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RESEARCH ARTICLE

Identification of Soil Characteristics in Pugung District Tanggamus Using the HVSR Method

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Abstract This study was conducted in Pugung District, Tanggamus Regency, a tectonically active zone with high earthquake shaking potential due to variations in local soil conditions. This research aims to identify subsurface characteristics and seismic microzonation based on natural frequency, dominant period, amplification, and seismic vulnerability index (K_g) parameters. Data were obtained from microtremor measurements at 39 points and analyzed using the Horizontal to Vertical Spectral Ratio (HVSR) method to determine f_0 and A_0. The results show that the natural frequency ranges from 2.05 to 11.5 Hz, reflecting variations from thick to thin sediment layers. Amplification values range from 2.84 to 10.61 times, where higher values correlate with softer sediment layers. The seismic vulnerability index (K_g) varies between 0.911 and 23.606, indicating safe zones in the northern part and high-risk zones in the eastern to southeastern areas. The dominant period ranges from 0.08 to 0.48 seconds, indicating soil characteristics from hard to very soft. These findings provide critical insights into subsurface conditions and seismic hazard levels for disaster mitigation and safe infrastructure planning.

Abstrak. Penelitian ini dilakukan di Kecamatan Pugung, Kabupaten Tanggamus, yang berada pada zona tektonik aktif dengan potensi guncangan gempa bumi tinggi akibat variasi kondisi tanah setempat. Penelitian ini bertujuan mengidentifikasi karakteristik bawah permukaan dan mikrozonasi seismik berdasarkan parameter frekuensi natural, periode dominan, amplifikasi, dan indeks kerentanan seismik (K_g). Data diperoleh melalui pengukuran mikrotremor di 39 titik lalu dianalisis menggunakan metode Horizontal to Vertical Spectral Ratio (HVSR) untuk menentukan nilai f_0 dan A_0. Hasil analisis menunjukkan frekuensi natural berada pada rentang 2,05 hingga 11,5 Hz, mencerminkan variasi ketebalan sedimen dari tebal hingga tipis. Nilai amplifikasi berkisar antara 2,84 hingga 10,61 kali, dengan nilai tertinggi berkorelasi dengan lapisan sedimen lunak. Indeks kerentanan seismik (K_g) berkisar antara 0,911 hingga 23,606, menunjukkan zona aman di bagian utara dan zona rawan di bagian timur hingga tenggara. Periode dominan tercatat antara 0,08 hingga 0,48 detik, yang mencerminkan karakteristik tanah dari keras hingga sangat lunak. Temuan ini menjadi dasar penting bagi mitigasi bencana dan perencanaan infrastruktur yang lebih aman.

1. Introduction

Sumatra Island is located along the Sunda subduction zone, where the Indo-Australian Plate subducts beneath the Eurasian Plate, causing frequent large earthquakes and volcanic activity. The impact of an earthquake on the surface is determined not only by its magnitude and distance but also by soil condition at the site. Differences in soil's physical and mechanical properties can amplify seismic waves (Amirudin et al, 2023), while indicators, such as the amplification factor (A_0), dominant frequency (f_0), and seismic vulnerability index (Kg) reflect the characteristics of soil layers in response to seismic waves (Nakamura, 1989). This study utilizes recorded microtremor data processed using the *Horizontal to Vertical Spectral Ratio* (HVSR) method to reveal the seismic micro-zonation conditions of Tanggamus based on variations in amplification, dominant frequency, and seismic vulnerability potential. This method was selected due to its non-destructive nature, efficiency, and ability to characterize subsurface layer conditions using natural ground vibrations (SESAME, 2004).

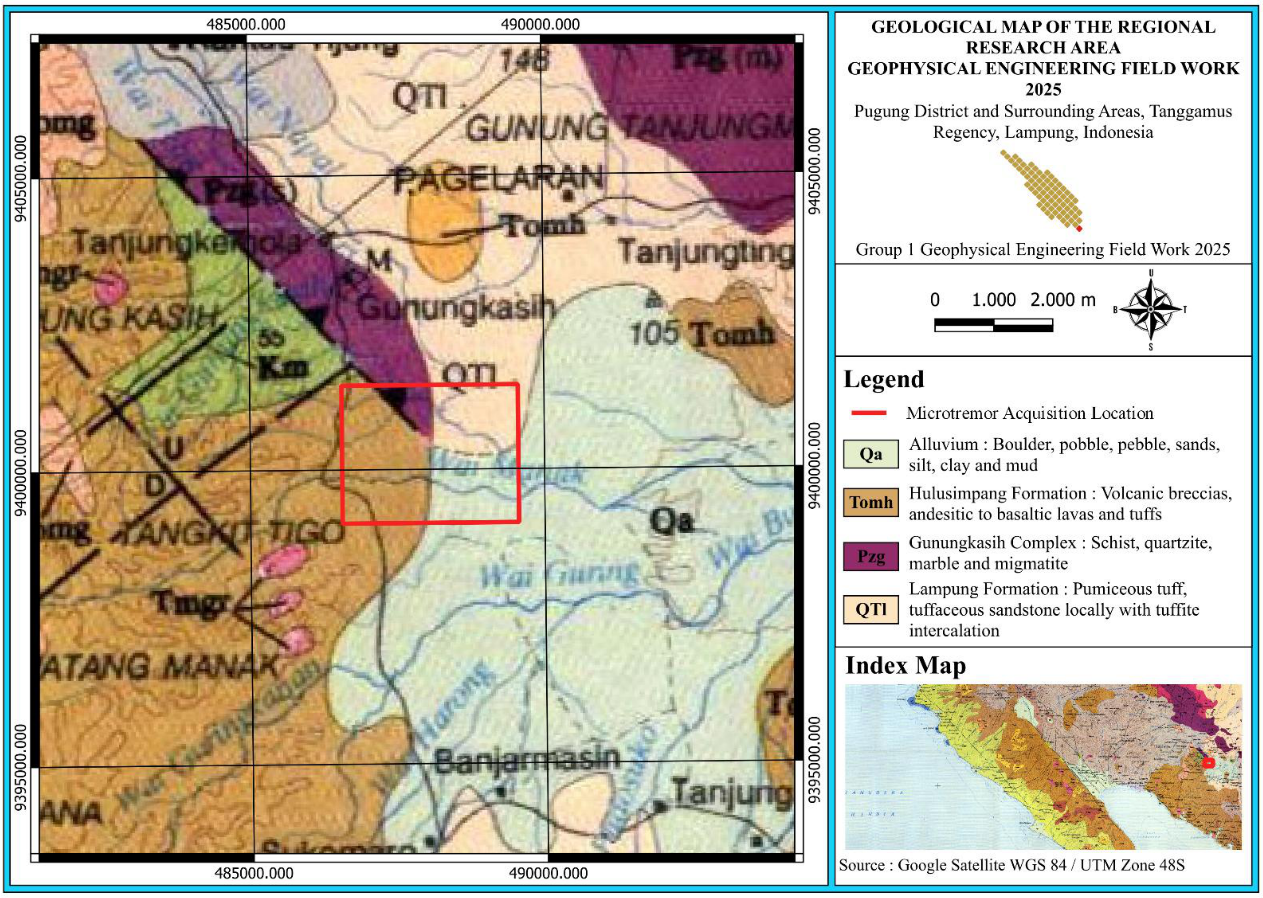


Figure 1. Regional Geological Map of Kotaagung (modified from Amin et al., 1993), with the red box indicating the study location.

