Preliminary study site characterization using HVSR microtremor in West Bandung Basin

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Abstract. Site characteristic become crucial factor in seismic hazard assessment correspond to the site response of earthquake motions. This study investigates site characterization in the western part of the Bandung Basin using the Horizontal-to-Vertical Spectral Ratio (HVSR) method. HVSR analysis was applied to the Rayleigh wave microtremor data that was conducted at observation sites i.e: Baros, Cibeber, Batujajar, and Giriasih. The analysis results revealed some soil parameters i.e: dominant period (Td) values ranging from 0.23 to 0.43 seconds, S-wave velocity structure down to a depth of 30 (Vs_{30}) in a range of 173.25 m/s in Cibeber to the highest was 281.76 m/s in Baros. The result of Vs_{30} analysis were used to classify local site which is Baros site can be classified into the stiff soil (SD) category, Cibeber and Batujajar belong to the soft soil (SC) category, and Giriasih is classified as very soft soil (SE). The findings of this study provide valuable information for seismic hazard assessment, seismic site classification, and earthquake-resistant structural design in the western part of the Bandung Basin.

1 Introduction

An earthquake is a sudden release of energy that generates seismic waves which spreads in all directions, causing the ground to shake and crack, often causing damage to the affected area. These events are primarily triggered by various geological activities, including volcanic eruptions and tectonic plate movements [1]. As widely recognized, the Bandung region is particularly susceptible to earthquakes due to its underlying geological structure, characterized by active tectonic zones [2]. The seismic sources in Indonesia that have been well identified can be defined into shallow crustal that are located on land, and megathrust that are located in the ocean [3].

This study located on eastern part of the West Bandung basin, where many active faults around it and the closest one is Lembang Fault. The Lembang Fault is an active geological structure extending 29 kilometers in West-east direction located in the Northern Bandung City. It exhibits a slip rate of 2 mm/year [3-5]. This movement indicates that the Lembang Fault is capable of generating earthquakes with magnitudes ranging from 6.5 to 7.0 Mw, with a recurrence interval of approximately 500 years [5]. Beside the Lembang fault, there are many active faults around the study area, including: Cimandiri, Nyalindung and Rajamandala segment of active faults [3] which considered can have an impact if an earthquake occurs.

Given the high earthquake intensity and vulnerability of the West Bandung region, mitigation measures are crucial to minimize the potential impact of seismic events. To effectively implement these measures, a comprehensive understanding of site characteristics, site effect distribution and quantifying site response to seismic motion are essential. This study aims to address this need by employing the microtremor Horizontal-to-Vertical Spectral Ratio (HVSR) method to characterize sites in West Bandung. The HVSR analysis will provide valuable insights into the dominant frequency, seismic vulnerability index, Vs_{30} and site class for the region. Analysis microtremor data by using HVSR method is very useful and has been widely applied for seismic microzonation [6].

2 Material and methods

2.1 Study area

The study area encompasses the western portion of the Bandung Basin, spanning from Cililin to Cihampelas, Batujajar, and Cimahi. This western region of the Bandung Basin is demarcated by Tertiary volcanic rocks and belongs to the Rajamandala Formation. The Rajamandala Formation is the sole non-volcanic sedimentary rock unit in the area, composed by limestone, mudstone, shale, and quartz sandstone [7, 8]. The study employed 14 single-station data measurement points with interval distance about 1 – 3 km to obtain general feature for the next study in more detail for this area, as illustrated in Fig. 1. The single station microtremor survey method using HVSR analysis developed by Nakamura (1989) is very possible to be carried out in densely populated or limited areas. The instrumentation used in the field work

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is a kind of seismograph using triaxial sensor developed by OYO Corp.

