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Estimate Sediment Thickness in Air Sempiang Village, Kepahiang Using the HVSR Method and the f_0 and A_0 Values

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ABSTRACT

Microtremor-based site characterization provides rapid constraints on near-surface stratigraphy where borehole or geotechnical data are limited. This study estimates relative sediment-thickness variation and site response in Air Sempiang Village (Kabawetan District, Kepahiang Regency, Bengkulu Province, Indonesia) using the horizontal-to-vertical spectral ratio (HVSR) method and the derived dominant frequency (f_0) and amplification factor (A_0). Ambient-vibration data were acquired at 13 measurement points (30 min per site) using a PASIGemini-2 three-component geophone. HVSR processing was performed in Geopsy 3.2.2, including time-window selection, spectral smoothing, and peak identification to obtain f_0 and A_0 . The resulting parameters were interpolated using inverse distance weighting in ArcGIS to generate spatial distribution maps. The estimated dominant frequencies are predominantly high (approximately 7–20 Hz), indicating generally shallow sediment cover and relatively stiff near-surface conditions, with localized lower- f_0 zones interpreted as thicker sediment accumulations. Amplification factors vary from 2 to 8, with moderate-to-high amplification concentrated in areas inferred to contain softer or thicker sediments, whereas lower A_0 values coincide with zones interpreted as being closer to competent bedrock. The combined f_0 – A_0 patterns delineate subareas that are more susceptible to medium- to high-frequency ground-motion amplification and provide a first-order basis for local-scale seismic microzonation and earthquake risk mitigation planning in the study area.

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1. INTRODUCTION

Indonesia is located at the convergence of major lithospheric plates, which drives frequent and potentially damaging seismic activity. In such tectonically active settings, earthquake impacts are not controlled solely by source characteristics but also by local site effects that can amplify or de-amplify ground motion depending on near-surface conditions. Consequently, rapid and spatially resolved site characterization is essential for supporting disaster mitigation and evidence-based development planning (H et al., 2024).

Within Bengkulu Province, Kepahiang Regency is situated in an active geodynamic context where near-surface materials are expected to vary laterally, producing different local responses under similar regional shaking. The spatial variability of sediment cover and weathered layers is particularly relevant because it may control resonance and amplification patterns at the scale of settlements and infrastructure corridors (Manyoe et al., 2019; Sugianto et al., 2022). Recent applications of ambient vibration techniques have demonstrated that microtremor-based mapping

can provide practical constraints on site conditions and sediment thickness variations where subsurface control is limited (Yang et al., 2025; Hossain et al., 2025).

Air Sempiang Village (Kabawetan District, Kepahiang Regency) represents a setting in which local geology suggests heterogeneity of surficial deposits and bedrock proximity, yet spatially explicit dynamic-soil parameters remain scarce. The absence of village-scale information on resonance-related parameters restricts the ability to anticipate which subareas may experience stronger shaking at specific frequency bands, and therefore, limits the effectiveness of local microzonation and mitigation efforts.

A practical approach to address this knowledge gap is to employ ambient vibration (microtremor) observations and estimate site response indicators that are sensitive to impedance contrasts in the shallow subsurface. The horizontal-to-vertical spectral ratio (HVSr) method provides a non-invasive route to derive the dominant frequency (f_0) and amplification factor (A_0), which can be mapped to delineate zones of contrasting near-surface conditions and relative sediment thickness variation (Demulawa & Daruwati, 2021).

The HVSr has been widely adopted for site characterization because it extracts resonance-related information from continuous ambient vibrations and can be implemented efficiently across multiple stations. The dominant frequency (f_0) is commonly interpreted as a proxy for the fundamental resonance controlled by the contrast between unconsolidated sediment and the underlying stiffer material, thereby providing an initial indicator of subsurface layering and bedrock depth variability (Arintalofa et al., 2020).

