International Journal of Research and Review
[Indexed, Peer-Reviewed Journal]
Volume 13; Issue: 5; May 2026
Website: www.ijrrjournal.com
Research Paper
E-ISSN: 2349-9788; P-ISSN: 2454-2237

Microtremor HVSR Analysis for Land Movement Identification in Pandanmurti Field, Sumowono District, Semarang Regency, Indonesia

M Irham Nurwidyanto[1], Gatot Yuliyanto[2]

[1]Department of Physics, Faculty of Science and Mathematics, Diponegoro University, Semarang, Indonesia.
[2]Department of Physics, Faculty of Science and Mathematics, Diponegoro University, Semarang, Indonesia

Corresponding Author: M Irham Nurwidyanto

DOI: https://doi.org/10.52403/ijrr.20260581

ABSTRACT

Local site effects significantly influence seismic wave amplification and slope instability in volcanic terrains characterized by weathered deposits and high rainfall intensity. This study applies the Horizontal-to-Vertical Spectral Ratio (HVSR) microtremor method to characterize local site effects and evaluate seismic vulnerability in Pandanmurti Field, Candigaron Village, Sumowono District, Central Java, Indonesia. The area experienced severe land deformation in 2017, resulting in extensive ground cracking, subsidence, and structural damage. Twenty ambient vibration measurements were recorded using a three-component seismometer and processed using Geopsy software following SESAME guidelines. HVSR analysis was performed to determine dominant frequency (f0), amplification factor (A0), seismic vulnerability index (Kg), peak ground acceleration (PGA), and ground shear strain (GSS). The results indicate dominant frequency values ranging from 0.03 to 0.12 Hz and amplification values between 4.3 and 6.7. Low dominant frequencies indicate thick unconsolidated weathered deposits, while high amplification values indicate strong impedance contrast between soft surface materials and compact subsurface layers. Seismic vulnerability index values range from 0.0008263 to 0.0265714 cm/s, whereas PGA values range from 10.09 to 46.76 gal. High seismic vulnerability zones spatially correlate with observed deformation areas and elevated ground shear strain values. The integrated interpretation demonstrates that areas characterized by low dominant frequency and high amplification exhibit higher instability potential. The study confirms that HVSR microtremor analysis is an effective and economical approach for identifying unstable site conditions and supporting disaster mitigation strategies in landslide-prone volcanic environments.

Keywords: Microtremor, HVSR, land movement, seismic vulnerability index, ground shear strain

1. INTRODUCTION

Landslides and land movement are among the most destructive geological hazards in tropical volcanic regions because they frequently cause environmental degradation, infrastructure damage, and economic losses. Indonesia is highly vulnerable to these hazards due to its active tectonic setting, steep topography, high annual rainfall, and widespread distribution of weathered volcanic deposits (Karnawati, 2005). Weathered volcanic materials generally exhibit low shear strength, high porosity, and significant water absorption capacity, which increase slope instability during intense rainfall and seismic activity.

Local geological conditions strongly influence seismic wave propagation and site amplification. Soft sedimentary layers and unconsolidated volcanic deposits may significantly amplify seismic waves and increase ground deformation susceptibility (Nakamura, 1989). Areas characterized by low dominant frequency and high amplification values are generally associated with thick weathered sediments and unstable subsurface conditions (Lermo & Chávez-García, 1993; Lachet & Bard, 1994). These local site effects are important indicators for evaluating landslide susceptibility and seismic vulnerability in volcanic terrains.

The Horizontal-to-Vertical Spectral Ratio (HVSR) microtremor method developed by Nakamura (1989) has become one of the most widely applied techniques for site characterization because it is rapid, non-destructive, inexpensive, and effective for estimating dominant frequency and amplification characteristics. HVSR analysis has been extensively used for identifying sediment thickness, local site effects, seismic microzonation, and unstable subsurface conditions in landslide-prone areas (Nakamura, 2000; Delgado et al., 2000). In addition, seismic vulnerability index and ground shear strain derived from HVSR parameters provide useful information regarding deformation susceptibility and ground instability. Recent studies also demonstrated that microtremor analysis provides reliable information for seismic site characterization and shallow subsurface investigation (Molnar et al., 2022).