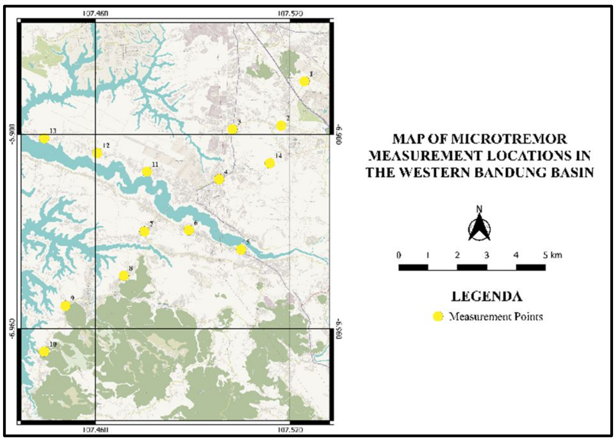

Fig. 1. Map of microtremor measurement locations in the Western Bandung Basin

2.2 HVSR method

This study utilized the single station microtremor method that was developed by Nakamura (1989). This method is relatively simple in operational because no require seismic source and requiring relatively short measurement times at each location.

The processing of microtremor data was conducted by using the HVSR method [9-11] involves employing specialized software like Geopsy to compute Fast Fourier Transform (FFT) and to generate HVSR curves by using mathematical equation 1 [12]:

$$HVSR = \frac{\sqrt{[(S_{North-South})^2+(S_{East-West})^2]}}{S_{Vertical}} \tag{1}$$

The HVSR curves are describe a correlation beween dominant frequency (f_0) or Period (T_0) and Spectrum amplitude (A_0). Further analysis are calculate of some parameter such as seismic vulnerability index (Ivs), which serves as a quantitative measure of a site's susceptibility to earthquake damage.

Dominant frequency, denoted as f_0, represents the natural frequency of the subsurface layers that was influenced by the thickness and hardness of the soil layer. Consequently, the dominant frequency reflects subsurface characteristics. Dominant frequency is also related to shear-wave velocity and thickness in the subsurface [8]. Lower dominant frequencies can suggest increased seismic vulnerability and indicate thicker sediment. The dominant frequency can be estimated using the following empirical relationship [13]:

$$f_0 = \frac{V_s}{4h} \tag{2}$$

Where f_0 is the dominant frequency (Hz), V_s is shear wave velocity (m/s), and h is the thickness of the sediment layer (m).

The dominant period is derived from the dominant frequency value (Fo), as shown in equation:

$$T_0 = \frac{1}{f_0} \tag{3}$$

where T_0 is the dominant period (s) and f_0 is the dominant frequency (Hz).

Seismic Vulnerability Index can indicate a potential of deformation and damage to the earthquake shaking. The correlation of some parameters i.e: seismic vulnerability index, dominant frequency and amplification factor can be shown by equation as follows [1]:

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

Where Kg is the seismic vulnerability index, Ao is the amplification factor, and fo is the natural frequency (Hz).

Vs_{30} reflect soil hardness that one of the crucial parameters in application to engineering purpose. This parameter can be calculated by averaged over the top 30 meters of the subsurface. The relationship of Vs_{30} and the amplification factor is crucial for understanding site-specific seismic response and predicting ground motion during earthquakes [14]. Vs_{30} values can be determined using the following equation [15]:

$$Vs_{30} = \frac{30}{\sum_{i=1}^{N} \frac{h_i}{Vs_i}} \tag{5}$$

Where *Vs30* is average of *Vs* for the top of 30m, h_i is thickness of layer i-th and Vs_i is velocity of i-th.

3 Results and discussion

3.1 HVSR analysis results

Recorded microtremor data comprises seismic wave signals in three components: Vertical, North-South, and East-West. Data processing divided into some steps which is the first step is to identify and extract stationary signals from the noisy background. This process involves filtering and analyzing the data series to obtain the coherent microtremor signals that provide valuable information about the subsurface structure.