To relate resonance to sediment thickness, studies often invoke simplified stratified medium relationships in which the fundamental frequency is governed by the shear wave velocity and thickness of the impedance-contrasting layer. Under a first-order approximation, lower f_0 values tend to indicate thicker or lower-velocity sediment packages, whereas higher f_0 values suggest shallower bedrock or stiffer shallow layers (Fadhilah et al., 2022).

In addition to resonance, the amplification factor (A_0) provides an operational measure of how strongly the motion may be amplified near the resonance frequency, supporting the relative ranking of site susceptibility. Amplification is frequently discussed as a key driver of observed damage variability because it reflects the combined effects of impedance contrast, damping, and near-surface heterogeneity (Wibowo et al., 2018; Arrouf et al., 2023). For interpretive consistency, f_0 -based site classes and resonance-related descriptors are commonly referenced using established empirical classifications (Nurwidyanto et al. 2023).

Recent studies applying HVSr at community to regional scales have shown the method's utility for producing spatial maps of f_0 and A_0 that support microzonation and preliminary inference of sediment thickness trends, particularly where drilling or dense geotechnical data are unavailable (Pohan et al., 2023; Yang et al., 2025). Complementary studies have emphasized that combining resonance (f_0) and amplification (A_0) improves interpretability relative to using either parameter alone, because spatial patterns can differentiate shallow stiff sites from thicker/softer sediment pockets that may generate stronger site effects (Hossain et al., 2025).

However, in Air Sempiang Village and its immediate surroundings, village-scale HVSr mapping remains limited, and the spatial coupling between local geology, f_0 - A_0 patterns, and inferred sediment thickness variation has not been reported in a way that directly supports local planning. Moreover, prior ambient-vibration implementations in comparable settings highlight that station density and consistent processing are critical for producing actionable maps; however, such an integrated, settlement-focused workflow has not been established for this area (Risa et al., 2023).

This study aims to (i) determine the dominant frequency (f_0) and amplification factor (A_0) from microtremor HVSr observations across Air Sempiang Village, (ii) generate spatial distribution maps of f_0 and A_0 , and (iii) interpret these patterns as indicators of sediment thickness variation and site response susceptibility for seismic microzonation. This study provides the first village-scale f_0 - A_0 mapping framework for Air Sempiang using a standardized HVSr workflow, establishing a baseline for hazard-informed development. The scope covers ambient vibration measurements at 13 points and interprets f_0 and A_0 as relative indicators without direct borehole validation or full velocity inversion.

2. METHOD

2.1. Materials

Ambient vibration measurements were collected using a PASIGemini-2 3D (three-component) geophone (N–S, E–W, and vertical components). Data processing and HVSR computation were conducted using Geopsy 3.2.2, whereas spatial visualization and interpolation were performed using ArcGIS.

2.2. Sample Preparation

Because this study is based on field microtremor observations (not laboratory samples), “sample preparation” refers to measurement point and instrument preparation. Each site was selected to represent the spatial variability of the near-surface conditions across the study area. Prior to recording, the sensor was placed on stable ground, oriented consistently to N–S and E–W, and checked to minimize coupling issues and obvious sources of transient noise.