The research conducted in Pugung District holds significant importance due to the limited mapping of microseismic distribution in this area. This study utilizes the Horizontal to Vertical Spectral Ratio (HVSR) method as an effort to expand the scope of previous research by Pinem et al. (2023) in Tanjung Kemala, which revealed that the eastern and northeastern parts exhibit relatively low Kg values, while the northwestern and central southwestern areas show relatively high Kg values. The research area in Pugung District exhibits greater geological complexity compared to Tanjung Kemala, as it contains the contact of four geological formation units (Amin et al., 1993). This geological complexity increases the potential risk of natural disasters, such as earthquakes, which can affect the stability of infrastructures and the sustainability of local communities.The HVSR method has proven effective in identifying geological characteristics, soil layer dynamics, and potential seismic hazards, as demonstrated by studies conducted by Darmawan et al. (2022) and Rananda et al. (2020). Therefore, this research aims to identify the distribution of f_0, A_0, Kg, and T_0 in the Pugung area. By understanding the soil characteristics and seismic vulnerability in this region, this study is expected to contribute to a broader understanding of seismic vulnerability in the Tanggamus area.

The study area comprises four different unit formations: Alluvium, Hulu Simpang Formation, Gunung Kasih Complex, and Lampung Formation. The metamorphic rocks of the Gunung Kasih Complex (Pzg) are interpreted as the oldest geological unit in the Kota Agung sheet, consisting of pelitic schist with minor gneiss. In addition, there is the Sidodadi Quartzite Unit, which contains quartzite with sericite schist-quartzite interbeds, as well as the Jundeng Migmatite Unit, composed of granitoid, schist, and gneiss intruded by granite veins. The Hulu Simpang Formation (Tomh) dates to the late Oligocene–early Miocene and was deposited in a transitional environment from land to shallow marine, consisting of volcanic breccia, lava, and andesitic–basaltic tuff, which are altered, quartz-veined, and contain sulfide minerals. The Lampung Formation (QTl), dates to the Plio-Pleistocene, is composed of pumice tuff, tuffaceous sandstone, with occasional tuffite interbeds formed in terrestrial to fluvial environments. Topographic variations up to 40 meters above sea level have led to the accumulation of alluvial deposits in the area, consisting of gravel, pebbles, sand, silt, and clay (Amin et al., 1993).

The Horizontal to Vertical Spectral Ratio (HVSR) method is used to determine the characteristics of the local soil response through three main parameters, namely the dominant frequency (f_0), dominant soil period (T_0), amplification factor (A_0), and seismic vulnerability index (Kg). The dominant frequency (fundamental frequency) is defined as the frequency at which the H/V curve shows a stable and significant peak with a location of high impedance contrast between sediment and bedrock, the H/V curve usually produces a clear peak at the frequency f_0 (SESAME Project, 2004). The value of the dominant frequency (f_0) of an area is influenced by several factors, namely the thickness of the sediment layer and the subsurface average velocity (vs), so it can be written as:

$$f_0 = \frac{Vs}{4H} \tag{1}$$

Where is the dominant frequency (Hz), Vs is the average s-wave or shear wave velocity (m/s), and H is the sediment layer thickness (m).

The dominant period is closely related to the depth of the soft sediment layer (Nakamura, 1989). A high period indicates thick soft sediment, and conversely, a low dominant period indicates thin soft sediment. Areas with a high dominant period generally have a high vulnerability to experiencing regional damage if struck by an earthquake. The dominant period is obtained from the derivative of the Natural Frequency (f_0) value formulated as:

$$T_0 = \frac{1}{f_0} \tag{2}$$

where T_0 is the dominant period (s) and f_0 is the dominant frequency (Hz). This parameter is an implementation to characterize the geology at the research location.

The amplification factor (A_0) is the peak value of the H/V curve at the dominant frequency f_0, which describes the soil's ability to amplify seismic waves due to local geological conditions. The A_0 value arises as a result of the seismic impedance contrast between the soft sediment layer and the harder bedrock, resulting in amplification of ground vibrations at certain frequencies (SESAME Project, 2004). The magnitude of the soil amplification value is related to the impedance contrast of the layer at the surface and the layer below. When the impedance contrast between these layers is high, there is a high amplification factor, and vice versa. So, the relationship between the impedance contrast. comparison function can be expressed as follows:

$$A_0 = \frac{\rho_b V_b}{\rho_s V_s} \tag{3}$$

Where A_0 is the amplification factor, ρ_b is the bedrock density (m/s), V_b is the bedrock wave propagation velocity (m/s), ρ_s is the sediment density (m/s), and V is the sediment velocity (m/s). Soils with large impedance contrasts generally produce high amplification (A_0) values, so that seismic waves can be amplified when they reach the surface and increase the potential for structural damage. This amplification occurs due to differences in elastic properties between the soft sediment and the harder bedrock. Based on microtremor research in East Padang Panjang, A_0values are classified into three main categories:

Table 1. Classification of amplification factor values

Zone	Classification	Amplification Factor Value
1	Low	$A_0 < 3$
2	Medium	$3 \leq A_0 < 6$
3	High	$6 \leq A_0 < 9$
4	Very High	$A_0 \geq 9$

Nakamura (1989) states that an area's the seismic vulnerability index (Kg) is a derived parameter that combines the influence of the dominant frequency (f_0) and the amplification factor (A_0) to describe the level of vulnerability of a soil layer to deformation due to an earthquake. The level of building damage is directly proportional to the soil vulnerability index (Kg). The seismic vulnerability value can be calculated using the equation:

$$K_g = \frac{A_0^2}{f_0} \tag{4}$$

The seismic vulnerability index (Kg) is used to identify areas potentially experiencing large amplification at low frequencies, which is particularly dangerous for tall buildings (Elizha et al., 2024). A high Kg value indicates that the combination of large amplification and low frequencies can increase the risk of structural damage in that area (Elizha et al., 2024). The Kg value becomes large when A_0 is high and f_0 is low, indicating that the soil amplifies low-frequency vibrations, which are particularly dangerous for multi-story buildings.

The classification of seismic vulnerability index values can be seen as follows:

Table 2. Classification of seismic vulnerability index

Type	Seismic vulnerability index value	Classification
I	$K_g < 3$	Low
II	$3 < K_g < 6$	Medium
III	$K_g > 6$	High

This concept is in line with the basic principles of HVSR in the SESAME document (2004) which explains that the peak of the H/V curve (A_0) appears due to the impedance contrast between sediment and bedrock and is directly related to changes in seismic wave amplitude, while the dominant frequency (f_0) reflects the resonance properties of the soil layer against earthquake waves.

2. Data and Methods

In this study, microtremor data obtained from acquisitions in Pugung District and its surroundings, Tanggamus Regency, Lampung Province, Indonesia, were used. The data were then processed using the Horizontal to Vertical Spectral Ratio (HVSR) method. The basic concept of the HVSR method is the similarity between the horizontal-to-vertical spectral ratio and the transfer of waves from the bedrock to the surface (Nakamura, 1989). An important parameter produced by the HVSR method is the dominant frequency and soil amplification, which are the peak values of the HVSR curve, related to the local geology and subsurface physical parameters (Sungkono and Santosa, 2011). The dominant frequency is the frequency value that frequently occurs and is therefore considered as the frequency of a layer of rock in a given area; in other words, the dominant frequency can indicate the type and characteristics of rocks in an area. Amplification is the magnification of seismic waves that occurs due to significant differences between layers; in other words, seismic waves will become amplified when traveling through a softer medium compared to the initial medium they passed through.

Measurements were conducted using a total of 39 data points in this study. From the processing results, there were 25 points that met the criteria and 14 points that did not meet the criteria for reliable curve and clarity or clear peak according to the SESAME (2004), as well as 1 point that was discarded because it could not be used due to longitude and latitude measurement errors. The measurement points used in the study can be seen on the acquisition design map in Figure 2.

