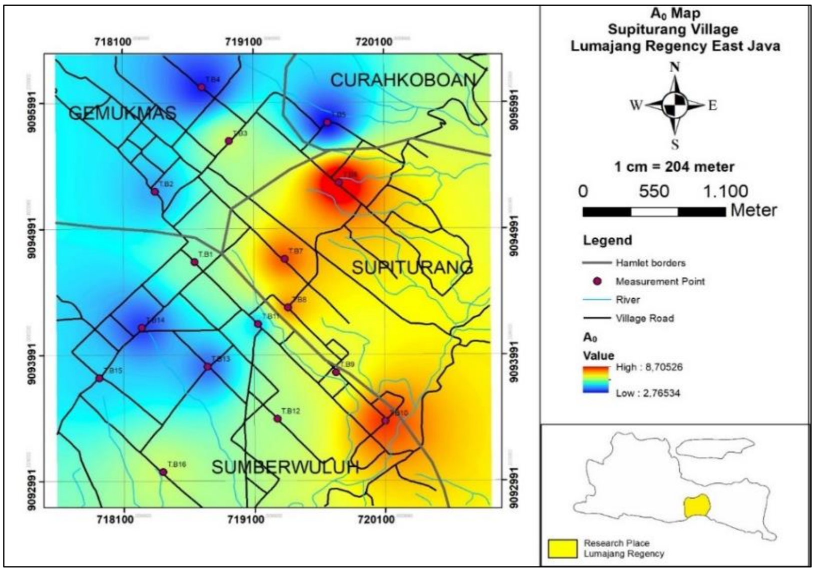

Fig 2. Distribution Map of A_0 Value of Supiturang Village

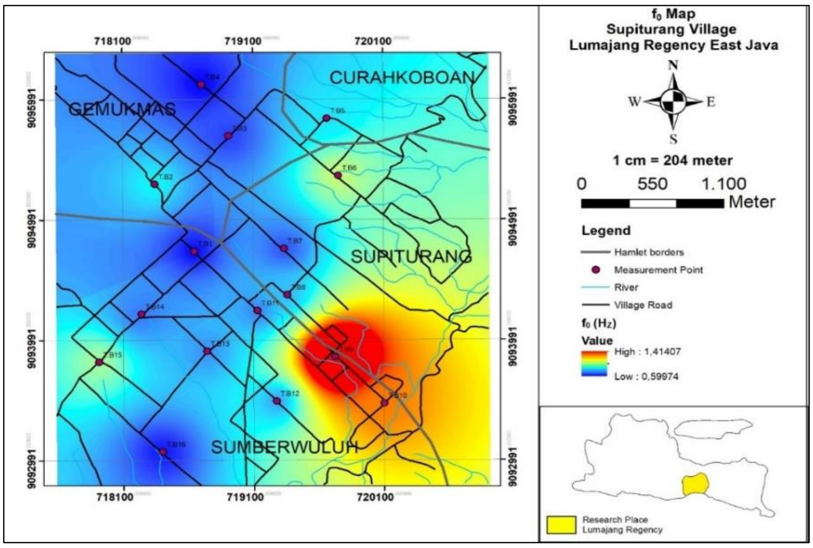

Fig 3. Distribution Map of f_0 Value of Supiturang Village

4.2. Distribution of Natural Frequencies (f_0)

The natural or dominant frequency (f_0) is the value obtained at the peak of the H/V curve. The dominant frequency value can describe the thickness of the local sediment. The natural frequency value is inversely proportional to the sediment thickness and directly proportional to the average velocity. According to equation (2), the smaller the natural frequency value, the greater the sediment thickness value. Parameter f_0 value is used as a reference in the analysis obtained in Figure 3.

Figure 3 is the dominant frequency distribution value of the dominant frequency value in Supiturang Village. The total measurement points in Supiturang Village are 16 points.

Figure 3 has a scale of 1: 204 meters with a plot area of 3 km2.

Supiturang Village has a spread of value ranges spread 0.599 Hz - 1.414 Hz. The dominance of low values is in all hamlets, namely Sumberwuluh, Gemukmas, and Curahkoboan. According to the Kanai classification, the frequency range indicates that the thickness of the sediment at the research site is thick, which is also supported by geological data that the constituent layers of the research site are formed by Semeru lava deposits that carry sedimentary material in the form of sand and tuff. In this case, the analysis can be done by referring to the micro zonation of the hamlet as in Table 2.

