

Identification of Subsurface Structures Based on Dominant Frequency and Amplification, Case Study at Bledug Kuwu, Central of Java, Indonesia

Rizka Nur Syihab¹, Gatot Yuliyanto², Tony Yulianto³

¹Post Graduate Student, Physics Department, Faculty of Science and Mathematics, Diponegoro University, Semarang, Indonesia,

²Physics Department, Faculty of Science and Mathematics, Diponegoro University, Semarang, Indonesia,

³Physics Department, Faculty of Science and Mathematics, Diponegoro University, Semarang, Indonesia.

Corresponding Author: Rizka Nur Syihab

DOI: <https://doi.org/10.52403/ijrr.20250659>

ABSTRACT

Horizontal to Vertical Spectral Ratio (HVSr) inversion research was conducted in Bledug Kuwu, Grobogan Regency, Central Java. This study aims to determine the subsurface structure of Bledug Kuwu. The data used is microtremor recording data from a 3-component seismometer. Microtremors are ground vibrations caused by natural or artificial events that have relatively low energy and low amplitude that are always present in any seismic recording and can describe geological conditions near the surface. The recording data is processed using the HVSr method to produce amplification and dominant frequency. The amplification of the research area was 0.57 to 6.69, the results of the processing showed that the closer to the big explosion, the smaller the amplification of that area. The dominant frequency value (f_0) in the study area was 0.52 to 9.7 Hz. The treatment results showed that the study area was dominated by type IV classification with a dominant frequency value of less than 2.5 Hz. Type IV classification showed that the area was composed of alluvial rocks formed from mud sedimentation, soft soils, mud deposits,

and which were classified into soft soils with a depth of 30 meters.

Keywords: Horizontal to Vertical Spectral Ratio (HVSr), microtremor, amplification, dominant frequency, Bledug Kuwu, mud volcano

INTRODUCTION

The phenomenon of the Bledug Kuwu mud volcano in Grobogan, Central of Java, is an intriguing geological manifestation to study. The mud activity in this area is suspected to be related to the presence of subsurface structures such as mud diapirs formed due to fluid pressure from certain depths [1]. Previous research indicated that the subsurface structure of Bledug Kuwu consists of clay sediment layers with low shear wave velocities, which facilitate the migration of mud to the surface [2]. Geophysical methods are used to study the subsurface structure of the earth, which are generally categorized into passive and active methods. Microtremor measurements using the HVSr method are a survey from passive methods and can reveal the dominant frequency and soil amplification factors [3].

The HVSr method has been widely used in seismic micro zonation studies and

identification of subsurface structures in various regions of Central Java. Studies in the city of Semarang used HVSR to determine the subsurface structure of the Semarang coast based on the HVSR method [4]. The HVSR method is used to identify areas of ground motion through microtremor HVSR methods [5]. Studies in the city of Semarang utilized HVSR to determine the structure and lithology of rocks in the Kaligarang Fault Zone [6]. The HVSR method has been applied in various countries to support seismic micro zonation and seismic vulnerability analysis [7]. The success of this method in various contexts demonstrates its potential for application in the Bledug Kuwu area.

The application of the HVSR method in Bledug Kuwu can provide important information regarding the subsurface structure underlying the mud volcano activity. The analysis of dominant frequency and amplification factors can identify sediment layers that play a role in the migration of mud to the surface [2]. This research aims to identify the subsurface structure of Bledug Kuwu using microtremor data and HVSR analysis to understand the mechanism of mud diapir formation and the associated geological hazard potential.