The microtremor data obtained was then processed using the Geopsy software to obtain the average H/V spectrum values from the vibration recordings whose data had been previously prepared. This Geopsy software provides an HVSR curve graph, which includes the dominant frequency value and the peak of the HVSR curve (soil amplification). In this processing, there are several steps to obtain the HVSR curve, including windowing to divide the signal into smaller parts aimed at extracting the microtremor signal from the recorded data and reducing interference or noise present in the signal. Noise in the microtremor signal can appear as sudden amplitude spikes. The windowing process is carried out by applying a window with a width of 60 seconds based on the SESAME (2004) guidelines.

Next, there is a Fast Fourier Transform (FFT) process to convert the data from the time domain to the frequency domain. Then, there is a smoothing stage using a bandwidth coefficient of 40 based on the guide by Konno & Omachi (1998). The smoothing process is carried out to obtain a smoother HVSR curve. After that, the H/V calculation is performed, and data deemed poor is rejected. Subsequently, an HVSR curve will be obtained, which will be processed to obtain the values of f_0, T_0, A_0, and Kg.

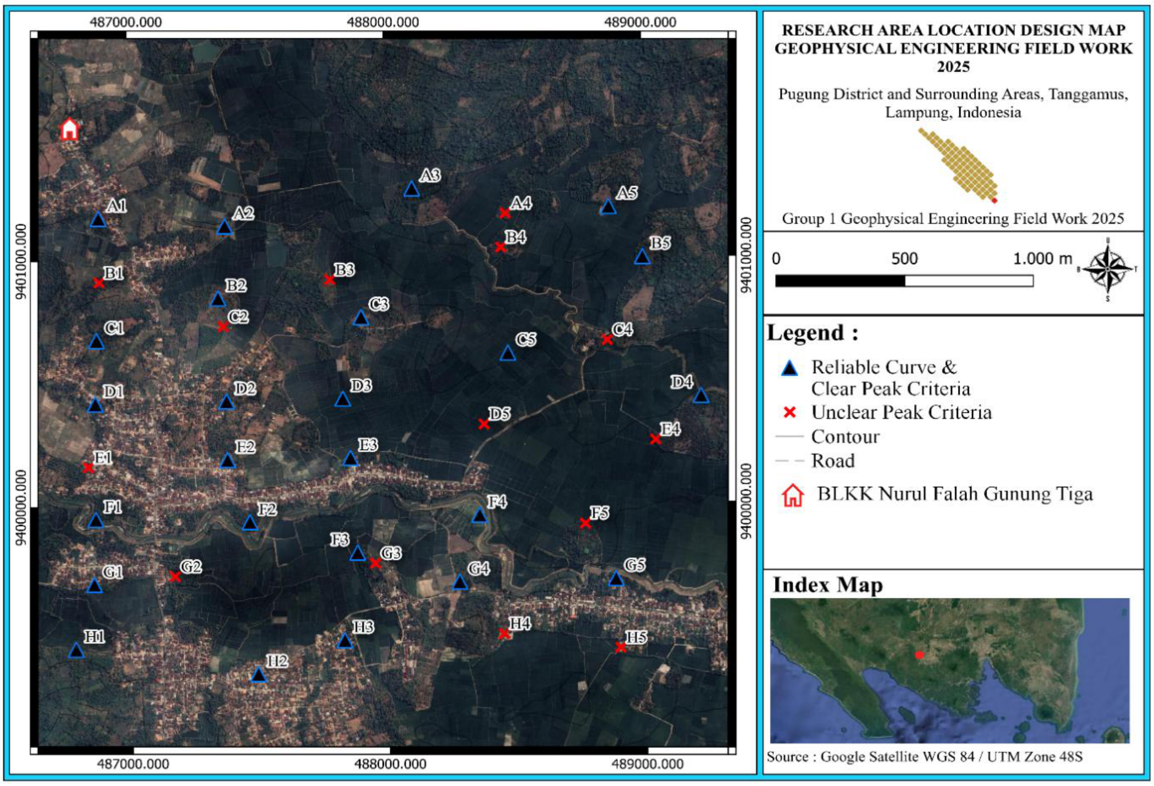


Figure 2. The measurement point locations used in the research

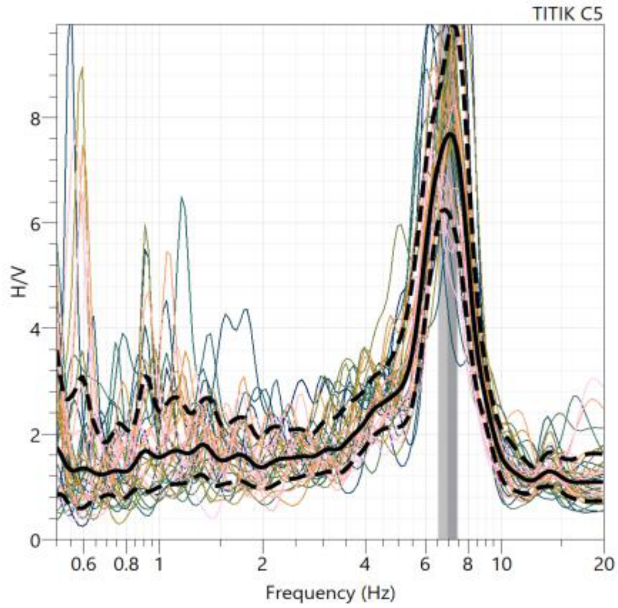
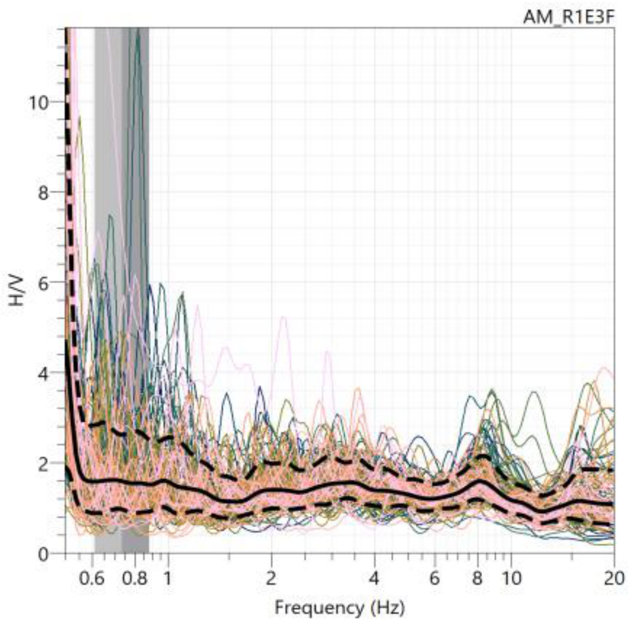
3. Results and Discussion

3.1 Results

Based on the data processing results, 39 HVSR curves were obtained from all measurement points. These results indicate variations in the shape of the curves, as depicted in Table 3. At measurement point C5, the HVSR curve exhibits a clear peak, which generally indicates a difference in impedance between two subsurface layers at a certain depth. Meanwhile, at point B4, the HVSR curve appears flatter, reflecting relatively uniform soil conditions or a high degree of homogeneity. These curves provide a picture of the different subsurface characteristics at each measurement location.

Microtremor signal measurements produce natural frequency parameters (f_0) and amplification values (A_0) which are used to analyze soil characteristics in the research area which are modeled in the form of a distribution map of dominant frequency values (f_0), amplification values (A_0), seismic vulnerability index (Kg), and dominant soil period (T_0). Each parameter is classified based on its type, kind, and value range, then its percentage is calculated against the total area of the research area.