Table 2 shows the distribution of each dominant frequency value in each hamlet. Based on the frequency Supiturang Village has the same value. In this case, it shows that the same layer continues the value in each hamlet. In the Kanai classification, the value shows that the sediment thickness in all hamlets has a thickness of more than 20 meters. This sediment thickness will show the level of soil conditions that have the potential to experience weathering or deformation when a shock occurs. So, a large sediment layer will raise the potential for ground motion.

Table 2. Distribution of f_0 Value of Supiturang Village

No	Hamlets	f_0 Value (Hz)	Description
1	Supiturang	0,8 – 1,4	Sediments thicker than 20 meters
2	Gemukmas	0,5 – 0,8	Sediments thicker than 20 meters
3	Curahkoboan	0,8 – 1	Sediments thicker than 20 meters
4	Sumberwuluh	0,5 – 1	Sediments thicker than 20 meters

4.3. Distribution of Soil Vulnerability Index (K_g)

The Soil Vulnerability Index is the result of calculations obtained from the components of the dominant frequency value and the amplification factor of the microtremor measurement results which show the level of soil strength against deformation. The soil vulnerability index describes the strength of soil movement due to ground motion or vibration that occurs, the greater the soil vulnerability value, the higher the soil conditions when deformed.

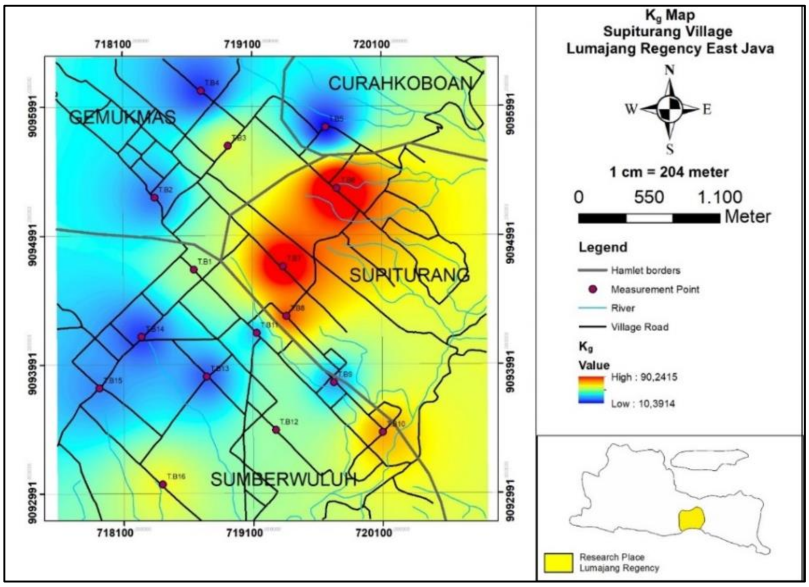

Fig 4. Distribution Map of Kg Value of Supiturang Village

Figure 4 maps the distribution of soil vulnerability index values in the Supiturang Village area. The map has a scale of 1 cm: 204 meters with 16 measurement points with a map area coverage of 3 km2. Supiturang Village has 4 hamlets on the map, namely Gemukmas, Supiturang, Sumberwuluh, and Curahkoboan.

The distribution map of the soil susceptibility index value in the Supiturang area has a dominant high value. The value is obtained by calculating the value of the dominant frequency and amplification parameters. Regarding parameter values, the 2 components have a low value in the dominant frequency and a high value in the amplification factor.

The highest value of the soil vulnerability index is in Supiturang hamlet at 90.2415 and the lowest is 10.3914 in Gemukmas hamlet. Based on the values obtained, 3 classifications can be produced which can be the potential for movement or deformation of the soil due to a vibration or wave that occurs as in Table 3.

Table 3 shows the distribution of soil vulnerability index values in each hamlet in Supiturang Village. The value is included in the low-high level. In its application, a high soil susceptibility index value indicates the soil strength in deforming due to a shock. The small value of the dominant frequency indicates the level of soil thickness, and the high amplification factor value indicates a difference in density contrast in the (weathered) layer. The Supiturang vulnerability index value is dominantly medium-high. This means that Supiturang Village will be vulnerable to shaking when an earthquake or tremor occurs.

