

IDENTIFICATION OF SUBSURFACE STRUCTURES OF ACCRETION AREA USING HVSr METHOD: A CASE STUDY OF BENGKULU CITY

Agnes Apriana*, M. Fikri Azhari*, Elfi Yuliza*, Refrizon*

*Department of Physics, Faculty of Mathematics and Natural Sciences, Bengkulu University, Bengkulu, Indonesia, agnesapriana01@gmail.com, mfazhari@unib.ac.id, elfi.yuliza@gmail.com, refrizon@unib.ac.id

Email Correspondence : refrizon@unib.ac.id

Received : May 15, 2025

Accepted : December 28, 2025

Published : December 31, 2025

Abstract: Bengkulu City, located in a tectonically active accretion zone, was selected as the study area due to its high susceptibility to seismic hazards. Horizontal to Vertical Spectral Ratio (HVSr) method based on microtremor data is an effective non-invasive technique to determine the dominant frequency (f_0), amplification factor (A_0), and shear wave velocity profile (V_s). This study aims to identify subsurface structures in the accretion area of Bengkulu City by analyzing microtremor data using the HVSr method. Data acquisition was conducted at 45 measurement points, recorded using a PASI Mod Gemini 2 Sn 1405 Seismometer. Data analysis utilized the Python version 3.7.0 computing platform, and the Terraware-HV to derive HVSr curves describing the f_0 and A_0 . The values of f_0 and A_0 were used to calculate the seismic susceptibility index (K_g). Furthermore, the inversion of HVSr curves was conducted to obtain the V_s . The results showed that f_0 0.90-2.10 Hz, A_0 2.08-5.49, K_g 4.36-21.68, and V_{s30} were identified as type D ($180 \leq V_s < 360$), which indicates that the subsurface rock consists of a stiff soil layer. Furthermore, V_s the inversion of the HVSr curve shows that vertically, the subsurface structure of the study area consists of several layers, namely soft soil, stiff soil, very dense soil, and soft rock. The 3D model of the V_s distribution confirms that the study area, consistent with its identity as an accretion zone, is predominantly composed of alluvial deposits, including layers of sand and clay.

Keywords: HVSr Method; Microtremor; Shear Wave Velocity (V_s); Subsurface Structure

Abstrak: Kota Bengkulu, yang terletak di zona akresi yang aktif secara tektonik, dipilih sebagai area penelitian karena kerentanannya yang tinggi terhadap bahaya seismik. Metode *Horizontal to Vertical Spectral Ratio* (HVSr) berbasis data mikrotremor merupakan teknik *non-invasif* yang efektif untuk menentukan frekuensi dominan (f_0), faktor amplifikasi (A_0), serta profil kecepatan gelombang geser (V_s). Penelitian ini bertujuan untuk mengidentifikasi struktur bawah permukaan daerah akresi Kota Bengkulu dengan menganalisis data mikrotremor menggunakan metode HVSr. Akuisisi data dilakukan pada 45 titik pengukuran menggunakan seismometer PASI Mod Gemini 2 Sn 1405. Analisis data memanfaatkan platform komputasi Python versi 3.7.0, dan Terraware-HV untuk memperoleh kurva HVSr yang menggambarkan f_0 dan A_0 . Nilai f_0 dan A_0 digunakan untuk menghitung indeks kerentanan seismik (K_g). Selanjutnya, dilakukan inversi kurva HVSr untuk mendapatkan profil V_s . Hasil penelitian menunjukkan f_0 0.90-2.10 Hz, A_0 2.08-5.49, K_g 4.36-21.68, dan V_{s30} yang teridentifikasi

adalah tipe D ($180 \leq V_s < 360$), yang menunjukkan bahwa batuan bawah permukaan terdiri dari lapisan *stiff soil*. Selanjutnya, V_s berdasarkan inversi kurva HVSR menunjukkan bahwa secara vertikal, struktur bawah permukaan daerah penelitian terdiri dari beberapa lapisan, yaitu *soft soil*, *stiff soil*, *very dense soil*, dan *soft rock*. Model 3D distribusi V_s menegaskan bahwa area studi, sesuai dengan identitasnya sebagai zona akresi, sebagian besar terdiri dari endapan aluvial, termasuk lapisan pasir dan tanah liat.

Kata kunci: Metode HVSR; Mikrotremor; Kecepatan Gelombang Geser (V_s); Struktur Bawah Permukaan

Recommended APA Citation :

Apriana, A., Azhari, M. F., Yuliza, E., & Refrizon. (2025). Identification of Subsurface Structures of Accretion Area Using HVSR Method: A Case Study of Bengkulu City. *Elkawnie*, 11(2), 111-126. <https://doi.org/10.22373/ekw.v11i2.30270>

Introduction

Accretion is a shoreline change caused by the transport of larger sediments towards the shore, which has the potential to change the shape of the surface and the stability of the shore (Atmojo et al., 2021). The sedimentation process on land is caused by land clearing, large amounts of freshwater flow due to prolonged rainfall, and transportation of sediments from river bodies to the sea (Istiqomah et al., 2015; Wicaksono et al., 2020). Accretion typically occurs in coastal regions with multiple river mouths, low wave energy, and frequent exposure to storms or other natural hazards (Istiqomah et al., 2015; Wicaksono et al., 2020). Accretion may cause siltation towards the sea, gradually forming land (Istiqomah et al., 2015). This phenomenon influences the geological and geomorphological dynamics of coastal regions, including the development of subsurface structures.

Therefore, identification of subsurface structures in accreting coastal areas is important to understand shallow geologic conditions while evaluating potential risks that may arise. One approach that can be used is the microtremor survey method with the Horizontal to Vertical Spectral Ratio (HVSR) technique. Microtremors are low-amplitude ground vibrations that occur continuously in the subsurface caused by human activities and natural factors (Putti & Satyam, 2020; Supriyadi et al., 2022; Arisona et al., 2023). Anthropogenic vibrations generally have frequencies $< 1 H_z$, whereas natural vibrations occur at frequencies $> 1 H_z$ (Putti & Satyam, 2020). The HVSR method is non-invasive, relatively fast, cost-effective, and effective in identifying sediment layer boundaries, making it suitable for coastal accretion environments. HVSR is a popular technique for analyzing microtremor data to identify subsurface characteristics. The result of data processing is an HVSR curve that displays frequency and amplitude. The HVSR curve can be further processed using the Rayleigh wave inversion technique to acquire information about the seismic wave velocity structure at shallow depths (Fatimah et al., 2022).