Table 3. Example of HVSR Curve from measurement results

	HVSR Curve	Criteria
C5		f_0 = 6.97909 A_0 = 7.65183 Criteria Reliable i. Pass ii. Pass iii. Pass Criteria Clear Peak i. Pass ii. Pass iii. Pass iv. Pass v. Pass
B4		f_0 = 0.73389 A_0 = 1.58445 Criteria Reliable i. Pass ii. Pass iii. Pass Pass Criteria Clear i. Fail ii. Pass iii. fail iv. Pass v. Pass

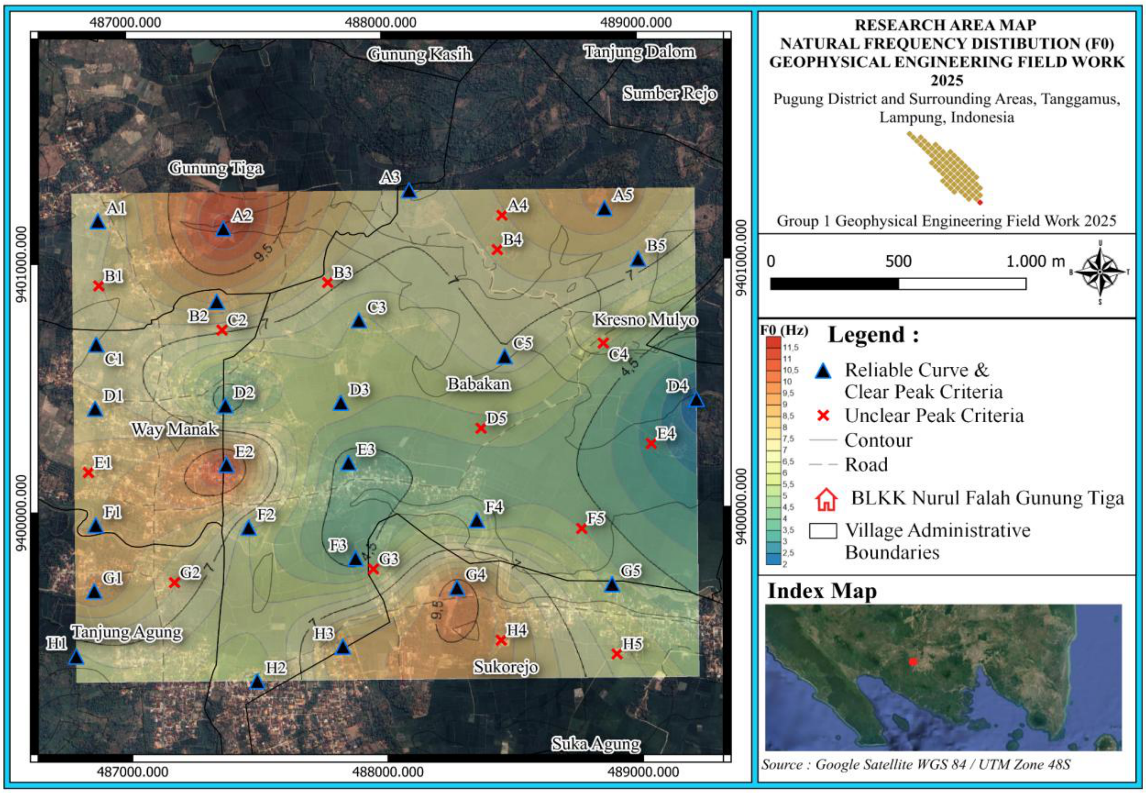


Figure 3. Distribution Map of f_0

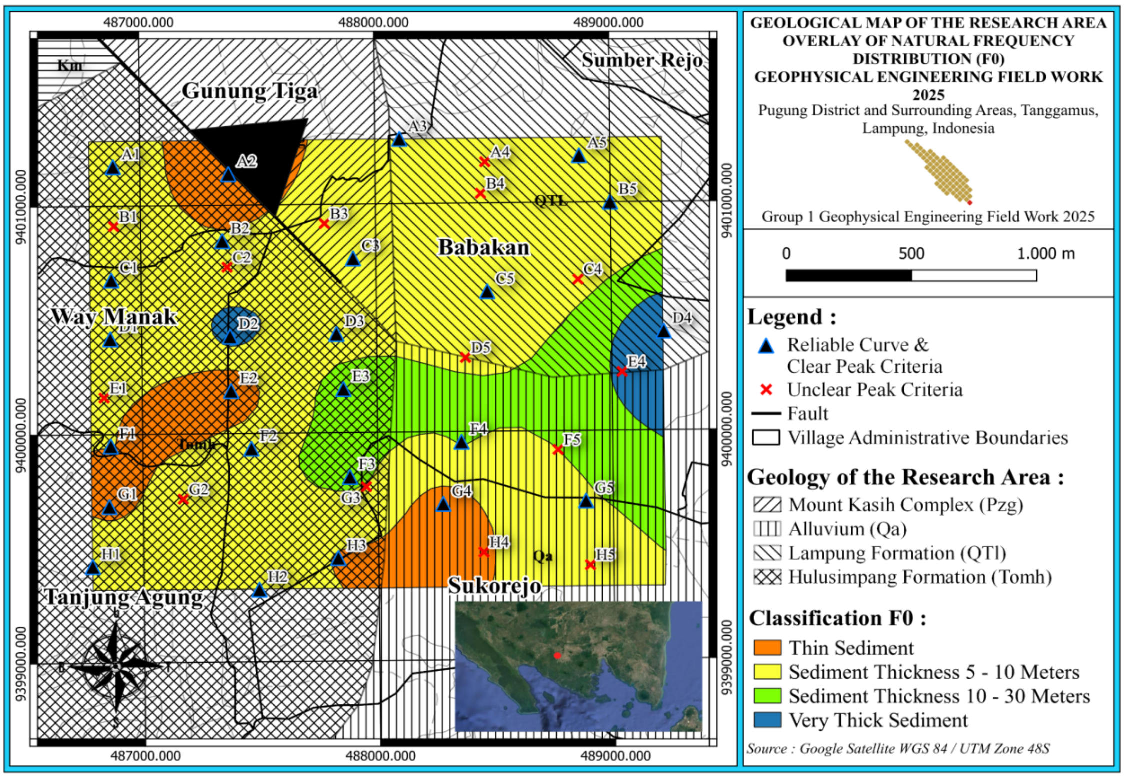


Figure 4. Geological map of the research area overlaid with a natural frequency classification map (f_0)

Table 4. Natural frequency value (f_0) of Pugung District, Tanggamus

Soil Classification	Type	Measurement Point	f_0(Hz)	Description
IV	I	C5, A3, A1, C1, B5, D1, F1, B2, H3, G1, A5, G4, A2, E2	6.979 - 11.5	Surface sediment is very thin, dominated by hard rocks
	II	E3, F4, G5, H2, C3, F2, D3	4.046 - 6.372	Surface sediment thickness is medium, about 5 – 10 m
III	III	D2, F3	3.543 - 3.896	Surface sediment is thick, about 10 – 30 m
II	IV	D4	2.055	Surface sediment is very thick