Pandanmurti Field, located in Candigaron Village, Sumowono District, Semarang Regency, Central Java, experienced severe land movement on March 1st, 2017. The event produced extensive ground cracking, subsidence reaching approximately 2.2 m, and severe damage to nearby residential areas. Previous investigations using geoelectrical methods identified shallow discontinuities interpreted as deformation zones. However, comprehensive evaluation of local site effects and seismic vulnerability using microtremor analysis has not been thoroughly conducted in this area.

Several previous studies in Central Java demonstrated that HVSR microtremor analysis is effective for identifying weak subsurface layers and landslide-prone zones (Yuliyanto, et al, 2021, Nurwidyanto et al, 2023, Nurwidyanto, et al, 2024). Nevertheless, integrated analysis combining dominant frequency, amplification factor, seismic vulnerability index, peak ground acceleration, and ground shear strain remains limited in the Pandanmurti area.

Therefore, this study aims to characterize local site effects and evaluate seismic vulnerability in Pandanmurti Field using HVSR microtremor analysis. The results are expected to provide important information regarding unstable subsurface conditions and contribute to disaster mitigation planning and land-use management in landslide-prone volcanic environments.

2. MATERIALS & METHODS

2.1 Study Area

The study area is located in Pandanmurti Field, Candigaron Village, Sumowono District, Semarang Regency, Central Java, Indonesia. Field conditions can be seen in Figure 1. Geologically, the area is dominated by volcanic deposits consisting of sandstone, claystone, breccia, and weathered volcanic materials. The region is classified as a medium-to-high landslide susceptibility zone according to the Indonesian Geological Agency.

2.2 Data Acquisition

Microtremor measurements were conducted at 20 observation points distributed across the affected area. Data acquisition employed a three-component seismometer connected to a digital data logger. Each measurement was recorded for approximately 10 minutes following SESAME European Project

(2004) recommendations. The recorded signals consist of two horizontal components (N–S and E–W) and one vertical component. HVSR data processing and spectral interpretation were performed using Geopsy and supported by ModelHVSR analysis principles proposed by Herak (2008).

2.3 HVSR Analysis

The HVSR method was applied to calculate the ratio between horizontal and vertical spectral amplitudes. The HVSR equation is expressed as:

$$HVSR = \sqrt{\frac{{S_{EW}}^2 + {S_{NS}}^2}{{S_v}^2}} \quad (1)$$

where S_{NS} and S_{EW} are the horizontal spectral amplitudes, while S_V represents the vertical spectral amplitude. Dominant frequency (f_0) was identified from the peak of the HVSR curve, while amplification factor (A_0) corresponds to the peak amplitude value.

Figure 1, Location of the research area

2.4 Seismic Vulnerability Index

The seismic vulnerability index *(Kg)* was calculated using Nakamura's equation

$$K_g = \frac{{A_0}^2}{f_0}\frac{1}{\pi^2 V_b} \quad (2)$$

where *(Kg)* is the seismic vulnerability index value, A_o is the peak value of the microtremor spectrum (Amplitude), f_o is the dominant frequency an V_b is velocity in basement value.

Higher Kg values indicate greater susceptibility to deformation and seismic amplification.

2.5 Peak Ground Acceleration (PGA)

The acceleration of the ground on the surface becomes maximum with the magnitude of the wave magnification value with the period function which can be written as (Canay, 1969):

$$\propto_g = \frac{5}{\sqrt{T_0}} 10^{\left(0,61M - \left(1,66 + \frac{3,66}{R}\right) logR + 0,67 - \frac{1,83}{R}\right)} \quad (3)$$

Where $\propto_g$ is the value of the ground vibration acceleration at the observation point (gal), T_0 is the dominant period of the ground at the observation point (s), is the Moment Magnitude, is the epicenter distance (km), and $\propto_g$ is the ground acceleration at the base rock (gal).