The accretion area in Bengkulu City was chosen as a case study due to its representative geology for coastal areas with accretionary processes. In addition,

from a geodynamic perspective, Bengkulu City holds significant importance due to its location adjacent to the subduction area between the Indo-Australian and Eurasian plates. The area is also situated near major segments of the Sumatra Fault, including the Musi and Manna segments, which further increases its vulnerability to seismic hazards such as earthquakes and seismic wave amplification (Rahman et al., 2023; Hadi et al., 2021).

This study aims to identify subsurface structures in the accretion area of Bengkulu City by analyzing microtremor data using the HVSR method. The findings are expected to enhance our understanding of the geological conditions in the Bengkulu City accretion area, and provide a scientific basis for regional spatial planning and disaster mitigation systems.

Method

Generally, the geological formations of Bengkulu City consist of alluvium (Qa), reef limestone (Ql), swamp deposits (Qs), alluvium terraces (Qat), andesite (Tpan), and bintunan formation (QTb) (Rahman et al., 2023; Hadi et al., 2021). According to the geological map (Figure 1), the area is predominantly composed of alluvium terraces, which represent the youngest surface deposits formed during the Holocene epoch (Quaternary period). Alluvium terraces are composed of sand, silt, clay, and gravel and formed through sedimentation processes in river, coastal, and swamp environments (Rahman et al., 2023; Hadi et al., 2021).

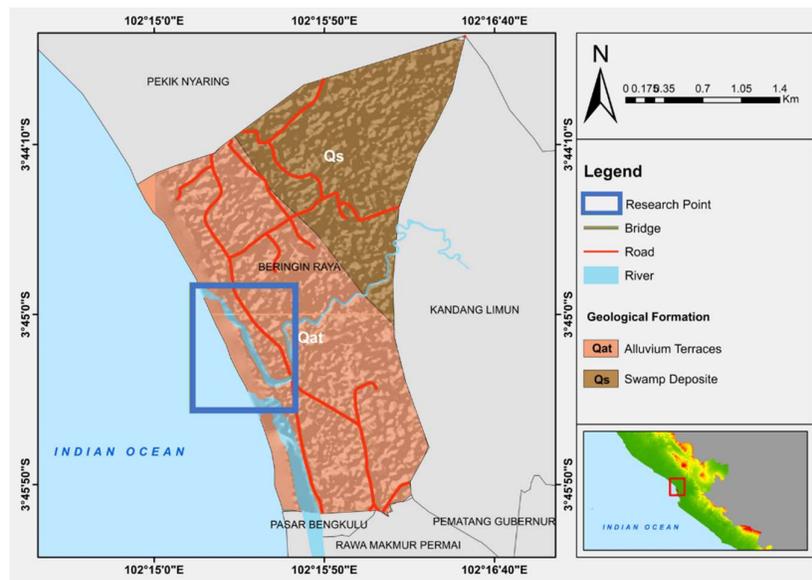


Figure 1. The study area's geologic map

The primary data for this study consist of microtremor measurements recorded using a PASI Mod Gemini-2 SN seismometer. Microtremor measurements were conducted at 45 points (Figure 2) with a distance of 50 meters

for each point. Each selected measurement point was located away from highways and crowded areas to minimize vibration sources that could introduce noise. Data were collected for 30 minutes at each point, with a sampling frequency of 200 H_z to ensure statistical stability and a reliable HVSR result. Seismometer-recorded microtremor measurements consist of three components, namely one vertical component and two horizontal components, North-South (N-S), and East-West (E-W) (Arisona et al., 2023; Farid et al., 2024). Data obtained from seismometer recordings are in the form of signal recording data stored in *SAF format (Panjaitan et al., 2023).

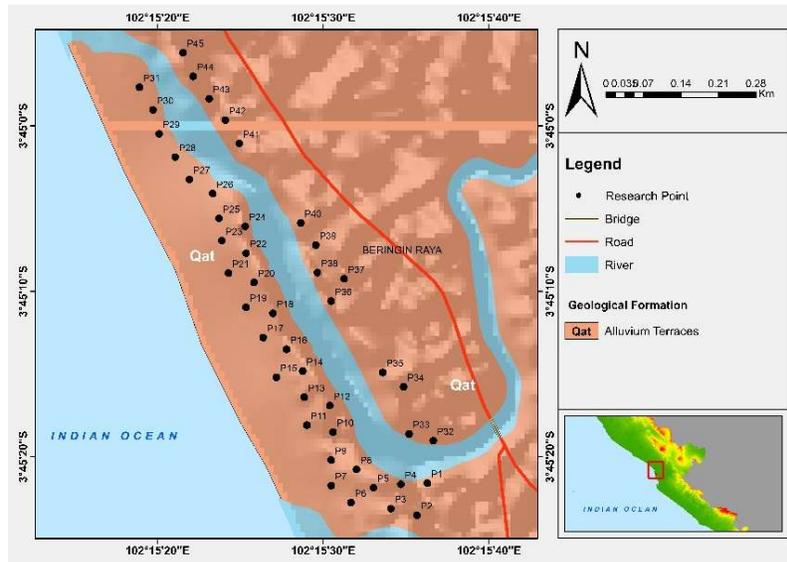


Figure 2. Map of microtremor measurement points

Microtremor data were processed using the HVSR technique implemented in the Terraware-HV software, executed within Python version 3.7.0. HVSR works by comparing the Fourier spectra of horizontal and vertical microtremor wave components (Mase et al., 2021; Arisona et al., 2023). The HVSR can be calculated using Equation (1).