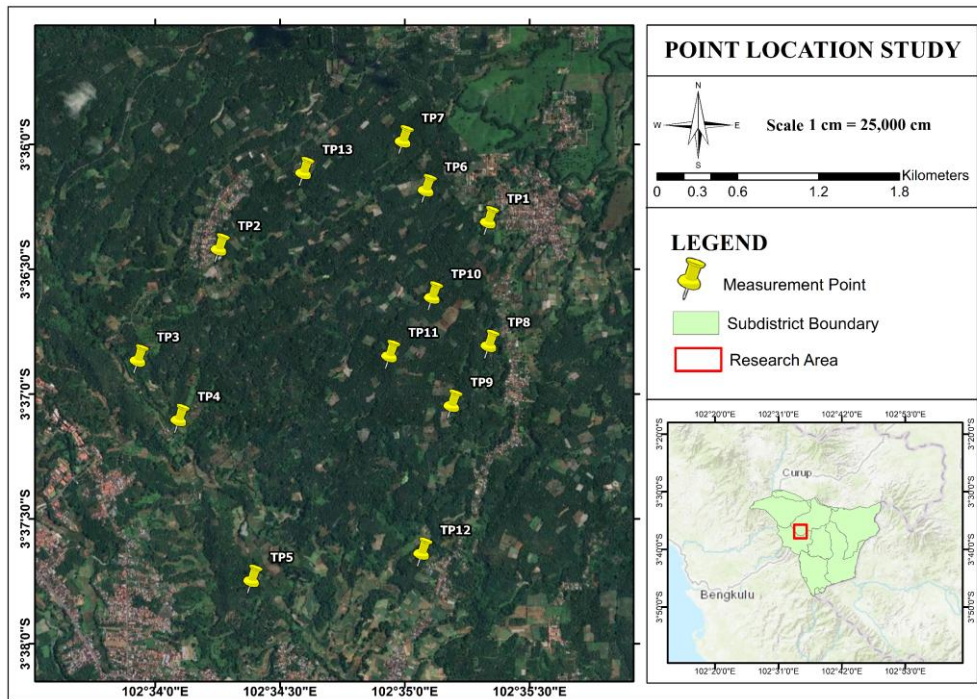


Figure 1. Point Location Study

Microtremor measurements were conducted at 13 sites to represent the near-surface conditions and lithology. The sites covered settlements and zones with varying sediment thicknesses. The geographic coordinates of each point are listed in Table 1.

Table 1. Measurement Point Coordinates

Point	Longitude (X)	Latitude (Y)
T1	102.589	-3.6051
T2	102.571	-3.60692
T3	102.5656	-3.61434
T4	102.5683	-3.61833
T5	102.5732	-3.62905
T6	102.5848	-3.60298
T7	102.5833	-3.59971
T8	102.5891	-3.61336
T9	102.5866	-3.61737
T10	102.5853	-3.61014
T11	102.5824	-3.61404
T12	102.5846	-3.62724
T13	102.5767	-3.60182

2.3. Field set-up and Data Processing

Microtremor data acquisition was conducted at 13 measurement points on October 27, 2024. At each point, ambient vibrations were recorded for 30 min. The coordinate positions are documented in decimal degrees (X = longitude, Y = latitude) and are reported in Table 1.

HVSR analysis was performed using Geopsy version 3.2.2. The process included time-windowing (>60 s), excluding windows with disturbances, frequency-domain processing (upper bound 20 Hz), and Konno-Ohmachi smoothing (constant 20). The dominant frequency (f_0) was identified at the primary HVSR peak, with the amplification factor (A_0) as the peak amplitude.

Equations are used as the physical basis to relate resonance to sediment thickness through a quarter-wavelength approximation:

$$f_n = \frac{V_s}{4H} \quad (1)$$

where f_n is the natural (fundamental) frequency, V_s is the shear-wave velocity of the sediment layer, and H is sediment thickness. The interpretation of land classification based on the natural frequency is presented in Table 2 (Nurwidyanto et al., 2023).

Table 2. Classification of land based on the marked natural frequency of microtremors by Kanai

Classification land		Frequency (Hz)	Compiler	Description
Type	Type			
IV	I	6,667- 20	Rock is tertiary or more old. Consisting of rock-hard <i>sand, gravel</i> , and other materials	The thickness sediment surface is very thin, dominated by hard rocks
III	II	4.0 – 6.667	Rock is tertiary or more old. Consisting of <i>rock-hard sand, gravel</i> , and other materials	Thickness of sediment surface enters in category medium, 5 - 10 m
II	III	2.5 – 4.0	Rock alluvial, with a thickness of more than 5 m. consists of <i>sandy gravel, sandy hard clay, loam</i> , and others	Thickness of sediment on the surface is entered in the category thick, about 10 – 30 m
I	IV	Less than 2.5	Rock alluvial, which is formed from sedimentation - delta, topsoil, mud, and others. Thickness ≥ 30 m	The thickness sediment surface is very thick.