MATERIALS & METHODS

Geology of The Research Area

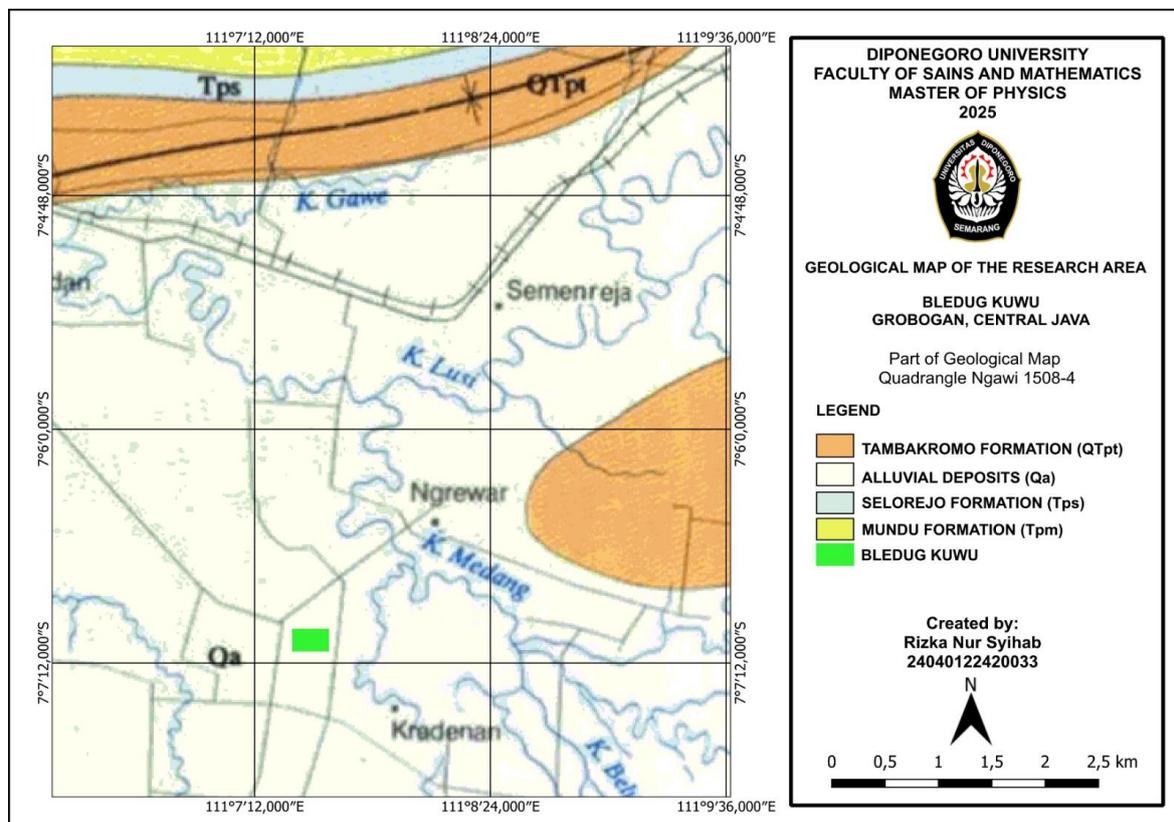


Figure 1. Geological Map of Grobogan, Central Java

The geological map of Grobogan shows that the lithology of Bledug Kuwu is composed of alluvial deposits (Qa) [8]. Bledug Kuwu is located in the area between the North Serayu Depression and Kendeng, with a clay morphology and a mud crust [9]. Bledug Kuwu is situated in a lowland area, and the mud eruptions of Bledug Kuwu

contain gas, water, steam, and salt. The region of Bledug Kuwu has a high salt content, which prevents any plants from growing in that location [10].

Research using the Self Potential method shows that the potential value decreases toward the Bledug eruption, with very low potential values indicating that the area is a

conductive region [11]. Subsurface geophysical studies of the Bledug Kuwu mud volcano show that the lithology consists of claystone with a resistivity of less than 5 ohm-meters and a density of 1.97 cc [12]. Research on the dominant frequency in Bledug Kuwu indicates that the average dominant frequency value of Bledug Kuwu is below 0.7 Hz [2].