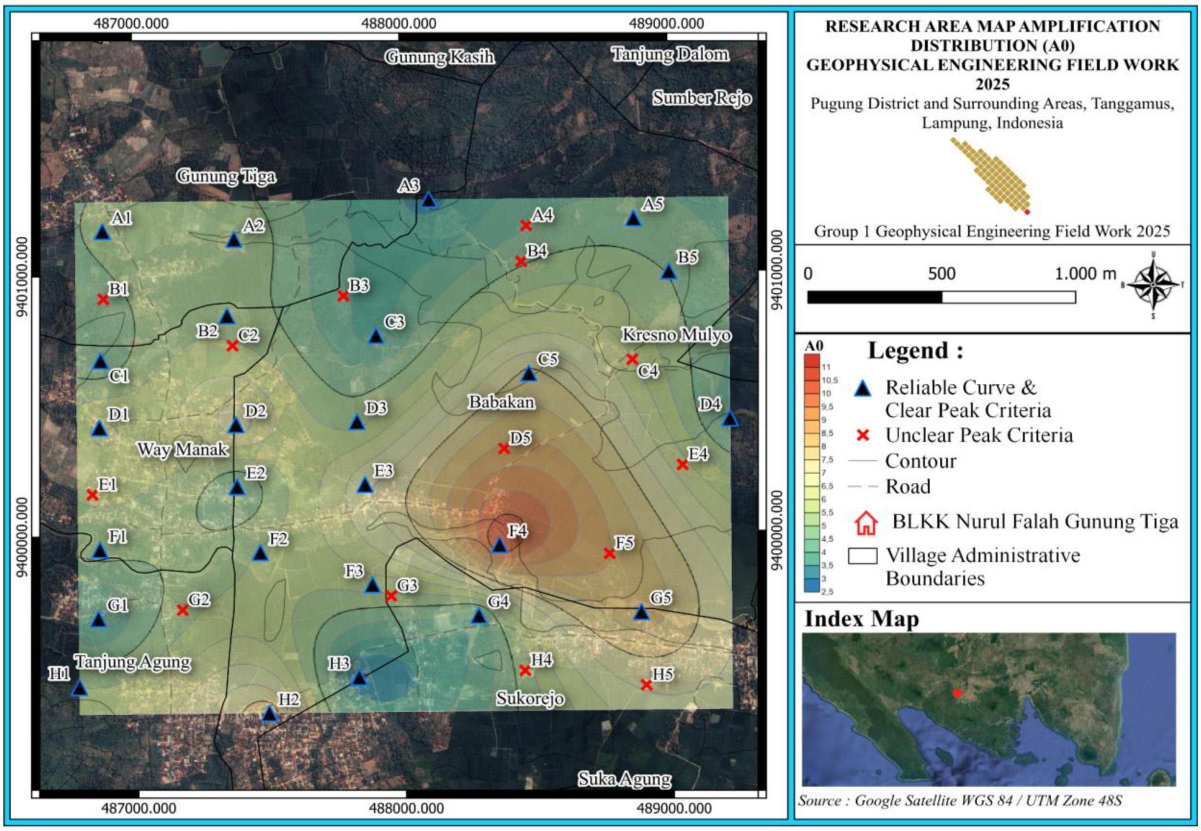


Figure 5. Distribution Map of A_0

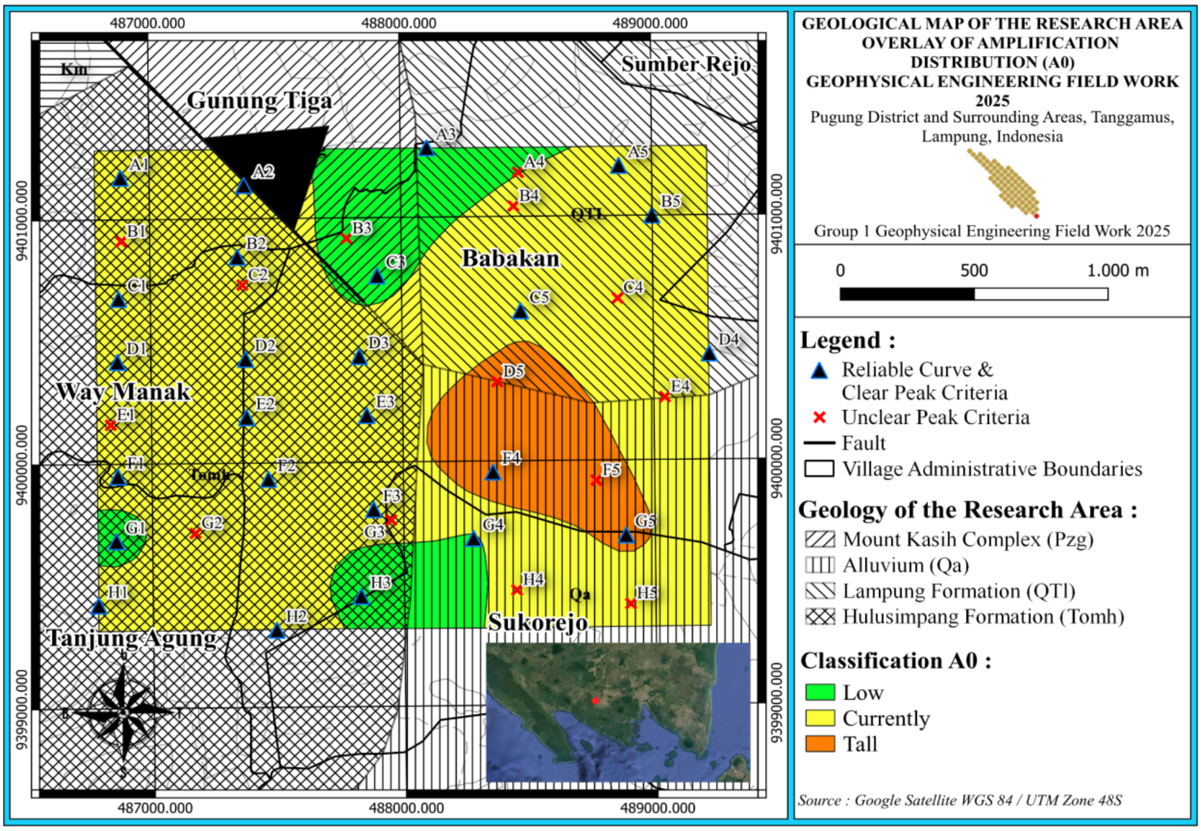


Figure 6. Geological map of the research area overlaid with an amplification classification map (A_0)

Table 5. Amplification factor value (A_0) of Pugung District, Tanggamus

Measurement Point	Classification Amplification	Amplification (A_0)	Zone
H3	Low	2.849	I A_0 (<3)
A3, C3, G1, G4, D4, E2, C1, A5, B5, A1, F1, D3, B2, H1, F2, A2, F3	Medium	3.323 - 5.796	II ($3 \leq A_0 < 6$)
D1, D2, E3, C5, H2, G5, F4	High	6.133 - 10.617	III ($6 \leq A_0 < 9$)