3. RESULT

3.1. Dominant frequency

The HVSR analysis shows that dominant frequency values in the study area range from 0.03 Hz to 0.12 Hz, as presented in Figure 2. Low dominant frequency values are predominantly distributed in the central and southeastern sectors of the study area, particularly around observation points SW03, SW14, and SW16. In contrast, relatively higher dominant frequency values are observed in the western and northern parts of the study area.

The spatial distribution of dominant frequency indicates variations in subsurface characteristics across the research area. Areas characterized by very low dominant frequency generally correspond to zones with thick unconsolidated weathered deposits and relatively deep bedrock conditions.

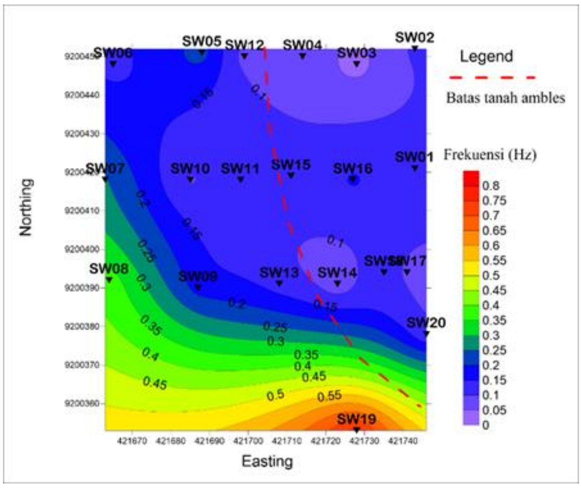

Figure 2, Spatial distribution of dominant frequency (f0) in the study area

3.2 Amplification

Amplification factor values obtained from HVSR analysis range from 4.3 to 6.7, as shown in Figure 3. High amplification anomalies are concentrated in the eastern and southeastern sectors of the study area, especially around points SW03, SW14, and SW16. Lower amplification values are observed in the western part of the study area.

The amplification contour pattern indicates significant variation in impedance contrast between surface materials and deeper subsurface layers. Areas with high amplification values spatially coincide with zones affected by land deformation and ground cracking

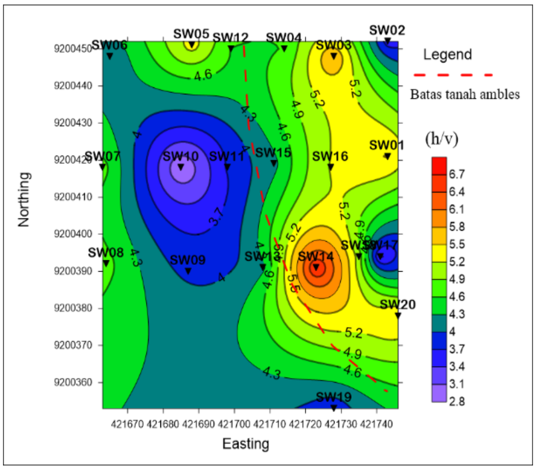

Figure 3. Spatial distribution of amplification factor (Ao) in the study area.

3.3 Seismic Vulnerability Index

The seismic vulnerability index values range from 0.0008263 cm/s to 0.0265714 cm/s, as presented in Figure 4. High Kg anomalies are concentrated in the central and southeastern sectors of the study area. The highest seismic vulnerability values are identified around points SW03 and SW14.

The distribution pattern of seismic vulnerability index demonstrates strong spatial correlation with areas affected by previous land movement events. Several zones characterized by high Kg values are also associated with high amplification anomalies and low dominant frequency values.