Microtremor

Microtremor is a natural harmonic vibration that occurs within the earth, specifically in sedimentary rock layers. This vibration arises due to micro vibrations beneath the earth's surface and is reflected between rock layers. The characteristics of microtremor are greatly influenced by the geological structure of the subsurface in specific locations, thus providing information about the condition of soil layers [13]. Nakamura explains that the ratio of horizontal to

vertical spectra in microtremor measurements can increase at resonance frequencies and show peak values at those frequencies. Nakamura assumes that the H/V value can reflect the level of soil strengthening or amplification [14].

Horizontal to Vertical Spectral Ratio (HVSr) Method

The HVSr method is a geophysical technique used to compare horizontal and vertical spectra. The principle of the HVSr method assumes that most microtremor waves consist of shear waves and eliminates surface waves. The HVSr method can be used to determine the amplification factor and the dominant period of the observation location [13] Data collection was carried out at 16 points, detailed points can be seen in Figure 2. The survey design in Figure 2 was prepared using the assistance of Google Earth.



Figure 2. Microtremor survey lines in Bledug Kuwu area

RESULT

Dominant Frequency

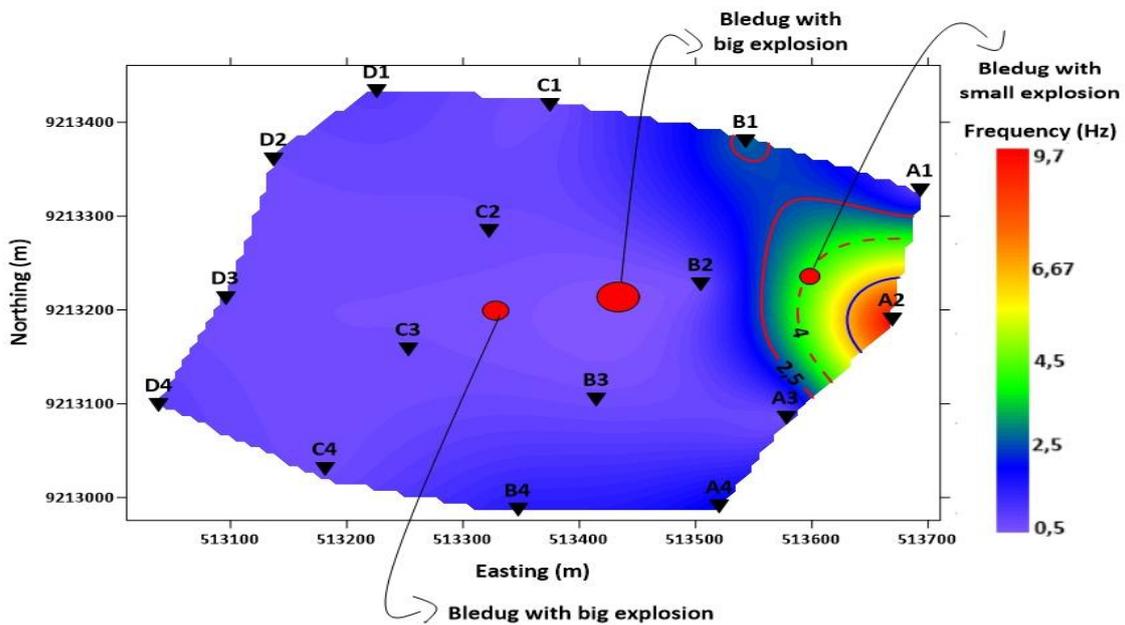


Figure 3. Dominant Frequency of The Research Area

The dominant frequency produced from the processing is shown in Figure 3. The dominant frequency values range from 0.52 to 9.7 Hz. The red on the contour map indicates that the dominant frequency values of 6.67 to 9.7 Hz are located in the area of point A2, which is close to the Bledug Kuwu eruption. The yellow represents the dominant frequency values of 4.5 to 6.67 Hz, with the yellow spread close to point

A2, near a small eruption of bledug. The green indicates the dominant frequency values of 2.5 to 4.5 Hz, which are near a small eruption located close to point A2. The blue dominates the research area, indicating dominant frequency values of 0.5 to 2.5 Hz.