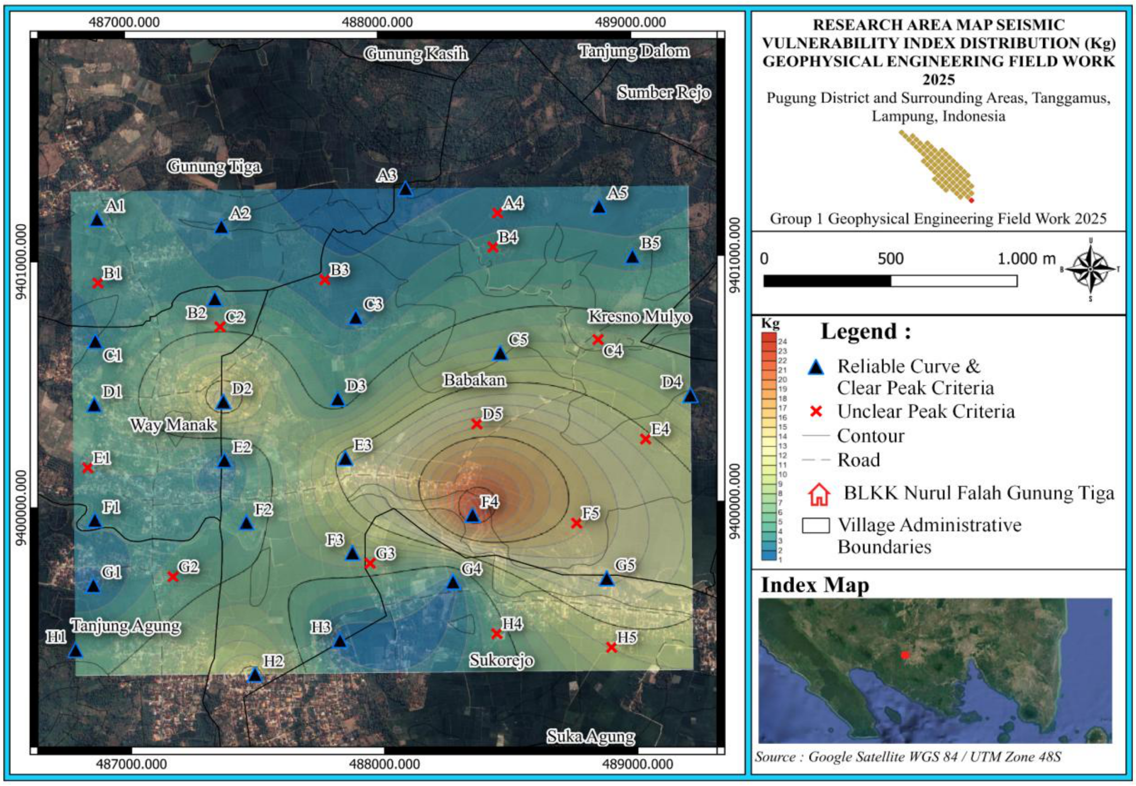


Figure 7. Distribution Map of Kg

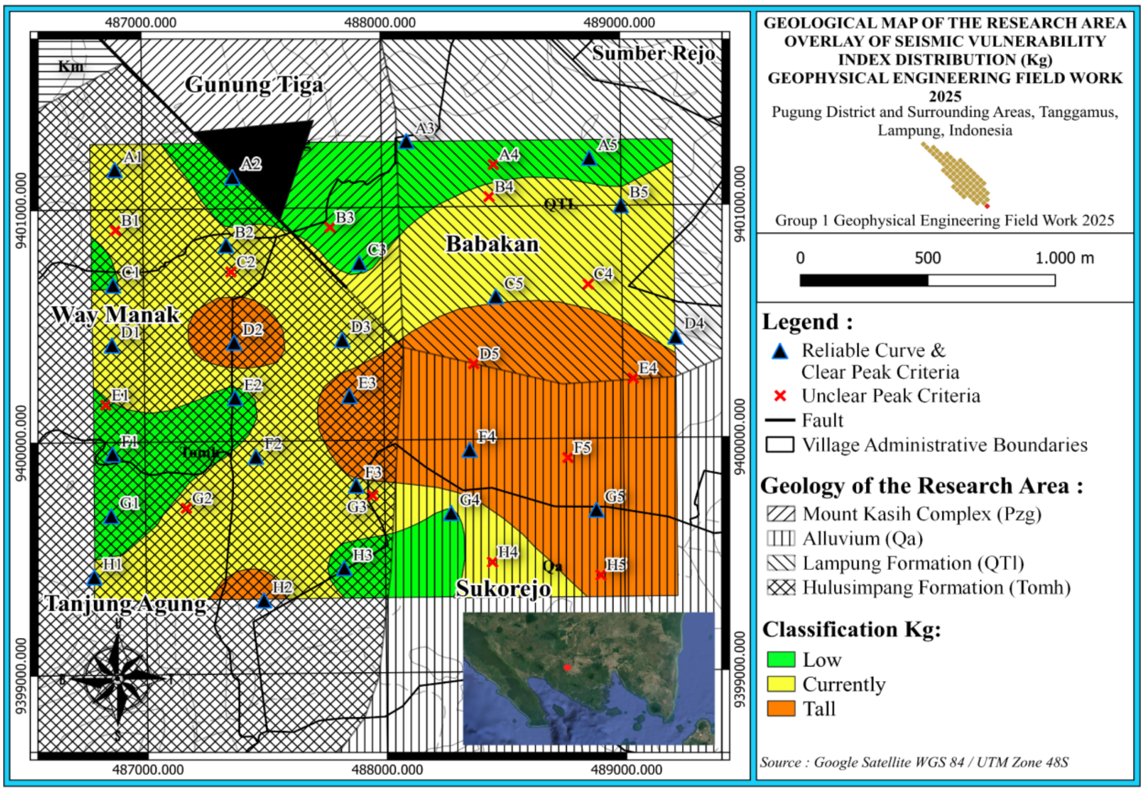


Figure 8. Geological map of the research area overlaid with a seismic vulnerability index classification map (Kg)

Table 6. Seismic Vulnerability Index (Kg) Value of Pugung District, Tanggamus

Measurement Point	Classification Index (Kg)	Seismic vulnerability	Zone
H3, G1, A3, E2, G4, C3, A5, A2, C1	Low	0.911 - 2.829	I Kg (<3)
B2, F1, B5, A1, D3, H1, D1, F2	Medium	3.323 - 5.160	II ($3 \leq Kg < 6$)
D4, C5, F3, H2, E3, G5, D2, F4	High	8.344 - 23.606	III ($6 \leq Kg < 9$)