The following equation is applied to interpret amplification in terms of impedance contrast:

$$A_0 = \frac{\rho_b \cdot V_b}{\rho_s \cdot V_s} \quad (2)$$

where A_0 is amplification, ρ_b and ρ_s are the densities of base rock and surface/soft rock, respectively, and V_b and V_s are the corresponding shear-wave velocities. Amplification classes are referenced in Table 3 (Pohan et al., 2023).

Table 3. Classification mark amplification

Zone	Classification	Factor Amplification
1	Low	$A < 3$
2	Currently	$3 \leq A < 6$
3	Tall	$6 \leq A < 9$
4	Very tall	$A \geq 9$

2.4. Parameters

The primary parameters derived and reported in this study include the dominant frequency (f_0 , Hz), defined as the frequency at the main HVSR peak and used to indicate site resonance and relative sediment-thickness variation (via Eq. 1), as well as the amplification factor (A_0 , dimensionless), defined as the peak HVSR amplitude at f_0 and used to represent the relative strength of site response (via Eq. 2). In addition, the measurement coordinates (X–Y) for each of the 13 sites (Table 1) are reported to support the spatial mapping and interpolation of the derived HVSR parameters.

2.5. Spatial Analysis

As this study did not employ inferential statistics, the analysis step focused on spatial interpolation and mapping. The point-based f_0 and A_0 values were interpolated in ArcGIS using Inverse Distance Weighting (IDW) to generate continuous distribution maps. These maps were used to delineate zones of contrasting resonance and amplification, supporting the interpretation of relative sediment thickness variation and site response susceptibility across the study area.

