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Utilization of Satellite Imagery and Integration of the HVSR Inversion Method for Coastline Changes in the Nangai Beach Tourism Area, North Bengkulu Regency

Putri Helinnes, Arif Ismul Hadi, Muchamad Farid, Yuni Setyowati, Debi Hardiansyah, Usman Gumanty, Hana Raihana, Andre Rahmat Al Ansory, Zaky Muammar

Physics department, Geophysics Study Program, Faculty of Mathematics and Natural Science University of Bengkulu, Bengkulu, 38371, Indonesia.

Email: ismulhadi@unib.ac.id

Abstrak

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Penelitian ini bertujuan untuk memberikan wawasan yang lebih besar tentang penanggulangan bencana abrasi bagi masyarakat dan pemerintah. Akibatnya, terdapat lapisan batuan keras dan lunak di area penelitian. Berdasarkan analisis, dapat dilihat bahwa kawasan wisata Pantai Nangai memiliki beberapa titik riset yang memiliki potensi perubahan garis pantai yang tinggi. Wisata Pantai Nangai merupakan kawasan yang memiliki potensi abrasi karena kawasan ini memiliki formasi Bintunan. Formasi ini didominasi oleh batuan konglomerat dari berbagai bahan, breksi, batu kapur karang, tanah liat tuf, batu apung dan kayu yang terkikis. Perubahan garis pantai diperoleh menggunakan data Citra Satelit, dan tahun 2011 hingga 2023 perubahan dapat dilihat antara titik 17 sebesar 35,63 meter dan pada titik 2 33,87 meter. Metode Horizontal to Vertical Spectral Ratio (HVSR) memperoleh nilai frekuensi dominan dan diproses dengan amplifikasi untuk menentukan indeks kerentanan seismik, ketebalan lapisan sedimen dan kecepatan gelombang geser yang digunakan untuk menentukan daerah yang rentan terhadap abrasi pantai. Berdasarkan interpretasi, hard rock ditampilkan dengan nilai frekuensi dominan (f_0) pada kisaran 2,35-5,08 Hz sedangkan soft rock ditunjukkan pada kisaran 5,71-9,05 Hz. Nilai kerentanan gempa (A_0) pada kisaran 0,49-2,68 adalah batuan lunak, sedangkan kisaran nilai 3,42-5,61 adalah batuan keras. Semakin rendah nilai kerentanan (k_g), semakin rentan terhadap abrasi area tersebut. Nilai kecepatan gelombang geser (V_s) rendah dengan kisaran 186,83-350,85 sedangkan nilai tinggi dengan kisaran 350,85-596,87. Lapisan batuan dengan penampang 3D dapat dilihat menggunakan perangkat lunak permodelan 3D dengan memasukkan nilai V_s .

Kata kunci : Abrasi, Citra satelit, HVSR, Tremor Mikro, Permodelan 3D

Abstract

The research findings are to provide greater insight into abrasion disaster management for the community and government. As a result, there are layers of hard and soft rock in the research area. Based on the analysis, it can be seen that the Nangai Beach tourist area has several research points that have high potential for coastline changes. Nangai Beach Tourism is an area that has the potential for abrasion because this area has Bintunan formations. This formation is dominated by conglomerate rocks of various materials, breccia, coral limestone, tuff clay, pumice and eroded wood. Coastline changes were obtained using Satellite Image data, from 2011 to 2023 changes can be seen between point 17 of 35.63 meters and at point 2 of 33.87 meters. The Horizontal to Vertical Spectral Ratio (HVSR) method obtains dominant frequency values and is processed by amplification to determine the seismic vulnerability index, sediment layer thickness and shear wave speed which are used to determine areas that are vulnerable to coastal abrasion. Based on the interpretation, hard rock is shown with a dominant frequency value (f_0) in the range 2.35-5.08 Hz while soft rock is shown in the range 5.71-9.05 Hz. The earthquake vulnerability value (A_0) in the range 0.49-2.68 is soft rock, while the value range 3.42-5.61 is hard rock. The lower the vulnerability value (k_g), the more susceptible the area is to abrasion. The shear wave velocity (V_s) value is low with a range of 186.83-350.85 while the high value is with a range of 350.85-596.87. A layer of rock with a 3D cross-section can be viewed using 3D modeling software by entering the value of V_s .

Keyword : Abrasion, Satellite image, HVSR, Microtremor, 3D Modeling

INTRODUCTION

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Indonesia is a coastal country that has a total of 17,508 islands with a coastline of 81,000 km, Indonesia is a country that is vulnerable to abrasion and erosion in coastal areas (Ramadhani, 2020). Coastal erosion or abrasion occurs due to the movement of part of the rock mass from a high place to a lower place due to a disturbance of the balance in its main strength, generally rock conditions that are prone to movement have a

soft, weak, unstable, and weakly cohesive geological structure (Sugianto et al., 2022). The Nangai beach tourism area is directly facing the open ocean which allows sea waves and ocean currents to potentially abrade the beach.