Amplification

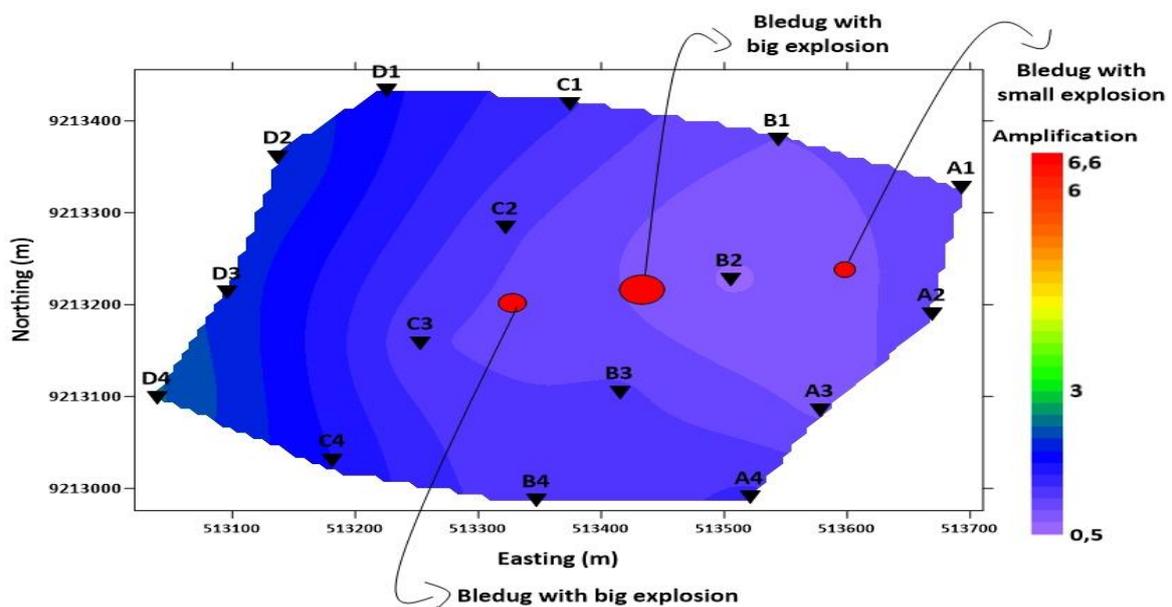


Figure 4. Amplification of The Research Area

The amplification generated from the processing is shown in Figure 4. The amplification in the research area ranges from 0.57 to 2.24. The red on the contour map indicates amplification between 6 to 6.6. The green and yellow represent amplification between 3 to 6. The blue dominates the research area, where blue indicates amplification between 0.5 to 3. Point B2 is the point with the smallest amplification of 0.57. Point B2 is the closest point to the major explosion at Bledug Kuwu.

DISCUSSION

The dominant frequency and amplification are obtained through the HVSR curve analysis in the data processing using Geopsy software. The dominant frequency value is the value that frequently appears and is recognized as the frequency value of the rock formation layers in the area. The classification in Table 1 regarding the dominant frequency shows that low dominant frequencies are associated with thick and soft sediment, while high dominant frequencies indicate thinner sediment thickness [15].

Table 1 Classification of Soil based on Natural Frequency Value [15]

Soil Classification	Frekuensi Dominant (Hz)	Description of Land
Type I	6,67 - 20	Tertiary or older rocks. Consist of hard sand gravel.
Type II	4 – 6,67	Alluvial rocks with a thickness of 5 cm consist of gravelly sand, sandy hard clay, clay, loam, and so on.
Type III	2,5 – 4	Alluvial rocks that are almost similar to soil type II, only differentiated by the presence of an unknown formation (buff formation).
Type IV	< 2,5	Alluvial rocks formed from delta sedimentation, topsoil, mud, soft soil, humus, delta deposits or sludge deposits, etc., which fall under soft soil, with a depth of 30 meters.