3. RESULTS AND DISCUSSION

3.1. Distribution of Natural Frequency Values (f_0)

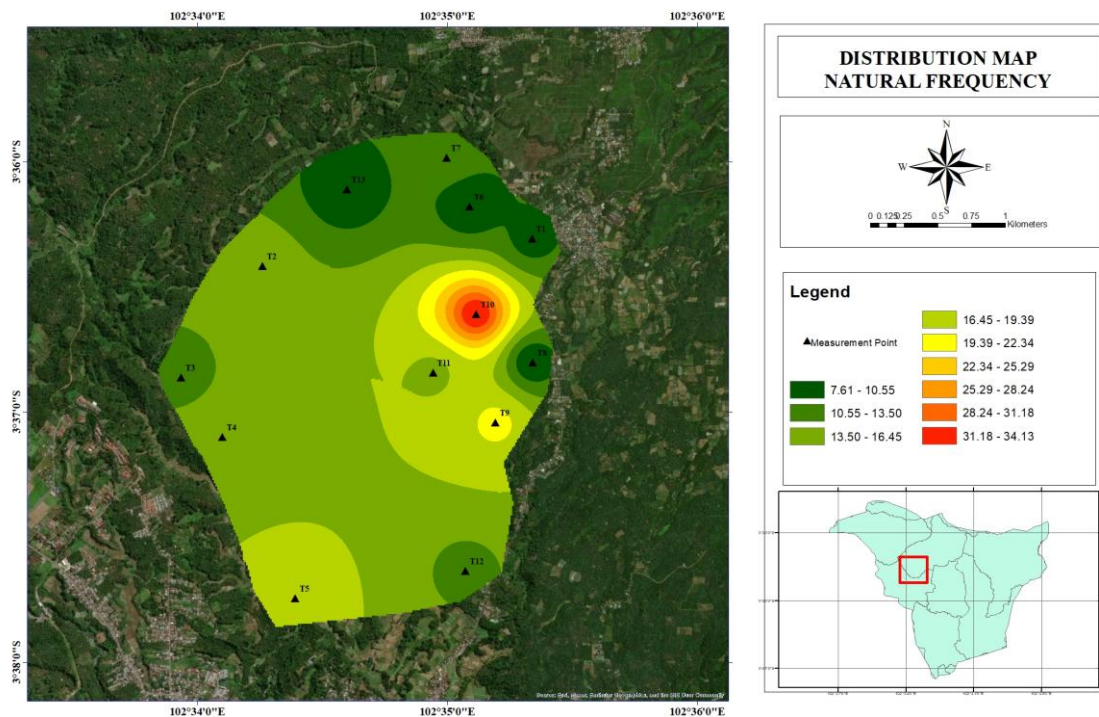


Figure 3. Distribution Map Natural Frequency

Figure 3 presents the spatial distribution of the dominant (natural) frequency (f_0) derived from the HVSR analysis across the study area. The f_0 values ranged from 7 to 35 Hz, with most locations concentrated in the 7–20 Hz interval. In the Kanai-based classification, these relatively high frequencies generally correspond to a thin sediment cover and/or shallow competent material, indicating a near-surface condition dominated by stiff layers (Nurwidyanto et al., 2023). This pattern is consistent with the regional setting in Kabawetan, where volcanic products associated with Mt. Kaba are expected to contribute to higher shear-wave velocities and a shallower impedance contrast boundary (Sugianto et al., 2022).

Zones exhibiting the highest f_0 (yellow to red on the map) indicate areas where the bedrock is interpreted to be shallower and the near-surface materials are more compact, which typically increases the resonance frequency through a higher shear wave velocity (Arinalofa et al., 2020; Fadhilah et al., 2022; Katili et al., 2024). Conversely, relatively lower f_0 zones (dark green) suggest local increases in sediment thickness and/or softer near-surface layers, although they are still within

a generally shallow-sediment regime. At the practical level, the predominance of high f_0 implies that the site resonance is more responsive to medium-to-high frequency earthquake energy, which is particularly relevant for low- to medium-rise structures whose natural periods may overlap with these frequency bands (H et al., 2024).