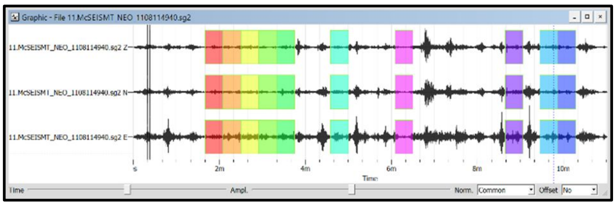

Fig. 2. Windowing of microtremor time series

The microtremor data in time series then divided into some segment consist of 20,48 s time window to select stationary data and noise present in the signal. The example of windowing process is shown in the site location 1 (Fig. 2). This window size selection is based on the characteristics of the noise and its impact on the data. Smoothing process was conducted by using Konno and Ohmachi method to removes high-frequency noise while preserving the underlying signal characteristics [16].

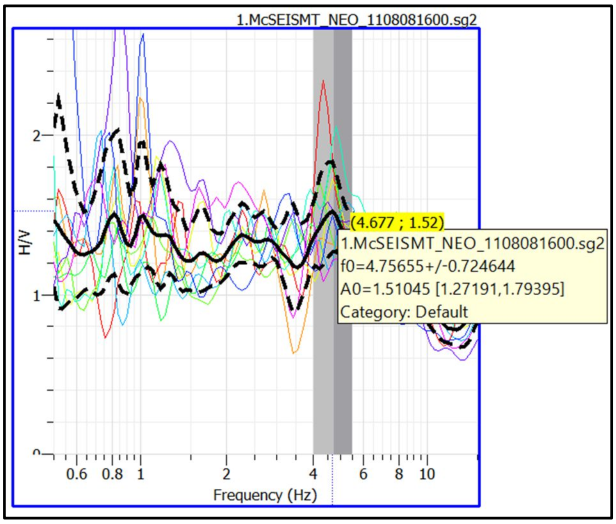

Fig. 3. Average horizontal-to-vertical spectral ratio curve (solid black line with standard deviation shown by dashed lines) statistically calculated from each time window's HVSR (colored lines).

Horizontal-to-vertical spectral ratio (H/V) curve (HVSR) describe distribution of amplitude of Fourier spectra (A_0) with respect to dominant frequency (f_0). As an example, shown in Fig. 3 for observation site 1, the extracted values for dominant frequency and amplitude were 4.677 Hz and 1.510, respectively.

The dominant frequency is determined from the peak amplitude of the H/V curve (represented by the solid black line without breaks). This dominant frequency reflects subsurface condition by referring to Kanai classification (1983) [17].

A comprehensive study was conducted to investigate the seismic response variations within the Western Bandung Basin, Indonesia. Utilizing the HVSR (Horizontal-to-Vertical Spectral Ratio) method, 14 sites were analyzed across the region, revealing a remarkable range of predominant frequencies (f_0) and amplification factors (A_0).

The highest dominant frequency value of 13.05 Hz was observed at the Batujajar research site. This finding indicates the presence of relatively hard and well-consolidated geological formations beneath the surface. This aligns with the geological history of the region, where sediments in Batujajar are relatively older compared to other areas in the basin. The extended time period has allowed for greater compaction and cementation, leading to increased stiffness and shear-wave velocity (Vs). Additionally, the relatively shallow depth to bedrock in Batujajar contributes to the higher f_0 value, as the stiffer bedrock material influences the overall seismic response.

The lowest dominant frequency value of 0.55 Hz was recorded in Cipatik, located at the foot of a mountain with steep and hilly topography. This low value suggests the presence of relatively soft and unconsolidated geological formations beneath the surface. This observation is consistent with the geological history of the area, where loose and easily compacted volcanic deposits dominate. The high water content in Cipatik's volcanic sediments further lowers Vs and amplifies the effect of seismic wave amplification.

The dominant period (T) is inversely proportional to the dominant frequency (f_0). In other words, as the frequency decreases, the period increases. While the relationship between dominant frequency/period and seismic vulnerability are shown by equation 5. An areas with higher dominant period values are considered to be at higher risk of earthquake damage, while areas with lower dominant period values are considered to be at lower risk [13].