The dominant frequency values processed in the research range from 0.5 to 10.00 Hz. The distribution of dominant frequency values in Bledug Kuwu is shown in Figure 3. The dominant frequency in Bledug Kuwu ranges from 0.52 to 9.70 Hz. The highest dominant frequency value of 9.70 Hz is at point A2 in the Bledug Kuwu location, and this frequency can be classified as type 1, associated with tertiary rocks consisting of hard gravelly sandstone [15]. The high dominant frequency value indicates the suitability of the rocks, as shown in Figure 1. The geological map of the Bledug Kuwu area indicates that this region is classified as code Qa, which means it is an alluvial deposit area consisting of silt clay, sand, and gravel [8].

The lowest dominant frequency value of 0.52 is located in Bledug Kuwu at point locations B2, C3, and D3. Based on the soil classification according to Kanai, this frequency value is classified as type IV with alluvial rock formed from sedimentation of

mud, soft soil, and mud deposits, which is categorized as soft soil with a depth of 30 meters [15]. This classification is consistent with the actual conditions at that point, and the research documentation for locations near B2, C3, and D3 is shown in Figure 5.

Amplification is a very striking difference between the layers traversed by seismic waves, which can lead to wave magnification. Seismic wave amplification occurs when traveling from a softer medium compared to the previous medium. The greater the wave velocity, the greater the amplification of that area, indicating that amplification is related to the density of the layer [16].

The results of the microtremor acquisition in Bledug Kuwu and Bledug Kramesan produced amplification values (A0) ranging from 0.57 to 2.24. The classification of vulnerability levels based on amplification values according to Daryono is shown in Table 2 [17].

Table 2. Classification of amplification vulnerability levels [17]

Amplification Level	Vulnerability Level	Meaning of Amplification
< 3	1	Low
3 – 6	2	Medium
6 – 9	3	High
> 9	4	Very High

The amplification based on Table 4.2 shows that the amplification of the research area ranges from 0.57 to 2.24, indicating low amplification [17]. The lowest amplification of 0.57 is located at point B2 and the highest amplification of 2.24 is located at point D4. The average amplification of the research area is 2.11, according to Daryono's classification, this amplification falls into zone 1, which is classified as low [17]. The results of the processing showed that the closer it is to a large explosion, the smaller the amplification of that area. The distribution of amplification values and frequency shows that the relationship between the two tends to be inversely proportional, areas with low frequency have high amplification and vice versa. The correlation between the two may be influenced by the sediment thickness values in the research area. [13].

CONCLUSION

Data processing with the HVSR method produces amplification and dominant frequency. The amplification of the research area was 0.57 to 2,24, the results of the processing showed that the closer it is to a large explosion, the smaller the amplification of that area. The dominant frequency value (f_0) in the study area was 0.52 to 9.7 Hz. The processing results showed that the study area was dominated by type IV classification with a dominant frequency value of less than 2.5 Hz. Type IV classification showed that the area was composed of alluvial rocks formed from mud sedimentation, soft soils, mud deposits, and which were classified into soft soils with a depth of 30 meters.

Declaration by Authors

Acknowledgement: None

Source of Funding: None

Conflict of Interest: No conflicts of interest declared.