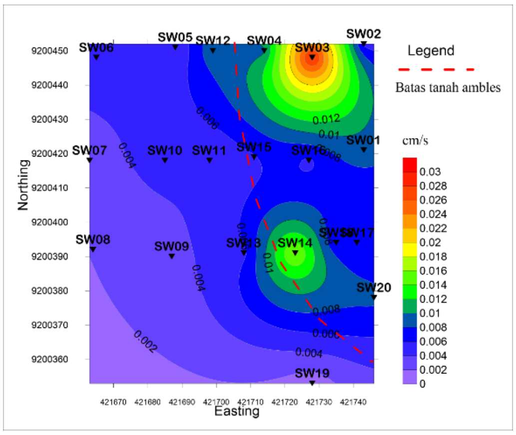

Figure 4. Spatial distribution of seismic vulnerability index (Kg) in the study area.

3.4. Peak Ground Acceleration (PGA)

The estimated PGA values range from 10.09 to 46.76 gal, as presented in Figure 5. Higher PGA values are concentrated in the southern and southeastern sectors of the study area, while lower values are generally distributed in the northern part.

The PGA distribution pattern indicates variations in local ground response characteristics across the study area. Zones characterized by high PGA values generally correspond to areas with soft subsurface materials and high amplification values.

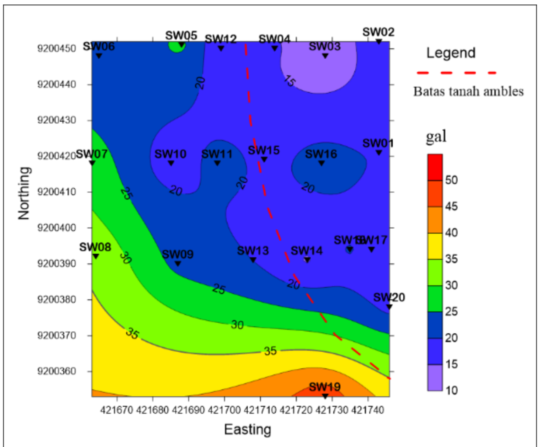

Figure 5. Spatial distribution of peak ground acceleration (PGA) in the study area.

According to Canay (1969), seismic wave amplification in soft sedimentary deposits may considerably increase surface ground motion intensity. Therefore, high PGA values identified in the study area indicate increased susceptibility to seismic-induced deformation and slope instability.

3.5 Ground Shear Strain

Ground shear strain values in the study area range from 0.03 × 10^{-3} to 0.30 × 10^{-3}, as presented in Figure 6. High GSS anomalies are predominantly distributed in the eastern and southeastern sectors of the study area, particularly around points SW03 and SW14.

The spatial distribution of ground shear strain indicates differences in deformation potential across the study area. Areas characterized by elevated GSS values generally coincide with zones exhibiting high amplification and seismic vulnerability index values.

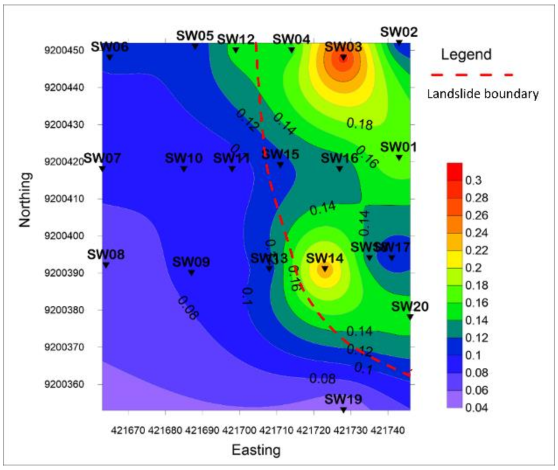

Figure 6. Spatial distribution of ground shear strain in the study area.

4. DISCUSSION

According to Lermo and Chávez-García (1993), high amplification values are commonly associated with soft sediments capable of amplifying seismic waves significantly. Similar conditions were also reported by Delgado et al. (2000), who demonstrated that high amplification anomalies correspond to unstable sedimentary zones in landslide-prone environments. The amplification distribution in Pandanmurti Field indicates that local geological conditions strongly control seismic wave propagation and local site effects. Bonnefoy-Claudet et al. (2006) explained that ambient noise wavefields are strongly influenced by local geological conditions and impedance contrasts within shallow subsurface layers. Parolai et al. (2002) reported that low dominant frequency values are generally associated with thick sedimentary deposits and low shear-wave velocity materials.