$$HVSR(f) = \sqrt{\frac{A_E(f)^2 + A_N(f)^2}{A_Z(f)^2}} \dots\dots\dots(1)$$

Where $A_E(f)$ is the east-west horizontal component spectrum, $A_N(f)$ is the north-south horizontal component spectrum, and $A_Z(f)$ is the vertical component spectrum (Fatimah et al., 2022). In data processing, the window selection process is carried out in the form of stationary signals. This is because the signal recorded by the seismometer is not only sourced from vibrations from the ground but can also be caused by noise sourced from vibrations of human activity, so it needs to be avoided. In TerraWare HV, the window selection process can be automated, but operators typically review and adjust the windows manually as needed to ensure

data quality before spectrum smoothing and HVSR inversion. Then, smoothing the Fourier spectrum with the Konno-Ohmachi method (Susilanto et al., 2016; Jamal et al., 2017). The data was filtered with a 0.1 Hz high-pass filter to remove slow trends or drifts, and a 20 Hz low-pass filter to suppress high-frequency noise. This frequency range is suitable for characterizing shallow soil layers and identifying dominant seismic resonance frequencies. The result of data processing is an HVSR curve that displays frequency and amplitude. The frequency is called the dominant frequency (f_0), and the amplitude is called the amplification factor (A_0) (Cipta et al., 2023; Susilanto et al., 2016). Next, calculating the seismic susceptibility index (K_g), the f_0 and A_0 values were analyzed using Microsoft Excel. In general, the calculation of the K_g is done through the following mathematical equation (Cipta et al., 2023; Supriyadi et al., 2022).

$$K_g = \frac{A_0^2}{f_0} \dots\dots\dots (2)$$

Then, the HVSR inversion process was performed using the Python version 3.7.0 computing platform, and the Terraware-HV. The HVSR inversion parameters are obtained from the inversion of the observed HVSR curves derived from field-recorded microtremor data. The parameters obtained from the inversion results are layer depth (h), V_s , V_p , and density. HVSR inversion is a process used to analyze the observed HVSR data and determine the most appropriate soil model (Jamal et al., 2017). The HVSR inversion results display a 1D profile (Figure 4) of V_p , V_s , density, and poisson values against depth which can provide information about the subsurface structure (Jamal et al., 2017).

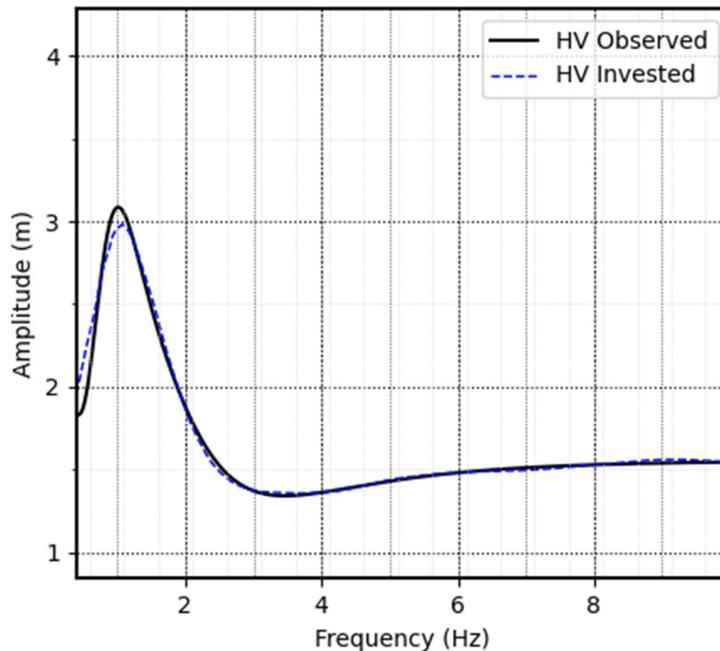


Figure 3. Matching curve of observation and inversion results

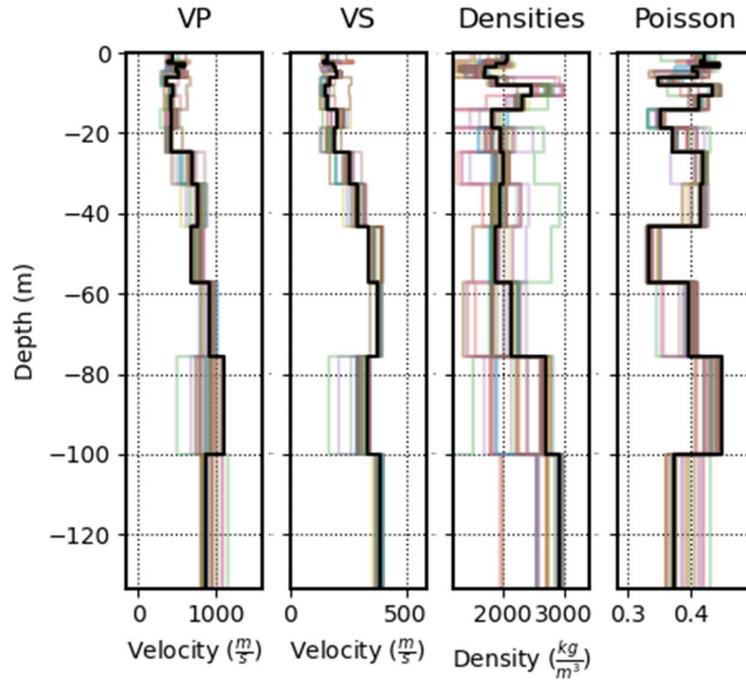


Figure 4. ID model resulting from HVSR curve inversion

Furthermore, the average shear wave velocity to a depth of 30 meters (V_{s30}) can be calculated using the following equation:

$$V_{S30} = \frac{\sum_{i=1}^n d_i}{\sum_{i=1}^n \frac{d_i}{V_{si}}} \dots \dots \dots (3)$$

Where n is the number of layers up to a depth of 30 m , i is the layer index, d_i is the thickness of the i -th layer, and V_{si} is the shear wave velocity of the i -th layer (m/s) (Indra et al., 2019; Nabhan et al., 2023). The V_{s30} values are interpreted as 2D distribution maps based on the National Earthquake Hazards Reduction Program (NEHRP) standard (Indra et al., 2019; Sugianto & Refrizon, 2021; Farid et al., 2024). Although the NEHRP classification is designed for grouping based on V_{s30} values, in this study, it was also used to visualize and interpret the 2D V_s distribution maps resulting from the inversion of HVSR curves at depths of 0, 15, 30, 45, and 100 m . The selected were chosen to represent near-surface to deeper subsurface layers and lateral variations in shear-wave velocity associated with accretion-related sedimentation processes, as resolved by the HVSR inversion result. Furthermore, the distribution of V_s values with depth was visualized in a 3D layered model using the Surfer software, which allowed for interpolation and rendering of both vertical and lateral variations of soil properties across the study area. The 3D visualization was generated by importing the inversion results from HVSR analysis and applying grid-based slicing to illustrate the subsurface structure effectively.