Table 3. Distribution of K_g Value of Supiturang Village

No	Hamlets	K_g Value	Description
1	Supiturang	60 – 90	High
2	Gemukmas	10 – 30	Medium
3	Curahkoboan	10 – 40	Medium
4	Sumberwuluh	15 – 60	High

4.4. Distribution of Shear Wave Velocity (V_{S30})

Shear wave velocity (Vs) is the velocity of waves traveling in the subsurface. This Vs value illustrates the strength condition of the rock layer that becomes the medium of velocity. In this case, the Vs value is obtained through the inversion process of the HVSR curve through the ellipticity curve method so that the 1D ground profile value is obtained through the initial model determined based on the lithology data obtained through the VES geoelectric method. Then picking the average Vs value to a depth of 30 meters to determine the type of soil classified by SNI 1726 (2019).

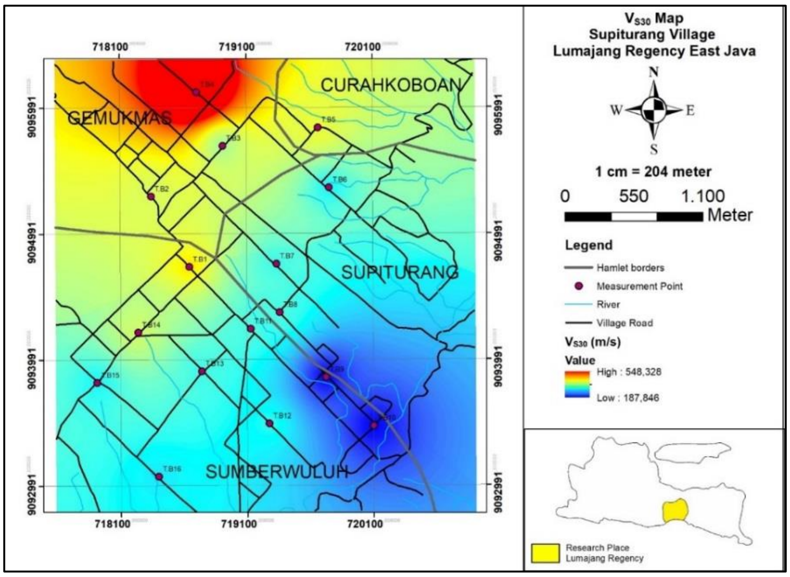

Fig 5. Distribution Map of V_{S30} Value of Supiturang Village

Figure 5 shows the distribution of V_{S30} values in Supiturang Village with 16 measurement points. The map has a scale of 1 cm: 204 meters with a research area of 3 km2. The Supiturang area has 4 hamlets included in the study, namely Supiturang, Sumberwuluh, Curahkoboan, and Gemukmas Hamlets.

The V_{S30} value in Supiturang Village has a range that varies from soft to medium soil. The value of the value distribution variation can be seen in the map with the lowest value of 187.846 m/s located in Sumberwuluh Hamlet and the highest value of 548.328 located in Gemukmas Hamlet. Based on the distribution pattern of the V_{S30} value, this shows that at a depth of 30 meters, it is still a type of soil that is not compact (sediment). The V_{S30} value of the variation in the map can be classified in each hamlet with the classification of soil types according to SNI 1726 of 2019 in Table 4.

Table 4. Distribution of V_{S30} Value of Supiturang Village

No	Hamlets	V_{S30} Value	Description
1	Supiturang	187,81 - 271,825	Medium Soil (SD)
2	Gemukmas	302,62 - 548,38	Medium Soil - Hard Soil (SD - SC)
3	Curahkoboan	322,115 - 332,33	Medium Soil (SD)
4	Sumberwuluh	188,29 - 317,17	Medium Soil (SD)

Table 4 shows the distribution of V_{S30} values in each hamlet in Supiturang Village. The distribution of V_{S30} values in each of these hamlets has a range of values that are classified as low. According to SNI 1726 of 2019, the soil classification with V_{S30} velocity is a medium soil type. This soil type is a reference that at a depth of 30 meters has a low level of soil cohesiveness. This is an interpretation that geologically the constituent layers of lithology in Supiturang Village are passive breccia and tuff breccia. So, it can be seen that the level of compactness of the layer is a medium soil with a high level of susceptibility to deformation or when it is shaken.