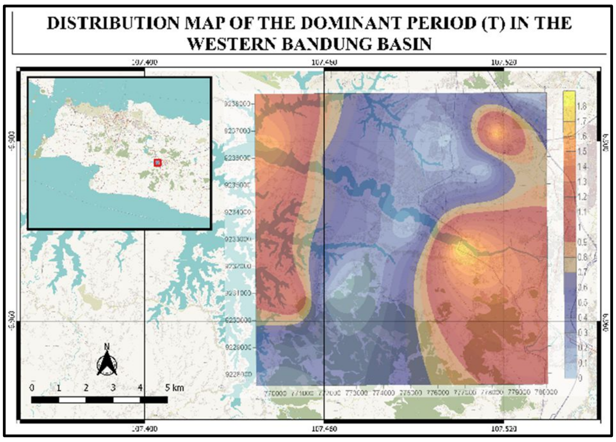

Fig. 4. Spatial distribution map of the dominant period (T) in the western Bandung Basin

A comprehensive analysis of dominant period values obtained from microtremor measurements at 14 locations within the western Bandung Basin unveils crucial insights into the region's soil characteristics and seismic response. The dominant period values are in a range from 0.07 to 1.8 seconds, indicating a predominant of low-period soils across the study area (Fig. 4).

Characterized by hard soil conditions, this category encompasses areas with dominant periods ranging from 0.07 to 0.09 seconds. These regions are likely underlain by hard bedrock or have a thin soil layer overlying bedrock. Due to the inherent rigidity of hard soils, seismic activity in these zones is typically low as the ground effectively dampens vibrations. Representing moderately hard soil conditions, this category encompasses areas with dominant periods ranging from 0.21 to 0.24 seconds. These regions exhibit thicker soil layers compared to Type I soils, potentially comprising deeper alluvial deposits or clay soils with a mix of denser materials. Such soils exhibit moderate responsiveness to seismic waves, with the potential for moderate amplification. Indicating soft soil conditions, this category encompasses areas with dominant periods ranging from 0.28 to 0.40 seconds. These regions feature thick sedimentary deposits, such as alluvial sediments or deep clay soils, which can lead to more significant seismic wave amplification, increasing the risk of earthquake-induced damage. These areas represent the accumulation of younger, less consolidated material. Characterized by very soft soil conditions, this category encompasses areas with dominant periods ranging from 0.45 to 0.62 seconds. These regions typically comprise extremely thick, loose sediments, such as marshlands or deep river deposits. Such areas possess a very high potential for seismic wave amplification, posing a substantial risk to infrastructure and buildings.

Table 1. Soil classification table based on microtremor dominant period values (modified from [17])

Soil Classification	Periode (T)	Characteristic
Type I	0.05 - 0.15	Hard (tertiary or older rocks), consist of hard sandy rock and gravel.
Type II	0.15 - 0.25	Medium, consist of gravel, sandy hard clay, and loam.
Type III	0.25 - 0.40	Soft, consist of sand, sandy clay, and clay.
Type IV	> 0.40	Very soft soil.

Areas with dominant period values ranging from 1.2 to 1.8 seconds, represented by shades of red to light yellow on the map, are primarily located in the western and southeastern parts of the region. According to Kanai's soil classification [17], the identified range of 1.2 to 1.8 seconds falls under category IV that has a high potential for seismic amplification, which has the potential to have a greater impact on building damage. This category encompasses very soft soil conditions, typically composed of thick sedimentary deposits such as clays, sands, and alluvial materials. These sediments, due to their slow acoustic properties, exhibit longer dominant periods.

The analysis of Seismic Vulnerability Index (SVI) values derived from microtremor measurements revealed a distinct spatial variation across the 14 measurement points. In general, the SVI values ranged from 0.25 to 14.04, indicating significant heterogeneity in seismic vulnerability within the Western Bandung Basin as shown in Fig. 5.