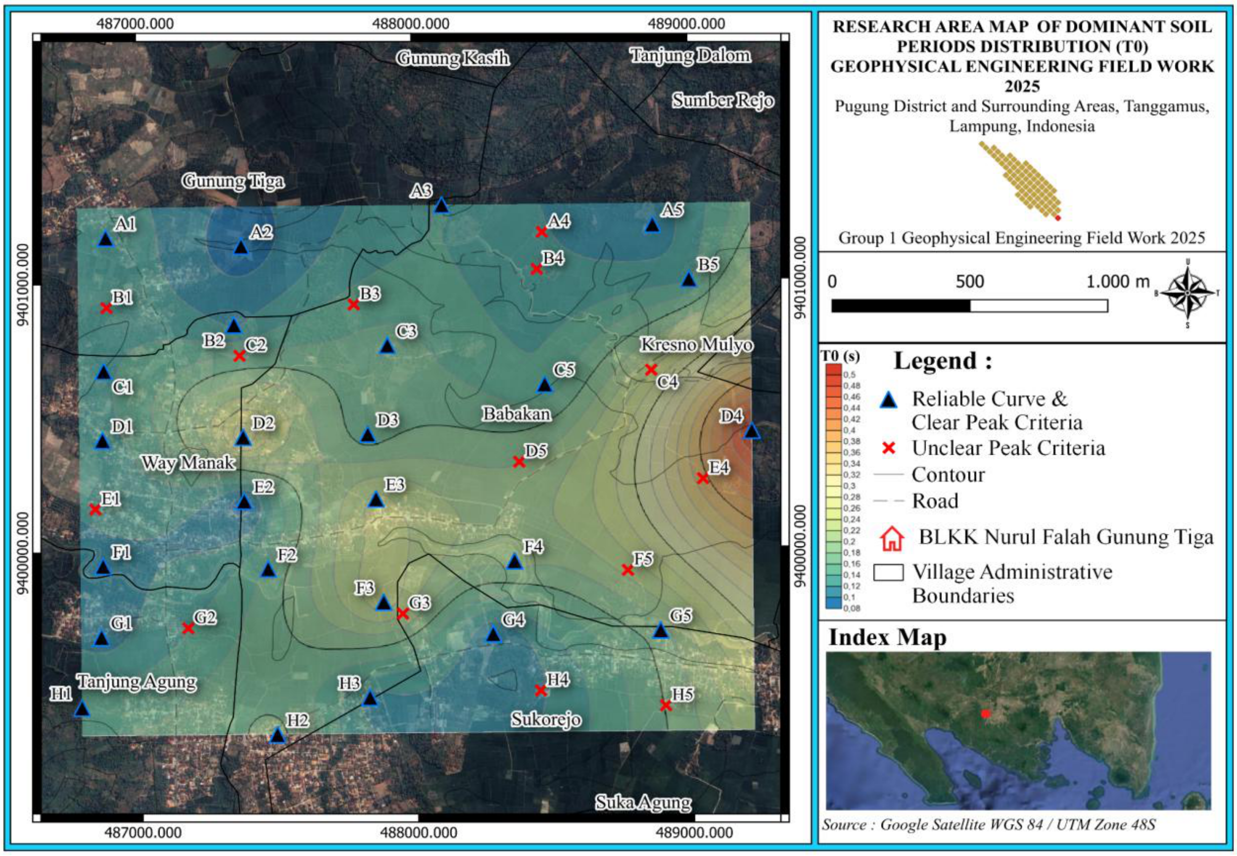


Figure 9. Distribution Map of T_0

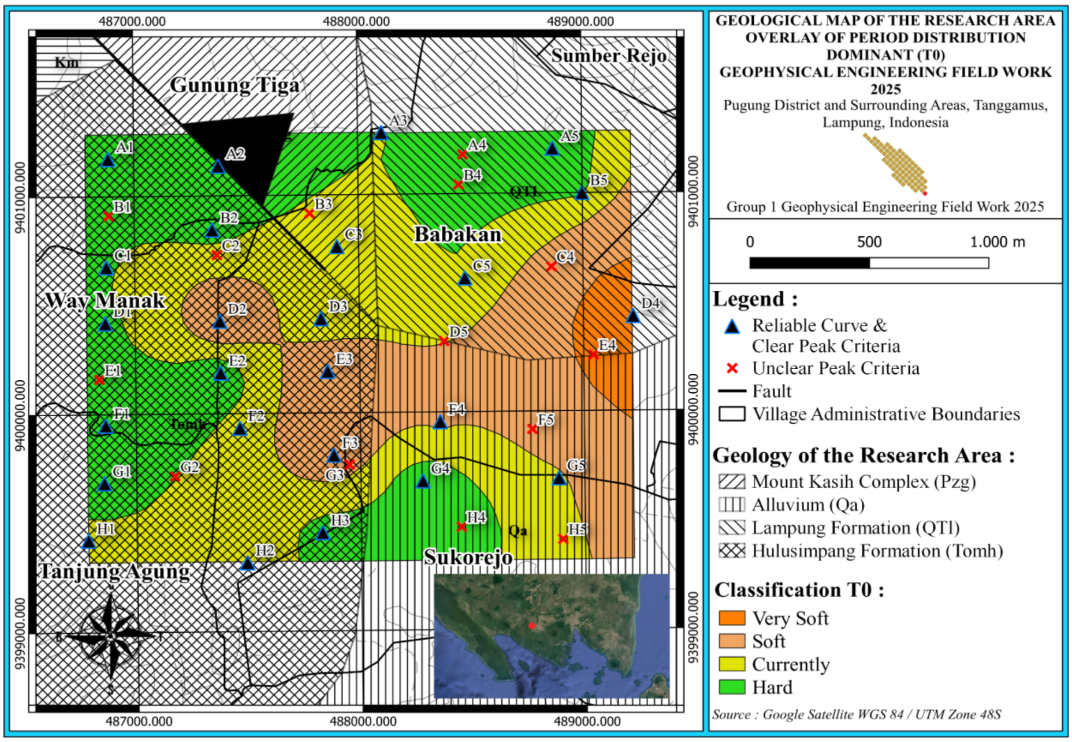


Figure 10. Geological map of the research area overlaid with a dominant soil period classification map (T_0)

Table 7. Dominant Soil Period (T_0) Value of Pugung District, Tanggamus

Soil Classification		Classification	Dominant Periods (s)	Character
Kanai	**Omete-Nakajima**			
Type I	Type A	E2, A2, G4, A5, G1, H3, B2, F1, D1, B5, C1, A1, A3, C5	0.08 - 0.143	Hard
Type II		H1, D3, F2, C3, H2, G5, F4, E3	0.156 - 0.247	Currently
Type III	Type B	F2, D2	0.256 - 0.282	Soft
Type IV	Type C	D4	0.486	Very Soft

3.2 Discussion

Natural frequency is the natural frequency or dominant frequency that frequently occurs in a region. The value of this natural frequency is related to the thickness of the sediment layer. The natural frequency value reflects the geological characteristics of the study area based on the soil response to earthquake vibrations. The magnitude of the natural frequency is greatly influenced by the condition of the subsurface structure. Pugung District, Tanggamus Regency has a variety of natural frequency values, with a minimum value of 2.05 Hz located to the east at point D4, marked in blue on the color bar. Meanwhile, the maximum value is 11.5 Hz located to the west at point E2 and northwest, precisely at point A2, marked in red. A high natural frequency usually indicates an area with thin sediment and relatively hard soil conditions. Conversely, a low natural frequency indicates the presence of thicker sediment and softer soil structure. This difference in value is related to the depth of the reflection plane below the surface, namely the boundary between the sediment layer and the bedrock that determines the vibration response. A map of the distribution of natural frequency values in the study area can be seen in Figure 3.

Based on Figure 4 and referring to the classification explained by Ariyanto et al. (2024), the study area is dominated by intermediate sediments or type IV, which on the map are shown in yellow and orange, distributed fairly evenly in the Gunung Kasih Complex Formation (Pzg) and the Lampung Formation. Referring to the regional geological map of Kota Agung by Amin et al. (1993), the thickness of the Pzg Formation is estimated to reach around 2500 meters, while the QTl Formation has a thickness of around 200 meters. The area with very thick sediments, represented by the blue color, is seen in the Lampung Formation.
Information on the formation thickness indicates that the QTl Formation tends to have softer layers.

The area categorized as low natural frequency is east of Babakan Village. Areas with medium natural frequency values, namely between 4,046 and 6,372 Hz, are Way Manak and Margomulyo Villages. High dominant frequency values ranging from 6,979 to 11.5 dominate in several areas, including parts of Gunung Tiga and Sukorejo Villages. Analysis of the distribution of dominant abundance in the Pugung District, Tanggamus, shows the dominance of soil types I and II based on the Kanai classification in Table 4, which includes hard and medium rock types. Areas with high dominant abundance tend to consist of harder soil and thin sediment layers.

In addition to natural frequencies, the H/V curve also provides information on the amplification value (A_0). The amplification factor is related to rock density. This parameter describes the extent to which seismic waves are amplified due to the impedance difference between the bedrock and the overlying sedimentary layer. The magnitude of amplification is inversely related to the shear wave velocity; the lower the wave velocity, the higher the amplification (Nakamura, 2008). The density of the rocks in the study area will affect the wave velocity value.