REFERENCES

1. Bonini, M. Mud Volcanoes Indicators of Stress Orientation and Tectonic Control. *Earth-Science Reviews*. 2012; 115:121–152.
2. Saka, B.G.M., Suryanto, W. *Pemodelan Bawah Permukaan Gunung Lumpur Bledug Kuwu, Grobogan, Jawa Tengah Berdasarkan Inversi Data Mikrotremor*. Tesis. Universitas Gadjah Mada. 2015.
3. Arintalofa, V. *Analisa Mikrotremor Menggunakan Metode HVSR untuk Mengetahui Karakteristik Bawah Permukaan Manifestasi Panas Bumi Diwak dan Derekan Berdasarkan Nilai Vp*. *Jurnal Energi Baru dan Terbarukan*. 2020; 2(2):54–61.
4. Nurwidyanto. *Struktur Bawah Permukaan Pantai Semarang Berdasarkan Metode HVSR*. *Indonesian Journal of Applied Physics*. 2023; 13(1):117.
5. Sasongko, Yuliyanto, G. *Karakteriasi Daerah Rawan Gerakan Tanah di Lapangan Pandanmurti Desa Candigaron Kecamatan Sumowono Kabupaten Semarang dengan Metode Mikrotremor*. *Jurnal Pembangunan Wilayah dan Kota*. 2020; 16(2):136–143.
6. Yulianto, T., Yuliyanto, G. *Microtremor Data and HVSR Method in the Kaligarang Fault Zone Semarang, Indonesia*. *Data in Brief*. 2023; 49:109408.
7. Gosar, A. *Study on the Applicability of the Microtremor HVSR Method to Support Seismic Microzonation in the Town of Idrija (W Slovenia)*. *Natural Hazards and Earth System Sciences*. 2017; 17(6):925–937.
8. Datun, et al. *Geological Map of The Ngawi Quadrangle, Jawa*. Geological Research and Development Centre. 1996.
9. Satyana, A. *Diapir Lumpur dan Gunung Berapi Lumpur di Depresi Jawa Hingga Madura: Asal-usul, Sifat, dan Implikasi Terhadap Sistem Perminyakan*. Asosiasi Perminyakan Indonesia. 2008.
10. Sabdaningsih, A. *Mitologi dan Sains: Bledug Kuwu di Kabupaten Grobogan*.

- Sabda: Journal of Cultural Analysis. 2018; 13(1):7–17.
11. Indriana, R.D., Nurdwiyanto, M.I., Haryono, K.W. Interpretasi Bawah Permukaan dengan Metode Self Potential Daerah Bledug Kuwu Kradenan Grobogan. Berkala Fisika. 2007; 10(3):155–167.
 12. Adhi, M., Wahyudi, Suryanto, W. Kajian Geofisika Bawah Permukaan untuk Memodelkan Sistem Gunung Lumpur Bledug Kuwu Purwodadi Jawa Tengah. Universitas Gadjah Mada. 2019.
 13. Nakamura, Y. Clear Identification of Fundamental Idea of Nakamura's Technique and Its Applications. Proceedings of the 12th World Conference on Earthquake Engineering. Auckland, New Zealand. 2000; 30 January–4 February.
 14. Nakamura, Y. A Method for Dynamic Characteristic Estimation of Subsurface Using Microtremor on the Ground Surface. Q.R. of R.T.I. 1989; 30(1):25–33.
 15. Kanai, K. Engineering Seismology. Tokyo University: Japan. 1983.
 16. Sitorus, N., Purwanto, S., Utama, W. Analisis Nilai Frekuensi Natural dan Amplifikasi Desa Olak Alen Blitar Menggunakan Metode Mikrotremor HVSR. Jurnal Geosaintek. 2017; 3(2):89.
 17. Daryono, Sutikno, J., Sartohadi, Brotopuspito. Pengkajian Local Site di Graben Bantul Menggunakan Indeks Kerentanan Seismik Berdasarkan Pengukuran Mikrotremor. Jurnal Kebencanaan Indonesia. 2009; 2(2):456–467.

How to cite this article: Rizka Nur Syihab, Gatot Yuliyanto, Tony Yulianto. Identification of subsurface structures based on dominant frequency and amplification, case study at Bledug Kuwu, Central of Java, Indonesia. *International Journal of Research and Review*. 2025; 12(6): 517-523. DOI: <https://doi.org/10.52403/ijrr.20250659>