Result and Discussion

Dominant frequency (f_0)

The dominant frequency (f_0) is the peak value of the frequency that often appears, so that its value represents the natural frequency of the rock layer of the area and can provide information about the characteristics of the rock layer (Ridwan et al., 2021). The high and low values of the dominant frequency are influenced by the subsurface structure of the study area, as well as the different sedimentary layers, even in the same area. A higher frequency indicates a thinner sediment layer, while a lower frequency suggests a thicker one (Purnama et al., 2021; Ridwan et al., 2021). The classification of the f_0 has been modified based on the approach proposed by Kanai, as shown in the following table (Nurwidyanto et al., 2023).

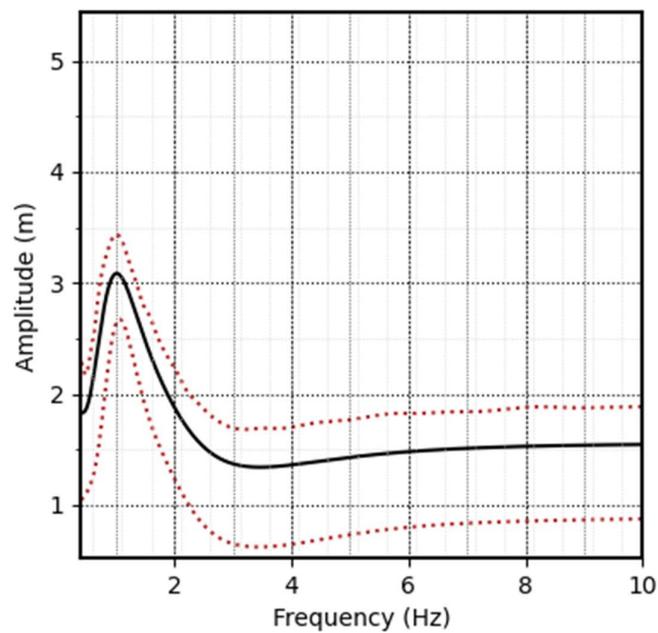


Figure 5. Example of HVSR curve

Table 1. Modified Kanai Classification of Dominant Frequency (f_0)

Type	f_0	Description of Geological Materials	Sediment Thickness
I	< 2.5	Alluvial rocks: mud deposits, topsoil, and sedimentation	Very thick surface sediment
II	2.5-4	Alluvial rocks: gravelly sand, clay, loam	Thick surface sediments (10-30 m)
III	4-10	Alluvial rocks: gravelly sand, clay, loam	Moderate surface sediments (5-10 m)
IV	6.667-20	Tertiary rocks: hard pebbly sandstone	Very thin surface sediment, hard rocks

The f_0 values obtained vary, starting from the range of $0.90\text{-}2.10 H_z$ (Figure 6). Spatial analysis of the f_0 across the study area shows that the f_0 values are mostly $< 2.5 H_z$ (Type I), which is typical of alluvial rocks with very thick sediment thickness consisting of silt, topsoil, and sedimentation (Nurwidyanto et al., 2023; Gemintang et al., 2022).

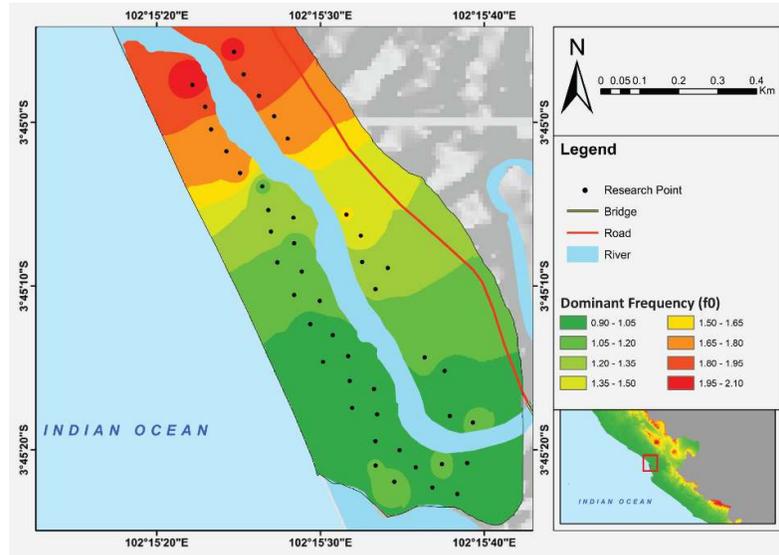


Figure 6. Dominant frequency distribution map

Amplification Factor (A_0)

The amplification factor (A_0) is a parameter that provides information about the difference in impedance contrast between the surface layer and the layer below (Ridwan et al., 2021). The A_0 is caused by the impedance contrast, which means that there is a considerable change in rock compactness between the sedimentary layer and the bedrock layer (Purnama et al., 2021). The greater the A_0 value, the greater the shock and risk. Conversely, the smaller the A_0 , the smaller the shock and risk (Syahputri & Sismanto, 2020). The A_0 factor values obtained in this study vary greatly from 2.08 to 5.49. Based on the classification table, the A_0 value of the study area is included in the low classification with a value range of 2.08-2.93 and the medium classification with a value range of 3.36-5.49 (Iswanto et al., 2019; Nurwidyanto et al., 2023).