4.5. Distribution of *Ground Shear Strain* (GSS)

Ground Shear Strain (GSS) is the ability of a soil medium or material to experience strain or shear when shaking occurs due to an earthquake. So that the GSS value will be directly proportional to the strength of the soil when the GSS value is greater, the greater the level of soil deformation that occurs. In its application, the GSS value can show specifically the potential for liquefaction and landslides because the GSS value will describe the level of strength of soil movement that occurs when shaking or vibration occurs.

Figure 6 is a map of the distribution of GSS values in Supiturang Village with 16 measurement points with an area of 3 km2 which has a scale of 1:04. The coverage area at the Supiturang Village research location includes 4 hamlets including Supiturang, Sumberwuluh, Curahkoboan, and Gemukmas Hamlets.

The distribution of the highest GSS value is in Supiturang Hamlet at 0.000204848 and the lowest value is in Fatma's Hamlet at 0.00002349. This value can be classified according to Reza Iswara & Hardy, 2020 with information as in **Table 5.**

Table 5. Distribution of GSS Value of Supiturang Village

No	Hamlets	GSS Value	Description
1	Supiturang	2×10^{-4}	Cracking, Land Subsidence
2	Gemukmas	$3 \times 10^{-5} – 1 \times 10^{-4}$	Cracking, Land Subsidence
3	Curahkoboan	$2 \times 10^{-5} – 9 \times 10^{-5}$	Cracking, Land Subsidence
4	Sumberwuluh	$3 \times 10^{-5} – 1 \times 10^{-4}$	Cracking, Land Subsidence

Table 5 is the result of the distribution of GSS values in each hamlet in Supiturang Village. Each of these hamlets has a range of values that can be classified according to Reza Iswara & Hardy, 2020which shows that if there is a vibration or shock with the same strength there will be a soil crack and soil subsidence. This refers to the parameter that the GSS value is directly proportional to the value of the soil susceptibility index and PGA. The GSS value can be a reference that when a larger shock occurs, it will potentially cause greater damage such as liquefaction disasters.

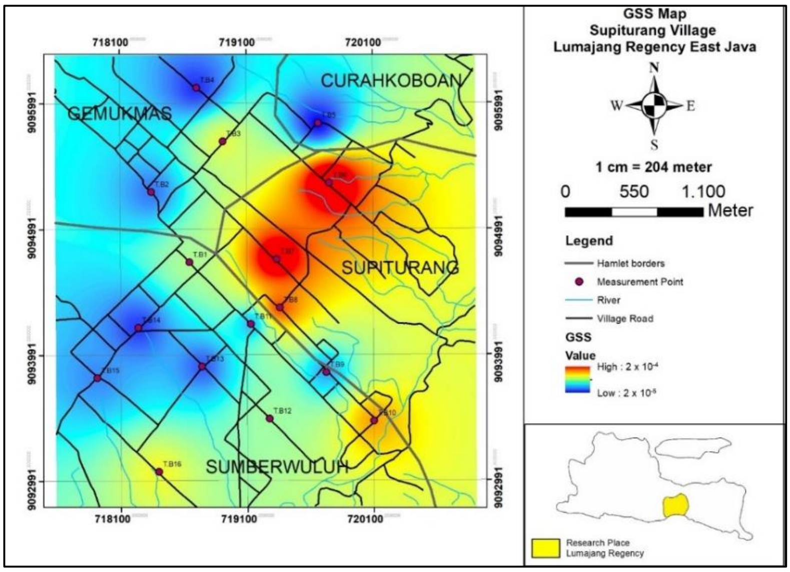

Fig 6. Distribution Map of GSS Value of Supiturang Village

4.6. Analysis of Earthquake Potential

Analysis of earthquake potential results from combining the parameters obtained in processing microtremor data results. The results are in the form of the value of the soil susceptibility index (Kg), Ground Shear Strain (GSS), amplification factor (A_0), dominant frequency (f_0), and the value of shear wave velocity 30 meters deep (V_{S30}). Combining these parameters uses class weights for each classification performed by data interpretation. The resulting score (5-20) was then used to classify the level of earthquake potential. This was done in Supiturang Village and the results were obtained as shown in Figure 7.