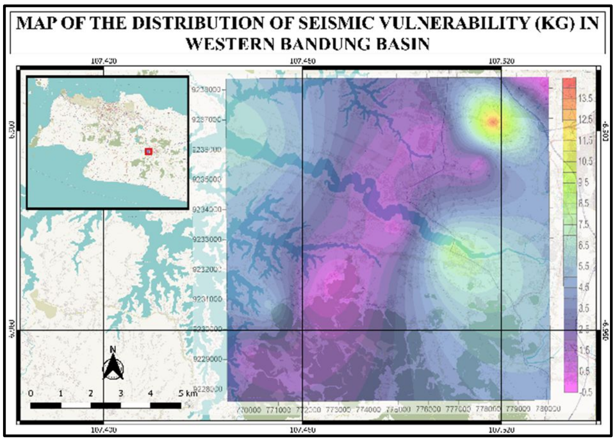

Fig. 5. Map of the spatial distribution of seismic vulnerability (kg) in the western Bandung Basin

The research points in the South Cimahi District show the highest seismic vulnerability index value, specifically 14.04. Referring to the geological map of the research area, these points feature hilly topography with steep slopes and are situated near an active fault, namely the Lembang Fault. The surface of this area consists of alluvial deposits, which increase the risk of strong ground shaking during earthquakes.

In contrast, the research points in the Cililin District exhibit the lowest seismic vulnerability index value, specifically 0.25. The soil in this area tends to be more compact and consolidated, such as bedrock or thin layers of soil overlying hard rock, naturally dampening seismic vibrations and reducing wave amplification. Additionally, this region is located far from seismic activity sources or active faults, thereby reducing earthquake risk. The area has relatively flat topography with minimal slopes, further the potential for seismic wave amplification.

3.2 1D S-wave velocity profiling

Site characterization include investigation of subsurface structure, thickness and hardness of soil/rock layers. Soil S-wave velocity is one of the important parameters for classifying soil types for engineering purposes [18]. Other parameters that can be used to determine the site class are based on the Standard Penetration Test (SPT) and soil shear strength [15].

Estimation of S-wave velocity was conducted by using inversion method to the HVSR curve by some soil parameters model including thickness, velocity and density. In this study, the ellipticity curve method of HVSR inversion with fitting is employed. The final model was considered by the smallest misfit between observed and calculated one. Some parameters that considered in the inversion process include compression-wave velocity (m/s), Poisson's ratio, shear-wave velocity (m/s), and density (kg/m^3) that constructed by referring to local geology/geotechnical condition.

Since this study was intended for shallow layer survey to estimate Vs_{30} and site class, then profile of S-wave velocity structure is constructed by modelling of subsurface down to a depth of 50 meters at each measurement location. The example of Vs profile were presented in Fig. 6 for four site resulting from inversion technique. It can be seen that the thickness and S-wave velocity are vary for each site that represent subsurface condition.

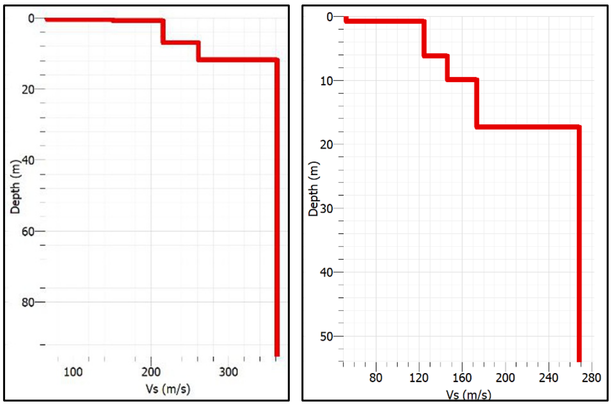

Fig. 6. The example of ground profiles generated from single microtremor data at site 1 and site 2