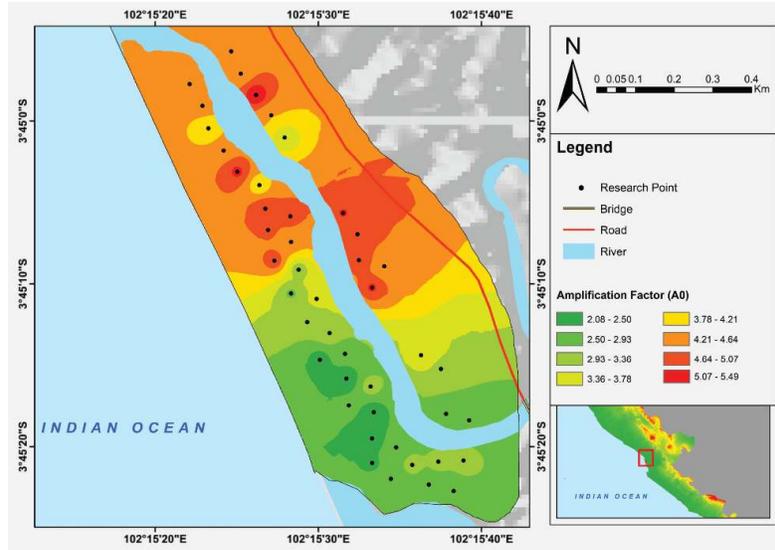


Figure 7. Amplification factor distribution map

Seismic Susceptibility Index (K_g)

The seismic susceptibility index (K_g) is a parameter that can provide information on the degree to which a region is susceptible to threats due to seismic activity, such as earthquakes (Panjaitan et al., 2023; Ridwan et al., 2021). The high and low K_g is influenced by the f_0 and the A_0 (Iswanto et al., 2019; Syahputri & Sismanto, 2020). The K_g is directly proportional to the sediment layer's thickness. If the K_g value is high, the sediment layer is thick; otherwise, if the K_g value, the sedimentary layer is thin (Syahputri & Sismanto, 2020).

Figure 8 shows the K_g values for which a distribution map was created. The K_g values obtained vary greatly. According to the classification table, the K_g value in this study area is only found at a few points that fall into the medium classification with $K_g < 6$, while the other points are dominated by $K_g > 6$ values with a high level of K_g classification. The high K_g value is due to geological conditions that are dominantly covered by type I soil classification, which is an alluvial rock with a very thick sediment thickness. The government and urban planners should give special attention to earthquake-resistant building design and bedrock depth when planning and constructing facilities and infrastructure in the accretion area of Bengkulu City, considering the high potential for damage in the event of an earthquake.

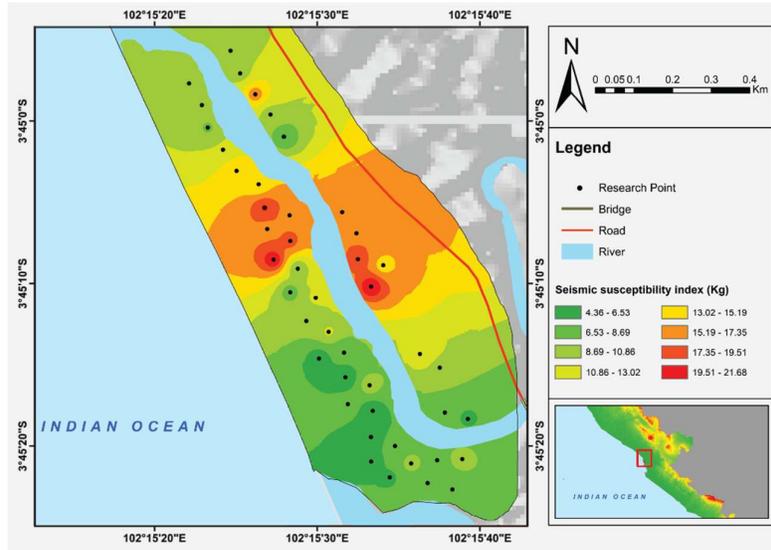


Figure 8. Seismic susceptibility index distribution map

Shear Wave Velocity (V_s)

Based on the NEHRP standard, the V_s value can be classified into several types, namely, type A is a hard rock classification, type B is a rock classification, type C is a very dense soil and soft rock classification, type D is a stiff soil classification, and type E is a soft soil classification (Indra et al., 2019; Sugianto & Refrizon, 2021; Farid et al., 2024). On the V_{s30} distribution map, $180 \leq V_s < 360$ is obtained, which falls into type D, a stiff soil classification. Stiff soils, composed of silt compacted sand, or dense consistency, are commonly found in the alluvial deposits of the accretion area in Bengkulu City. These soils tend to exhibit a higher potential for earthquake wave amplification, thereby increasing the seismic risk for structures built on such deposits.

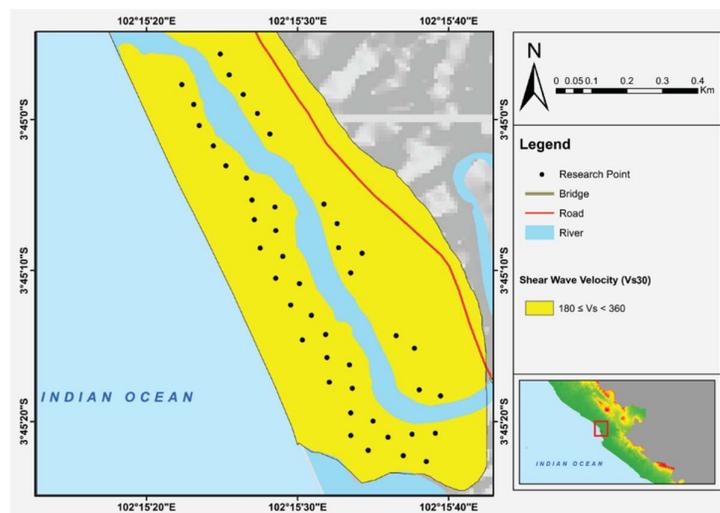
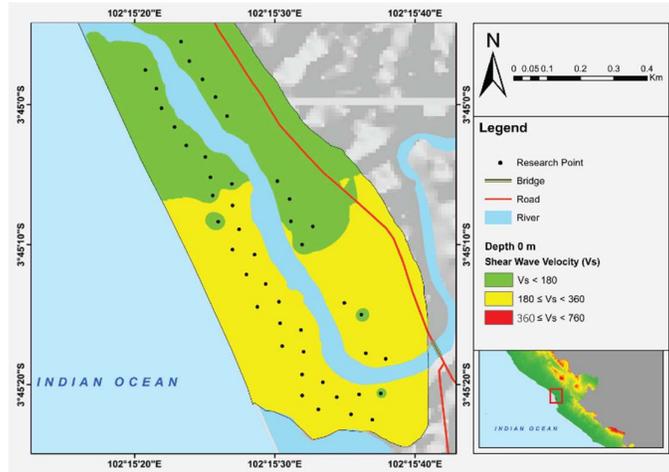
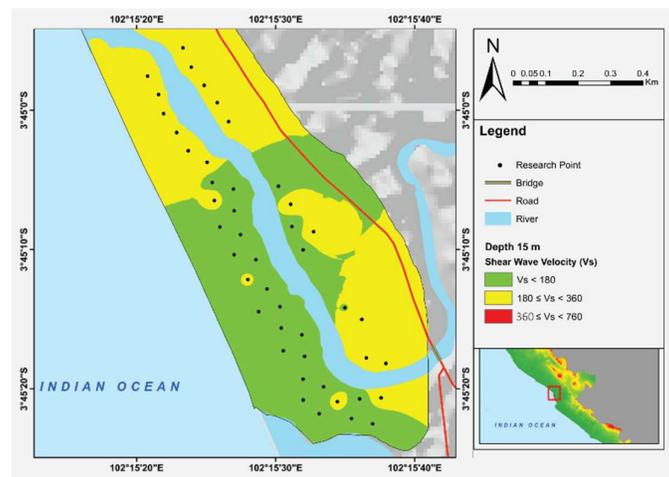