3.2. Distribution of Factor Values Amplification (A_0)

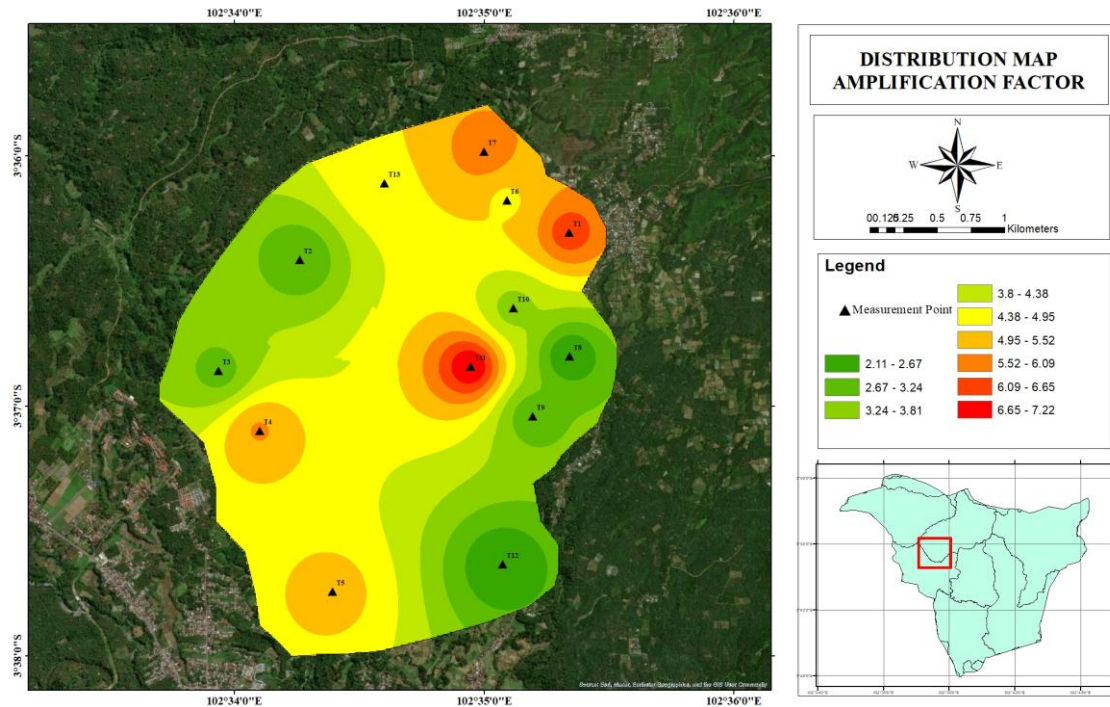


Figure 4. Distribution Map Amplification Factor

Figure 4 shows the mapped amplification factor (A_0) obtained from the HVSR peak amplitudes. The A_0 values ranged from 2 to 8, indicating spatial variability in the surface layer dynamic response. Low-amplification areas ($A_0 \approx 2-3$, dark green) represent comparatively stiff ground conditions and limited soft-sediment thickness, whereas moderate amplification ($A_0 \approx 3-6$, light green to orange) reflects areas with more compliant near-surface materials capable of increasing wave amplitudes within a moderate range, consistent with the classification scheme in Table 2 (Pohan et al., 2023).

The highest amplification zones ($A_0 \approx 6-8$, red) indicate a stronger impedance contrast and/or locally softer and thicker sediments, which can increase the resonance-related motion at the surface (Wibowo et al., 2018; Hossain et al., 2025). In broad terms, the dominance of A_0 values between approximately 2 and 5 supports the interpretation that much of the area is controlled by shallow volcanic bedrock and limited soft cover, whereas localized high- A_0 pockets warrant attention in microzonation and mitigation planning (Sugianto et al., 2022; H et al., 2024).

Taken together, Figures 3 and 4 demonstrate a coherent relationship between resonance and amplification: areas with relatively lower f_0 tend to coincide with higher A_0 , consistent with the working hypothesis that thicker/softer sediments promote stronger amplification, whereas shallow, stiff conditions produce higher f_0 and lower A_0 (Fadhilah et al., 2022; Risa et al., 2023). This combined interpretation aligns with broader evidence that HVSR-based spatial variability can be used as a first-order proxy for relative sediment thickness patterns, especially in areas with limited direct subsurface control (Demulawa & Daruwati, 2021; Wiyuda et al., 2022; Yang et al., 2025). The results also reflect the general behavior reported in site response syntheses: amplification is fundamentally linked to impedance contrast and near-surface mechanical properties, which can vary substantially even over short distances (Hossain et al., 2025; Wibowo et al., 2018).

This study has several limitations. First, the analysis was based on 13 measurement points; therefore, small-scale heterogeneity may remain unresolved. Second, distribution maps were generated using IDW interpolation, which can introduce uncertainty in areas far from

measurement points and may smooth or exaggerate localized anomalies depending on point spacing and spatial gradients. Consequently, the maps are best interpreted as relative zoning indicators rather than as definitive boundaries. Future work should increase station density and integrate complementary constraints (e.g., geotechnical data, MASW, or other near-surface geophysical profiling) to strengthen sediment thickness interpretation and refine microzonation outputs (Arintalofa et al., 2020; Yang et al., 2025).

4. CONCLUSIONS

This study delineated the site response characteristics and relative sediment thickness variability in Air Sempiang Village using the microtremor HVSR. The dominant frequency (f_0) distribution is largely high, indicating generally shallow and stiff near-surface conditions, whereas localized lower- f_0 zones suggest comparatively thicker and/or softer sediment accumulations. The amplification factors (A_0) varied from low to high across the area, highlighting subareas where a stronger impedance contrast and greater site-response potential were expected. Taken together, the coupled f_0 - A_0 patterns provide a practical first-order basis for village-scale microzonation and for prioritizing mitigation in zones that may experience stronger medium-to-high-frequency ground motion amplification.

The main limitations are the restricted number of measurement points and the uncertainty inherent to spatial interpolation; therefore, the resulting maps should be interpreted as relative zoning indicators rather than definitive boundaries. Future work should increase station density and integrate independent subsurface constraints (e.g., near-surface velocity profiling and/or borehole control) to validate sediment thickness interpretation and refine hazard-relevant zoning for local planning and risk reduction.

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