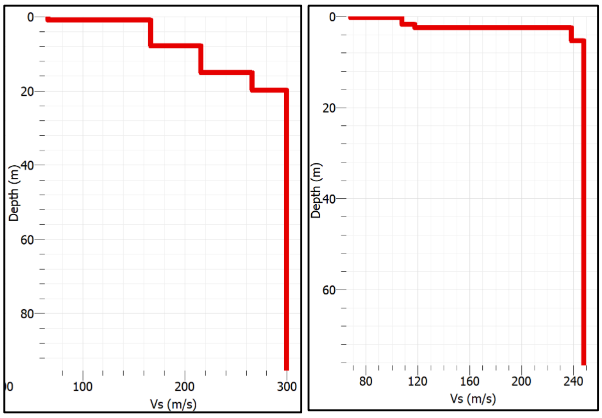

Fig. 6. Continue for site 3 and site 4

Site classification of this study area then was determined based on Vs30 by referring to Indonesian National Standard (SNI-1726-2017) [15].

The Vs values for each layer are then calculated down to a depth of 30 meters to derive the Vs30 value using the following equation and the example are shown in the location of Cimahi Tengah.

$$V_{S30} = \frac{30}{\sum_{i=1}^{N} \frac{h_i}{Vs_i}} \tag{6}$$

$$= \frac{30}{\frac{0.43}{66.73} + \frac{0.44}{150.88} + \frac{6.06}{215.88} + \frac{4.98}{260.80} + \frac{18.09}{362.18}} = 281.76\, m/s \tag{7}$$

Referring to result of Vs30 calculation above, point 1 in Cimahi Tengah District has a Vs30 about 281.76 m/s, indicating that this site can be classified into the SD (medium soil) category at a depth of 30 meters from the surface. Based on the calculation of Vs30 values, it shows that the four points sampled in the Cimahi - Batujajar District area are predominantly of the SE (soft soil) to SD (medium soil) types.

The calculated Vs30 values for the four location points range from 173.25 m/s to 281.76 m/s. Based on the standard Vs30 site classification, in general the study area can be described in Fig. 7 by using kriging method which is Vs30 are in a range of 173.25 m/s to 281.76 m/s.

The lowest Vs30 value of 173.25 m/s was recorded at the observation point in Baros, Cimahi Tengah District. Based on the standard Vs30 site classification table (Table 1.) [15], this value corresponds to the SE (Soft Soil) category. This classification indicates that the subsurface materials at this location are relatively loose and deformable, suggesting a higher susceptibility to ground motion amplification and liquefaction hazards during earthquakes. In contrast, higher Vs30 values ranging from 213.30 m/s to 281.76 m/s were observed at the research points in Cibeber, Cimahi Selatan District, and Batujajar, Bandung Barat District. These values fall within the SD (Stiff Soil) category according to the Vs30 site classification table. This classification suggests that the subsurface materials at these locations are moderately rigid and can transmit seismic waves more efficiently, implying a lower likelihood of severe ground motion amplification.