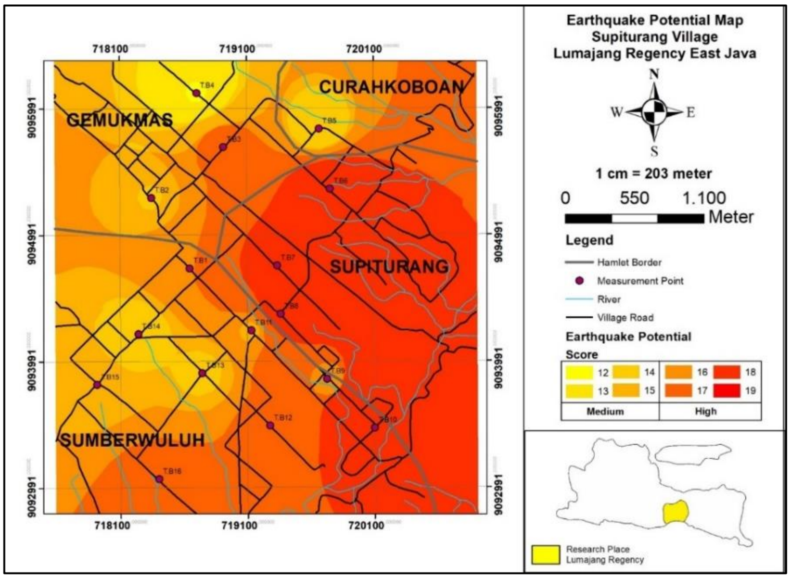

Fig 7. Distribution Map of Vulnerability Score of Supiturang Village

Figure 7 is a map of the results of the analysis of earthquake potential in Supiturang Village. The map in Figure 7 has a scale of 1: 203 meters with an area of 3 km2. There are 16 measurement points with a spacing of 500 meters covering 4 hamlets, Supiturang Hamlet, Sumberwuluh, Gemukmas, and Curahkoboan.

Table 6. Distribution of Vulnerability Score of Supiturang Village

No	Hamlets	Vulnerability Score	Description
1	Supiturang	17 – 19	High
2	Gemukmas	12 – 19	Medium – High
3	Curahkoboan	12 – 19	Medium – High
4	Sumberwuluh	12 – 19	Medium – High

Based on the distribution of scores obtained from weighting the classification of each microtremor parameter, it is found that Supiturang Village has a medium-high score. Where the lowest score is 12 and the highest score is 19. The distribution of scores in each hamlet is shown in Table 6.

Table 6 shows the distribution of the total score of the microtremor parameters. The score shows the level of vulnerability of the Supiturang Village soil to shocks caused by earthquakes. The score is obtained from the summation of each microtremor parameter used. Supiturang Hamlet has a high potential level due to the high soil susceptibility index value, moderate ground shear strain, low dominant frequency, high amplification, and low V_{S30}. While the other three hamlets have moderate to high soil susceptibility index values, moderate ground shear strain, low dominant frequency, moderate to high amplification, and low V_{S30}.

So, from the map in Figure 7, it can be seen that the yellow color zone with a score of 12 - 16 has a moderate level of vulnerability, indicating that the level of shocks experienced in the zone is medium. While the red color zone has the highest level of vulnerability with a score of 17-19, which indicates that if a shock occurs, Supiturang Hamlet experiences the highest level of deformation than the other three hamlets.

Conclusions

Supiturang Village has the results of the amplification value factor which is classified as medium-high (2.7 - 8.7), low dominant frequency value (0.5 - 1.4 Hz), medium-high soil vulnerability index (10 - 90), V_{S30} value which includes medium-hard soil (187.81 - 548.38 m/s), and GSS value which shows the response of cracks and soil subsidence to shaking (2 x 10^{-5} - 2 x 10-4). The results of the earthquake potential analysis of Supiturang Village have a medium-high earthquake potential (score 12 - 19).

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