High Kg anomalies are concentrated in sectors characterized by low dominant frequency and high amplification. These conditions indicate the presence of weak unconsolidated deposits that are highly susceptible to deformation. Nakamura (2000) reported that seismic vulnerability index values provide important information regarding deformation susceptibility because the parameter reflects the relationship between amplification and resonance frequency. High Kg values therefore represent unstable ground conditions with increased vulnerability to seismic loading and land deformation.

The distribution of seismic vulnerability in the study area demonstrates strong correlation with observed ground cracking and subsidence zones.

According to Canay (1969), seismic wave amplification in soft sedimentary deposits may considerably increase surface ground motion intensity. Therefore, high PGA values identified in the study area indicate increased susceptibility to seismic-induced deformation and slope instability. Kleinbrod (2017) demonstrated that ambient vibration measurements are effective for identifying unstable slope conditions and rock mass deformation.

Point SW03 exhibits the highest deformation potential based on combined analysis of low frequency, high amplification, high seismic vulnerability index, and elevated ground shear strain.

The combination of low dominant frequency and high amplification demonstrates significant local site effects caused by thick weathered volcanic deposits. These conditions contribute to increased seismic amplification and instability potential. The interpreted unstable zones are characterized by thick unconsolidated materials with low rigidity and high-water content.

The integration of dominant frequency, amplification, seismic vulnerability index, and PGA analysis indicates that the central and southeastern parts of the study area represent the most vulnerable sectors. Point SW03 is interpreted as the most unstable area because it exhibits low dominant frequency, high amplification, elevated seismic vulnerability index, and high ground shear strain.

The results are consistent with previous investigations conducted in volcanic terrains of Central Java, where unstable zones are generally associated with low-frequency anomalies and strong site amplification (Nurwidyanto et al., 2023).

Overall, the study demonstrates that HVSR microtremor analysis provides valuable information for identifying unstable subsurface conditions and supporting disaster mitigation planning in landslide-prone areas. Méric et al. (2007) successfully applied seismic noise analysis for characterizing unstable soft-rock landslide zones.

5. CONCLUSION

HVSR microtremor analysis successfully identified unstable subsurface conditions in Pandanmurti Field, Central Java. Low dominant frequency values indicate thick weathered volcanic deposits, while high amplification values reflect strong impedance contrasts between surface sediments and compact subsurface layers. Integrated analysis of dominant frequency, amplification, seismic vulnerability index, PGA, and ground shear strain indicates that the central and southeastern sectors, especially around point SW03, represent the most vulnerable zones for future land movement. The study confirms that HVSR microtremor analysis is an effective, rapid, and economical method for evaluating local site effects and supporting landslide disaster mitigation in volcanic environments.

Declaration by Authors

Acknowledgement: None

Source of Funding: None

Conflict of Interest: No conflicts of interest declared.

6. REFERENCES

1. Bonnefoy-Claudet, S., Cotton, F., & Bard, P. Y. (2006). The nature of noise wavefield and its applications for site effects studies: A literature review. Earth-Science Reviews, 79(3–4), 205–227. https://doi.org/10.1016/j.earscirev.2006.07.004
2. Canay, R. (1969). A study on earthquake response of soil layers based on microtremor observations. Bulletin of the Earthquake Research Institute, 47, 457–482.
3. Delgado, J., López Casado, C., Estevez, A., Giner, J., Cuenca, A., & Molina, S. (2000). Mapping soft soils in the Segura River valley (SE Spain): A case study of microtremors as an exploration tool. Journal of Applied Geophysics, 45(1), 19–32. https://doi.org/10.1016/S0926-9851(99)00042-8
4. Herak, M. (2008). ModelHVSR: A Matlab tool to model horizontal-to-vertical spectral ratio of ambient noise. Computers & Geosciences, 34(11), 1514–1526. https://doi.org/10.1016/j.cageo.2007.07.009
5. Karnawati, D. (2005). Bencana Alam Gerakan Massa Tanah di Indonesia dan Upaya Penanggulangannya. Yogyakarta: Universitas Gadjah Mada Press.
6. Kleinbrod, U., Burjánek, J. and Fäh, D., 2017. On the seismic response of instable rock slopes based on ambient vibration recordings. Earth, Planets and Space, 69(1), pp.1-15.