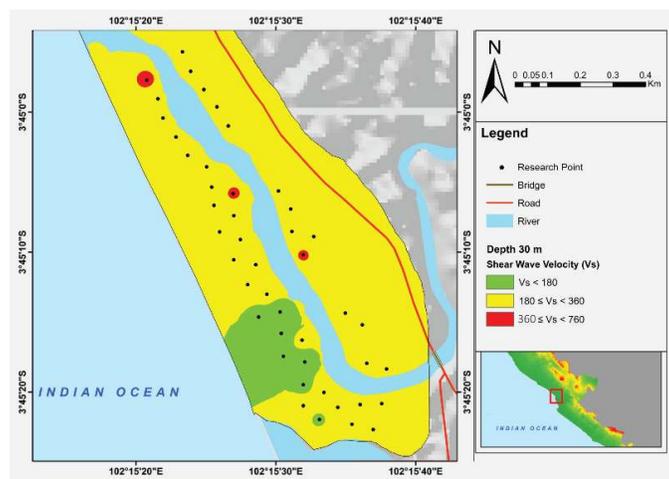
Figure 9. V_{s30} distribution map



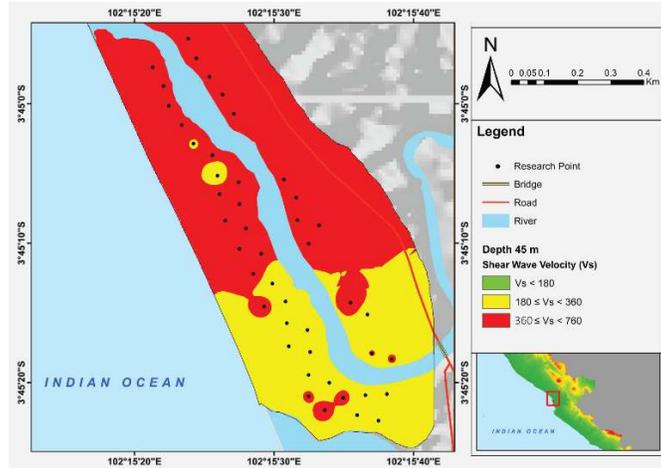
(a)



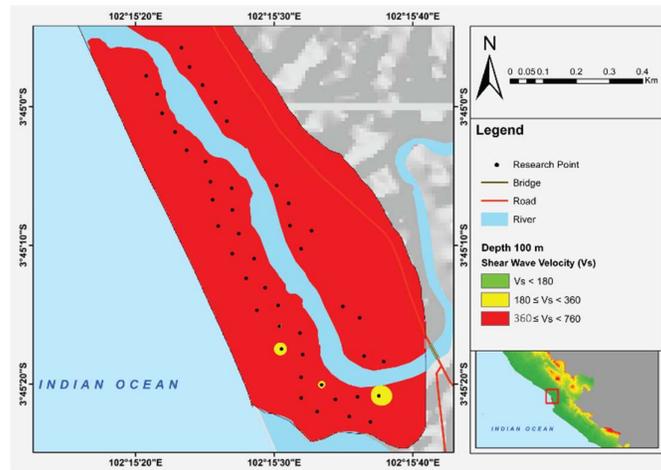
(b)



(c)



(d)



(e)

Figure 10. Map of distribution for V_s values at depths of (a) 0 m, (b) 15 m, (c) 30 m, (d) 45 m, and (e) 100 m

Figure 10 shows the distribution of V_s values at depths of 0, 15, 30, 45, and 100 m in the Bengkulu City accretion area. The depth profiles of 0 m (Figure 10a) and 15 m (Figure 10b) are dominated by soft and stiff soils. As shown in Figure 10b, at a depth of 15 m, V_s values exhibit spatial variability, with certain measurement points showing a decrease, while others display a notable increase. The findings in this study suggest that the local geological condition is influenced by young sedimentation that is still loose or has a high water content.

At depths of 30, 45, and 100 m, V_s values show an upward shift in classification, transitioning from soft and stiff soil categories to very dense soil and soft rock classifications. However, at a depth of 30 m (Figure 10c), there are only a few measuring point areas that begin to increase from soft soil and stiff soil to very dense soil and soft rock. At a depth of 45 m (Figure 10d), it can be seen that

most of the measurement point are dominated by very dense soil and soft rock. At a depth of 100 m (Figure 10e), almost all measurement point are dominated by very dense soil and soft rock. At depths of 0, 15, 30, and 45 m, there are significant variations in V_s , indicating higher heterogeneity in the soil layer or loose material. Significant variations in V_s values at these depths are caused by changes in lithology, soil material, or non-uniform sedimentation processes. Meanwhile, the distribution of V_s at a depth of 100 m tends to be more homogeneous than V_s at shallow depths (0, 15, 30, and 45 m). This indicates that at a depth of 100 m, the subsurface geological conditions are relatively uniform, indicating a transition to denser layers or more consolidated rocks.