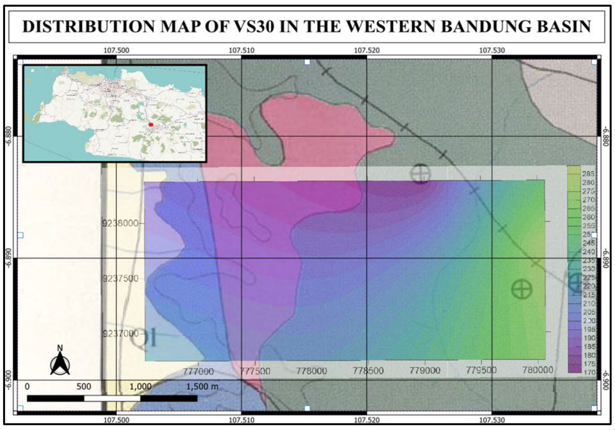

Fig. 7. Spatial distribution map of Vs30 in the Western Bandung Basin

In contrast to the Cimahi site, higher Vs30 values ranging from 213.30 m/s to 281.76 m/s were observed at the research points in Cibeber, Cimahi Selatan District, and Batujajar, Bandung Barat District. These values fall within the SD (Medium Soil). This classification suggests that the subsurface condition at these locations are moderately rigid. The smallest of Vs30 was obtained at the Cibeber site in Cimahi Selatan area which is Vs30 is about 173.25 m/s that can be classified into site class SE (soft soil). This location is typically associated with unconsolidated alluvial deposits.

The correlation of observed spatial variation in Vs30 values and seismic site classifications to the topography of the region, in general, indicate the lowest Vs30 (Baros site) is located at a lower elevation, while the location with higher Vs30 values (Cibeber and Batujajar) are situated at higher elevations. This suggests a correlation between elevation and subsurface characteristics has a good agreement.

The high Vs30 value of 281.76 m/s recorded at the Baros observation point indicates hard and dense soil conditions. This classification is typically associated with bedrock or compacted soils, such as sandstone or consolidated sedimentary rocks. The high shear wave velocity suggests that the subsurface materials at this location are rigid and efficient in transmitting seismic waves, implying a lower likelihood of severe ground motion amplification. The Vs30 value of 213.30 m/s obtained at the Cibeber research point suggests softer soil conditions compared to Baros. This could be attributed to the presence of clay deposits or looser soils, which generally exhibit lower shear wave velocities than bedrock. The softer soil conditions at Cibeber may result in a higher susceptibility to ground motion amplification compared to Baros. The Vs30 value of 221.31 m/s recorded at the Batujajar research point indicates intermediate soil conditions, falling between the hard and dense soils of Baros and the softer soils of Cibeber. This suggests that the subsurface materials at Batujajar may consist of a mixture of sedimentary rocks, volcanic rocks, or clayey materials, influencing the overall shear wave velocity.

Since Vs_{30} reflect geological properties included type of soil/rock and geomorphology, therefore integrating local geological considerations are required for seismic hazard assessment. Study in more detail of site characteristic and geology local, and their effect to the earthquake motion are crucial to improve understanding related to seismic wave propagation and building damages.

4 Conclusion

The analysis of HVSR, dominant period, seismic vulnerability, HVSR inversion, and Vs_{30} in the western part of the Bandung Basin shows a variation in Vs_{30} values and seismic site classifications in the region. Vs_{30} values range from 173.25 m/s to 281.76 m/s, with seismic site classifications ranging from SE (Soft Soil) to SD (Stiff Soil). This variation is influenced by local geological factors such as rock type, soil composition, and other geological conditions. Based on the result of Vs_{30} calculation at entire observation site shows a good correlation to the topography.

This information is important for earthquake hazard assessment and building structure evaluation. S-wave velocity structure reflect site local condition that was related to the amplification phenomenon of the seismic motion. Deep understanding of site characterization as resulting from HVSR microtremor analysis is crucial for developing of seismic hazard analysis for this study area and implementing mitigation measures to minimize seismic risk in the western part of the Bandung Basin.