Based on the distribution of Amplification (A_0) values in Figure 5, it can be seen that the amplification level in the study area varies from low to high with a range of approximately 2.84 to 10.61 times amplification. This variation is related to wave speed which is influenced by rock density; when rock density is low, waves will propagate more slowly, resulting in greater amplification. Areas with low amplification are found in the south and north, especially around points H3 and A3, indicated by the blue color. Moderate amplification is seen in the east at point C1 and in the middle at point E3, marked in yellow. Meanwhile, the zone with high amplification is in the southeast at point E4, shown in red.

Based on Table 5, Pugung District generally has a moderate amplification value, which is included in zone II with a range of 3,323 to 5,796 times the amplification. High amplification values indicate the potential for greater damage during an earthquake, because areas with high amplification are able to amplify the seismic waves they receive, while low amplification tends to cause a smaller impact. Therefore, as seen in Figure 5, the areas around points D1, D2, E3, C5, H2, G5, and F4 require caution and are advised not to construct large and tall buildings. This condition can also be confirmed by calculating the seismic vulnerability index (Kg). Theoretically, the higher the A_0 value, the greater the impedance contrast in that area. Conversely, a small A_0

value indicates a low impedance contrast. However, the final interpretation is still influenced by the shear wave velocity to determine whether the constituent material is a soft or more compact layer.

According to Setiawan (2009), amplification values are divided into several categories. First, areas with amplification values <3, indicated in green on the map, are generally located in the northern and southern parts. This region is interpreted as having low impedance contrast between the lower and upper layers. Second, the moderate amplification category, with a range of 3 to 6, is indicated in yellow and is spread across almost all formations on the map. Third, the high amplification category, with values 6 to 9, is shown in orange and is located in the southeastern part of the map; this area shows high impedance contrast between the lower and upper layers. Based on Figure 6, it can be seen that regional geological conditions do not have a significant influence on amplification values. The four existing formations generally show moderate amplification values. This situation is likely influenced by local factors or local conditions that cause uniformity in these amplification values.

The seismic vulnerability index provides an overview of the level of vulnerability of the research area, namely Pugung District, Tanggamus, to the potential impact of earthquakes. The seismic vulnerability index value is calculated using the equation . From this equation, it can be seen that the natural frequency and amplification factor have a significant influence on the magnitude of the vulnerability index. When amplification is high and the natural frequency is low, the seismic vulnerability index value will increase, and conversely, the seismic vulnerability index will decrease if the amplification is low and the natural frequency is high. Based on the analysis results, this vulnerability index shows a pattern that is comparable to the amplification factor and inverse to the dominant frequency value. As can be seen in Figure 7 which shows the results of the distribution of seismic vulnerability index values in the research area. Based on the research data that has been obtained, the seismic vulnerability index value spread across Pugung District, Tanggamus ranges from 0.911 to 23.606. The area with the lowest value, namely 0.911 at point H3, is in the southern part, while the highest value, reaching 23.606 at point F4, is in the southeastern region. A low seismic vulnerability index generally indicates a more compact soil layer, reducing the impact of earthquake shaking. Conversely, a high index value indicates a softer layer, potentially causing more significant damage.

Based on the seismic vulnerability index (Kg) distribution map in Figure 7, the study area can be divided into three main categories according to the classification of Refrizon et al. (2013). Zones with low Kg values (<3) are shown in green and are spread across several areas, particularly in Tanjung Agung Village, the southern and southeastern parts of Sukorejo Village, and the northeastern part of Babakan Village. These areas are interpreted as safe zones because they have relatively compact subsurface conditions so that earthquake shocks are not significantly amplified. Furthermore, zones with medium Kg values (3–6) depicted in yellow dominate the center of the map, covering most of Way Manak Village, the central part of Babakan Village, and the central–northern part of Sukorejo Village. Meanwhile, zones with high Kg values (>6) marked in orange are seen occupying areas in the eastern and southeastern parts of the study area. Areas included in this category include the eastern and southeastern parts of Sukorejo Village, as well as the southern part of Babakan Village, with several small dots also appearing in the Way Manak area. This zone is classified as a danger zone because the conditions of the lower layers tend to be softer, thus having a greater potential to amplify earthquake shocks.

Figure 8 shows that, based on the classification of Kg values in Table 6, the study area is dominated by a safe zone marked in green and located in the northern part of the map, and a danger zone indicated in orange in the western part of the map. Going forward, these areas should be studied more deeply and carefully considered in construction planning, so that development carried out around the danger zone can be carried out in a safer and more planned manner.

The dominant period is obtained through calculations using the dominant frequency parameter, and this value is closely related to the depth of the soft sediment layer (Nakamura, 1989). Figure 9 below displays the distribution of dominant periods in Pugung District, Tanggamus. From the results of processing the measurement data points, the dominant period identified in the area shows variations with a range of 0.08 to 0.48 seconds. The lowest value was found in Way Manak Village at point E2, namely 0.08 seconds, which is visualized in blue. Meanwhile, the highest dominant period value of 0.48 seconds is in the eastern part of Babakan Village and is depicted in red.

In general, a high dominant period value indicates the presence of a soft sediment layer with a greater thickness, while a low dominant period value indicates the presence of harder sedimentary material. This understanding refers to the opinion of Kanai and Omete-Nakajima regarding the classification of soil types based on their dominant period. The soil classification in the study area based on the dominant period value can be seen in Table 7. The area has a variety of soil characteristics, ranging from hard soil, medium soil, soft soil, to very soft soil. This soil condition is closely related to the response to earthquake shocks. In hard soil, earthquake vibrations tend to be more damped, while in soft soil vibrations are more easily transmitted. Areas with low dominant period values dominate most of the Way Manak and Gunung Tiga areas, while areas with high dominant period values are dominated in the eastern region. The distribution of high dominant period values is also found in Babakan Village at point D4. Areas with high dominant period values are dominated by the Alluvium Formation and the Lampung Formation (QTl), while those with low dominant period values are dominated by the Gunungkasih Complex as shown in Figure 10.

4. Conclusions

Based on the processing and analysis of HVSR data in Pugung District, Tanggamus Regency, it can be concluded that the subsurface characteristics of the study area exhibit significant variations in geotechnical properties and seismic conditions. The variation in natural frequency values (2.05 – 11.5 Hz), dominant period (0.08 – 0.48 seconds), amplification factor (2.84 – 10.61), and seismic vulnerability index (0.911 – 23.606) reflects differences in sediment thickness, soil compactness, and impedance contrast between rock layers. Areas with low natural frequency values, high dominant periods, high amplification, and high seismic vulnerability index generally indicate the presence of thick and soft sediment layers. These zones are mainly located in the eastern and southeastern parts of the study area and are categorized as regions with higher seismic hazard potential due to the soil's ability to amplify seismic waves. In contrast, areas with high natural frequency values, low amplification, and low vulnerability index are dominated by more compact and shallow materials, making them relatively safer from earthquake shaking effects. The microzonation results indicate that most parts of the study area fall within the moderate to vulnerable category based on seismic parameters. Therefore, this information can be used as a basis for earthquake risk mitigation planning, particularly in spatial planning, foundation evaluation, and prioritizing earthquake-resistant infrastructure development. Overall, the objective of the study to identify subsurface characteristics and reveal seismic microzonation 16 conditions based on natural frequency variation, dominant period, amplification, and seismic vulnerability index has been successfully achieved. The findings obtained can serve as important reference material for disaster risk reduction efforts in Pugung District and its surrounding areas.

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Data Availability Statement

The data used and analyzed in this study were obtained through HVSR measurements conducted during the Geophysical Engineering fieldwork using instruments provided by the Geophysics Study Program, Institut Teknologi Sumatera (ITERA). The datasets are not publicly available due to institutional policy restrictions but may be accessed from the corresponding author upon reasonable request.

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