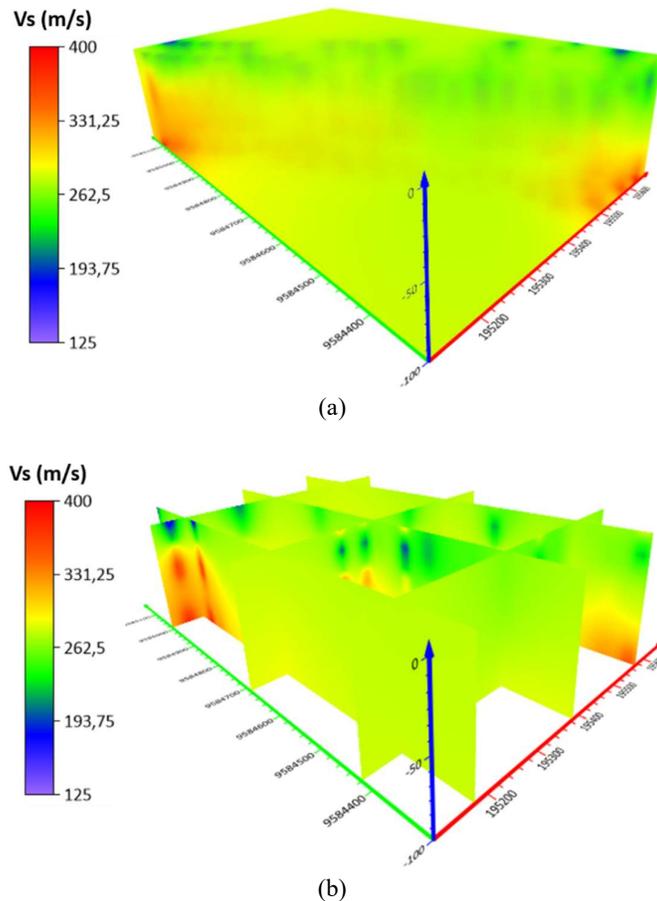


Figure 11. 3D modeling V_s (a) geological 3D layers and (b) geological cross-sections

The subsurface lithological conditions in the study area are also visualized and interpreted on 3D maps layer. Based on the shear wave velocity (V_s) values obtained from the HVSR curve inversion results, Figure 11 shows that the V_s of the layer ranges from 125 to 400 m/s. The subsurface layer in the study area is composed of sand, clay, and alluvial deposits, according to the table of V_s values by material type (Indra et al., 2019).

Conclusion

This study successfully characterized the shallow subsurface structure of the accretion area in Bengkulu City, revealing zones with high seismic vulnerability. The HVSR analysis and V_s profiling indicate that the 0–100 m subsurface is composed of alternating layers of soft soil, stiff soil, very dense soil, and soft rock, primarily consisting of sand, clay, and alluvial deposits formed during Quaternary sedimentation. These conditions suggest that certain areas are prone to amplification of earthquake waves, highlighting the necessity of incorporating site-specific geotechnical and geophysical data in urban planning and disaster-mitigation strategies.

Conflict of Interest

All authors contributed to and were responsible for field data collection, HVSR analysis, data processing, visualization, interpretation of results, and manuscript preparation. Throughout the writing process, Artificial Intelligence (AI) software was used to a limited extent to support sentence construction and grammar checking, without affecting data interpretation, methodology, or research conclusions.

Acknowledgements

This study is funded by the Physics Study Program of Bengkulu University through MBKM Independent Project activities in fiscal year 2024. Thanks to Risky Budi Yarmanto, Rozylla Agustina, Muamar Gerry, Rahmat Saputra, Fascal Verojenases, Samuel Kristian Alfredo Banjarnahor, and Ahmad Fakhri Jamallulail, who have contributed to this study.

References

- Arisona, Manginsih, S. L., Praja, N. K., Hasria., & Azhar. (2023). Pemetaan Lapisan Tanah Menggunakan Data Mikrotremor HfR dan Dampaknya Terhadap Daya Dukung Tanah di Kawasan Kota Kendari. *Jurnal Geologi Dan Sumberdaya Mineral*, 24(1), 51–58. <https://doi.org/10.33332/jgsm.geologi.v24i1.724>
- Atmojo, A. T., Welly, T. K., Simbolon, K., & Zulfikar, A. N. (2021). Studi Perubahan Garis Pantai Pesisir Kota Bandar Lampung Menggunakan Data Penginderaan Jauh. *Journal of Science, Technology, and Visual Culture*, 1(3), 149–154.
- Cipta, A., Afif, H., Arifin Pradipto, M. J., Omang, A., & Solikhin, A. (2023). Optimizing HVSR Curves, Slope, and Geologic Information for Vs30 and Seismic Vulnerability Zoning in Likupang. *Journal of Environment and Geological Hazards*, 14(1). <https://doi.org/10.34126/jlbg.v14i1.463>
- Farid, M., Mase, L. Z., & Fathani, T. F. (2024). The Investigation of Subsurface Beds using Microtremor and Geoelectric Methods in A Liquefied Area in