References

1. Kurniawan, R., Eva, M. N., Marjiyono, and Sismanto. Pemetaan daerah rawan resiko gempa bumi menggunakan metode HVSR di kotamadya Denpasar dan sekitarnya, Bali. KURVATEK, **2**, 21-30, (2017).
2. Ambarwati, I. W., Feranie, S., and Tohari, A. Analisis Potensi Likuifaksi Di Wilayah Cekungan Bandung dengan Menggunakan Metode Uji Penetrasi Konus. RISET Geologi dan Pertambangan, **30**, 21-37. (2020).
3. Irsyam M, Cummins PR, Asrurifak M, Faizal L, Natawidjaja DH, Widiyantoro S, Meilano I, Triyoso W, Rudiyanto A, Hidayati S, Ridwan M, Hanifa NR, Syahbana AJ Development of the 2017 national seismic hazard maps of Indonesia. Earthq. Spectra **36**, 112–136. (2020)
4. Meilano, I., Abidin, H. Z., Andreas, H., Gumilar, I., Sarsito, D., Hanifa, R., Rino, Harjono, H, Kato, T, Kimata, F, and Fukuda, Y, Slip rate estimation of the Lembang fault West Java from geodetic observation: Journal of Disaster Research, **7**, 12–18. (2012)
5. Daryono, M. R. and Natawidjaja, D. H. Lembang Active fault study using high resolution digital elevationmodel (DEM)image: Poster session presented at Geotechnology Science Week, Research Centre for Geotechnology, Indonesia Institute of Science, Bandung, Indonesia. (2015)
6. Gosar, A., Study on the applicability of microtremor HVSR method to support seismic microzonation in the town of Idrija (W Slovenia), Nat. Hazards Earth Syst. Sci. Discuss. (2017)
7. Bronto, S., and Hartono, U. Potensi sumber daya geologi di daerah Cekungan Bandung dan sekitarnya. Jurnal Geologi Indonesia, **1**, 9-18, (2006).
8. Silitonga, P.H. Geological Map of the Bandung Quadrangle, Jawa, Scale 1:100.000, Geological Research and Development Centre. (2003)
9. Nakamura, Y. A Method for Dynamic Characteristics Estimation of Subsurface using Microtremor on the Ground Surface, Quarterly Report of Railway Technical Research Institute (RTRI), **30(**1). (1989),
10. Nakamura, Y, Clear Identification of Fundamental Idea of Nakamura's Technique and Its Applications, 12 WCEE 2656. (2000)
11. Nakamura, Y, On The H/V Spectrum, The 14 th World Conference on Earthquake Engineering October 12-17, (2008)
12. Rahman, A. S., Nugroho, H., Permana, D., Sativa, O., Riyanto, A., Sirait, R. K et al. Analisis nilai periode dominan tanah dan amplifikasi akibat gempabumi Tarutung M5.8 01 Oktober 2022 terhadap kerusakan infrastruktur berdasarkan metode HVSR. **4**, 28-33, (2023).
13. Putra, A. K., Yatini, Y., and Paripurno, E. T, Application of HVSR method on microtremor data for analysis of earthquake potential in Candipuro District, Lumajang, Indonesia. Journal of Geoscience, Engineering, Environment, and Technology, **8**, (2023).
14. Bustari, A. A., and Wibowo, N. B. Pemetaan sebaran nilai Vs30, faktor amplifikasi tanah, dan peak ground acceleration wilayah Bantul Timur. Cakrawala Jurnal Ilmiah Bidang Sains, **1**, 73-80. (2023).
15. (BSN) Badan Standardisasi Nasional Indonesia SNI-03-1726-2019: Tata cara perencanaan ketahanan gempa untuk struktur bangunan gedung dan non gedung. (2019)
16. Ambarsari, D. Analisis Mikrotremor Dengan Metode HVSR Untuk Mikrozonasi Kabupaten Gunungkidul Yogyakarta. Tugas akhir–sf, 141501. (2017).
17. Haerudin, N., Alami, F., and Yogi, I. B. S. The effect site analysis based on microtremor data using the Horizontal to Vertical Spectral Ratio (HVSR) method in the Bandar Lampung City. In Journal of Physics: Conference Series, **1572**, 1, 012075. (2020).
18. Kyaw, Z. L., Pramumijoyo, S., Husein, S., Fathani, T.F., Kiyono, J. Ground Motion in Yogyakarta City, Yogyakarta Special Province, Indonesia on Densely Microtremor Observations and Shear Wave Velocity, J. SE Asian Appl. Geol., Jan–Jun 2013, **5**(1), 10–20, (2013)