7. Lachet, C., & Bard, P. Y. (1994). Numerical and theoretical investigations on the possibilities and limitations of Nakamura's technique. Journal of Physics of the Earth, 42(5), 377–397. https://doi.org/10.4294/jpe1952.42.377
8. Lermo, J., & Chávez-García, F. J. (1993). Site effect evaluation using spectral ratios with only one station. Bulletin of the Seismological Society of America, 83(5), 1574–1594.
9. Méric, O., Garambois, S., Malet, J. P., Cadet, H., Guéguen, P., & Jongmans, D. (2007). Seismic noise-based methods for soft-rock landslide characterization. Bulletin of the Seismological Society of America, 97(5), 1523–1537. https://doi.org/10.1785/0120060191
10. Molnar, S., Cassidy, J. F., Castellaro, S., Cornou, C., Cox, B., & Yong, A. (2022). Application of microtremor methods for seismic site characterization: State of the art review. Earth-Science Reviews, 225, 103911. https://doi.org/10.1016/j.earscirev.2021.103911
11. Nakamura, Y. (1989). A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface. Quarterly Report of Railway Technical Research Institute, 30(1), 25–33
12. Nakamura, Y. (2000). Clear identification of fundamental idea of Nakamura's technique and its applications. Proceedings of the 12th World Conference on Earthquake Engineering, Auckland, New Zealand, 2656, 1–8.
13. Nurwidyanto, M I, Zainuri, M, Wirasatriya, A, Yulianto, G, 2023, Microzonation for Earthquake Hazards with HVSR Microtremor Method in the Coastal Areas of Semarang, Indonesia, Geographia Technica, Vol.18, pp 177 to 188, DOI: 10.21163/GT_ 2023.181.13.
14. Nurwidyanto, MI, Harmoko U, Gernowo, R, Fernando, GA, Koesuma S, 2024, Analysis of Earthquake Vulnerability of the Demak Coastal Area Based on the HVSR (Horizontal to Vertical Spectral Ratio) Method. Indonesian Journal of Applied Physics (IJAP) Vol. 14 No. 2 page 365-376, https://jurnal.uns.ac.id/ijap/article/view/90703, DOI: https://doi.org/10.13057/ijap.v14i2.90703.
15. Parolai, S., Bormann, P., & Milkereit, C. (2002). New relationships between Vs, thickness of sediments, and resonance frequency calculated by the H/V ratio of seismic noise for the Cologne area (Germany). Bulletin of the Seismological Society of America, 92(6), 2521–2527. https://doi.org/10.1785/0120010248
16. SESAME European Research Project. (2004). Guidelines for the implementation of the H/V spectral ratio technique on ambient vibrations: Measurements, processing, and interpretation. European Commission Research General Directorate, Project No. EVG1-CT-2000-00026 SESAME.
17. Yuliyanto G, Nurwidyanto, MI, 2021, Analysis of landslide in Bungkah, Sepakung, Banyubiru using ground shear strain method and shear wave profile from HVSR method, Journal of Physics: Conference Series, doi:10.1088/1742-6596/1943/1/012027

How to cite this article: M Irham Nurwidyanto, Gatot Yuliyanto. Microtremor HVSR analysis for land movement identification in Pandanmurti field, Sumowono District, Semarang Regency, Indonesia. *International Journal of Research and Review*. 2026; 13(5): 806-813. DOI: *10.52403/ijrr.20260581*

******