- Bengkulu City After the Bengkulu-Mentawai Earthquake. *Indonesian Journal on Geoscience*, 11(3), 377–390. <https://doi.org/10.17014/ijog.11.3.377-390>
- Fatimah, A., Sriyanto, S. P. D., Sunardi, B., & Wandono, W. (2022). Identifikasi Karakteristik Tanah dan Struktur Kecepatan Gelombang Geser Menggunakan Data Mikrotremor di Daerah Lembang, Jawa Barat. *Jurnal Geofisika*, 20(01), 38–44. <https://doi.org/10.36435/jgf.v20i1.521>
- Gemintang, K. N., Hanatha, F. D., Indriatmoko, T. W., Qurrotu'aeni, W. S., Azis, B. N. L., & Hamdalah, H. (2022). Identifikasi Zona Rawan Amblesan Berdasarkan Parameter Hvsr Dan Ground Shear Strain Di Daerah Gua Pindul. *Jurnal Geosaintek*, 8(3), 232. <https://doi.org/10.12962/j25023659.v8i3.14395>
- Hadi, A. I., Farid, M., Refrizon, R., Harlianto, B., Hudayat, N., & Krisbudianto, M. (2021). Pemetaan Potensi Kerentanan Gempabumi Pada Kota Bengkulu Menggunakan Data Mikrotremor dan Metode Analytical Hierarchy Process. *Jurnal Fisika Flux: Jurnal Ilmiah Fisika FMIPA Universitas Lambung Mangkurat*, 18(2), 105. <https://doi.org/10.20527/flux.v18i2.9479>
- Indra, I., Efendi, R., & Abdullah, A. (2019). Estimasi Kecepatan Gelombang Geser Bawah Permukaan Pada Lapisan Dangkal Menggunakan Data Mikrotremor di Daerah Mambo. *Gravitasi*, 17(2), 10–19. <https://doi.org/10.22487/gravitasi.v17i2.12418>
- Istiqomah, F., Sasmito, B., & Amarrohman, F. J. (2015). Aplikasi Digital Shoreline Anaysis System (DSAS). *Jurnal Geodesi Undip*, 5, 78–89.
- Iswanto, E. R., Indrawati, Y., & Riyanto, T. A. (2019). Studi Mikrotremor dengan Metode Horizontal to Vertical Spectral Ratio (HVSR) di Tapak RDE, Serpong. *Eksplorium*, 40(2), 105. <https://doi.org/10.17146/eksplorium.2019.40.2.5489>
- Jamal, R. J., Lantu., Aswad, S., & Sulaiman, C. (2017). Mikrozonasi Kawasan Rawanbencana gempabumi Dengan Studi Peak Ground Acceleration Menggunakan Metode Boore Atkinson Dan Data Mikrotremor Di daerah Kupang. *Jurnal Gecelebes* 1(1), 5–12.
- Mase, L. Z., Sugianto, N., & Refrizon. (2021). Seismic hazard microzonation of Bengkulu City, Indonesia. *Geoenvironmental Disasters*, 8(1). <https://doi.org/10.1186/s40677-021-00178-y>
- Nabhan, M. A., Hadi, A. I., Fadli, D. I., Harlianto, B., Refrizon, R., & Ramdani, R. (2023). Distribusi Vs30 Secara Mikrozonasi Berdasarkan Data Inversi Seismik Pasif di Sepanjang Jalan Provinsi Alternatif Kabupaten Bengkulu Tengah-Kepahiang. *Geomatika*, 25(2), 67–76.
- Nurwidyanto, M. I., Zainuri, M., Wirasatrya, A., & Yuliyanto, G. (2023). Struktur Bawah Permukaan Pantai Semarang berdasarkan Metode HVSR. *Indonesian Journal of Applied Physics*, 13(1), 117. <https://doi.org/10.13057/ijap.v13i1.66864>

- Panjaitan, A., Saragih, R., Hutahuruk, A., & Suhendra. (2023). Mikrozonasi Kawasan Potensi Longsor Menggunakan Metode Mikrotremor di Kabupaten Bengkulu Utara-Lebong. *Jurnal Ilmiah Fisika FMIPA Universitas Lambung Mangkurat*, 20(2), 2541–1713. <https://doi.org/10.20527/14957>
- Purnama, A. Y., Nurcahya, B. E., Nurhanafi, K., & Perdhana, R. (2021). Mikrozonasi Berdasarkan Data Mikrotremor dan Kecepatan Gelombang Geser di Kotamadya Yogyakarta. *Positron*, 11(2), 86. <https://doi.org/10.26418/positron.v11i2.46860>
- Putti, S. P., & Satyam, N. (2020). Evaluation of Site Effects Using HVSR Microtremor Measurements in Vishakhapatnam (India). *Earth Systems and Environment*, 4(2), 439–454. <https://doi.org/10.1007/s41748-020-00158-6>
- Rahman, A. S., Permana, D., Pramono, S., Rahmatullah, F. S., Sativa, O., Moehajirin, Santoso, E., Oktavia, N. H., Octantyo, A. Y., Wallansha, R., Kaluku, A., Pradita, J. S., Habibah, N. F., Dharma, Y., Persada, Sugianto, D., Silvia, U. N., Sugiharto, A., Muzli, ... Adi, S. P. (2023). Identifikasi Ketebalan Sedimen Di Kota Bengkulu Menggunakan Metode Spac. *Buletin Meteorologi, Klimatologi, Dan Geofisika*, 4(4), 1–7.
- Ridwan, M., Yatini, Y., & Pramono, S. (2021). Mapping of Potential Damage Areas in Lombok Island Based on Microtremor Data. *Jurnal Pendidikan Fisika Indonesia*, 17(1), 49–59. <https://doi.org/10.15294/jpfi.v17i1.27028>
- Sugianto, N., & Refrizon, R. (2021). Struktur Kecepatan Gelombang Geser (Vs) di Daerah Rawan Gerakan Tanah (Longsor) Jalan Lintas Kabupaten Bengkulu Tengah-Kepahiang. *Indonesian Journal of Applied Physics*, 11(2), 134. <https://doi.org/10.13057/ijap.v11i2.41699>
- Supriyadi, Khumaedi, Sugiyanto, Fadilah, A. R., & Muttaqin, W. H. (2022). Study of the Subsurface Structure Based on Microseismic Data in the Heritage Area of Kota Lama Semarang, Indonesia. *International Journal of GEOMATE*, 23(97), 211–219. <https://doi.org/10.21660/2022.97.j2357>
- Susilanto, P., Ngadmanto, D., Hardy, T., & Pakpahan, S. (2016). Penerapan Metode Mikrotremor HVSR untuk Penentuan Respon Dinamika Kegempaan di Kota Padang. *Jurnal Lingkungan Dan Bencana Geologi*, 7(2), 79–88.
- Syahputri, A., & Sismanto, S. (2020). Identifikasi Potensi Tanah Longsor Menggunakan Metode Mikrotremor Di Dusun Tegalsari Desa Ngargosari Kecamatan Samigaluh Kabupaten Kulon Progo. *Jurnal Fisika Indonesia*, 24(2), 66. <https://doi.org/10.22146/jfi.v24i2.53636>
- Wicaksono, A. D., Awaluddin, M., & Bashit, N. (2020). Analisis Laju Perubahan Garis Pantai Menggunakan Metode Net Shoreline Movement (Nsm) Dengan Add-in Digital Shoreline Analysis System (Dsas) (Studi Kasus : Pesisir Barat Kabupaten Pandeglang). *Jurnal Geodesi Undip*, 9(2), 21–31. <https://ejournal3.undip.ac.id/index.php/geodesi/article/view/26919>