Abrasion disasters in North Bengkulu regency have a major impact on society and government, this area experiences changes in coastline up to 25 meters / year known through the results of satellite data (Farid et al., 2014). Factors that cause shoreline changes include the energy of large ocean waves hitting the beach, the angle formed between the wavefront at breakup and the shoreline, the subsurface structure of the beach, the slope of the water bottom, the type and size of sediment deposited, and the morphological shape of the shoreline (Lubis et al., 2020). This research needs to be done to find out the continuous changes in the coastline, this research knows the driving factors and information for coastal resource management, sustainable development planning and environmental protection (Aryastana et al., 2016).

Previous research has been conducted by (Farid et al., 2024) in the Central Bengkulu Regency area regarding the Combination of HVSR and MASW Methods with Landsat 8 Images to Assess Shoreline Changes Along the Central Bengkulu Coastal Region, the study shows that Central Bengkulu Regency has experienced significant shoreline changes with an average annual shoreline change speed of 1.5 meters / year with the highest speed of 4.1 meters / year, the subsurface structure along the coast of Central Bengkulu shows a rigid soil structure and is prone to erosion (Farid et al., 2024).

This research was conducted using the microseismic method (HVSR) which can estimate the value of Amplification factor (A_0), dominant frequency (f_0), seismic susceptibility (k_g) and Vertical Spectral (V_s) (WIDYAWARMAN & Fauzi, 2020). The HVSR method utilizes the natural harmonic vibrations of the soil caused by nature (Tanjung et al., 2019). Further processing is carried out using modeling software to create 3D visualization and to analyze the distribution and calculate the volume of the object under study (Sari et al., 2022). In addition, satellite images were used in this study to see changes in the coastline from 2011 to 2023 using Google earth pro software (Pattipawaej & Oktaviani, 2023).

Based on UAV (unmanned aerial vehicle) data information of the research area (Figure 1 a and b), the phenomenon of abrasion is quite significant (Lubis et al., 2022), there is a land surface that is eroded due to the powerful waves and winds so that it can be worrying and can have a dangerous impact on the surrounding community or tourist visitors in the area.

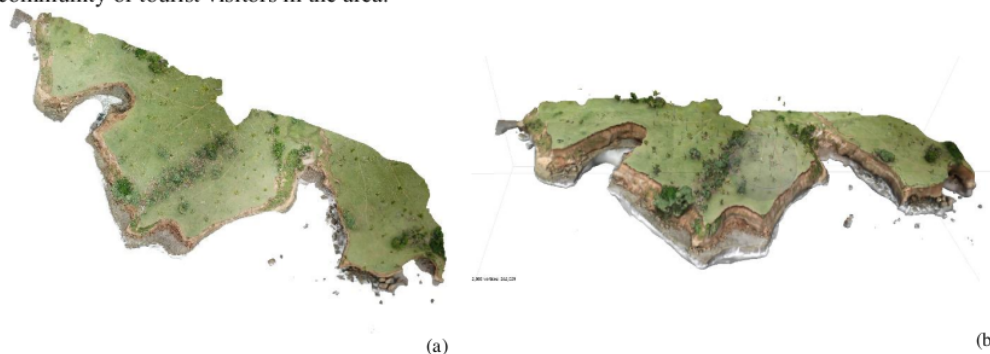


Figure 1. (a) UAV data capture results from the top side (b) UAV data capture results from the vertical side

Abrasion disasters in the North Bengkulu Regency area have certainly proven to be detrimental to the surrounding community and tourist visitors, the impact can include environmental conditions and the way coastal land is utilized, showing the importance of observing shoreline changes, especially in the field of disaster mitigation (N. S. Rahmawati et al., 2024).

The purpose of this research is to determine changes in coastline from 2011 to 2023 with the expected benefits of this research is to support the availability of data and information, and become a reference source of data and information for disaster mitigation in coastal and marine areas (Geurhaneu & Susantoro, 2017).

METHOD

4 The research was conducted from November 26, 2023 to May 31, 2024. The location of observation data collection was carried out in the Nangai beach tourism area, North Bengkulu Regency. The research data collection was carried out in two stages, namely primary data collection and secondary data collection. Primary data collection uses a seismometer on May 29 to 31, 2024, seismometer data serves to determine subsurface conditions while drones are used as data validation at the research point. Initial survey activities were carried out to determine geological conditions and determine data collection points (Raehanayati et al., 2013). In this study, 30 points were taken with a distance of about 100 meters between points. Figure 2 is the design of microtremor data acquisition in the research area.

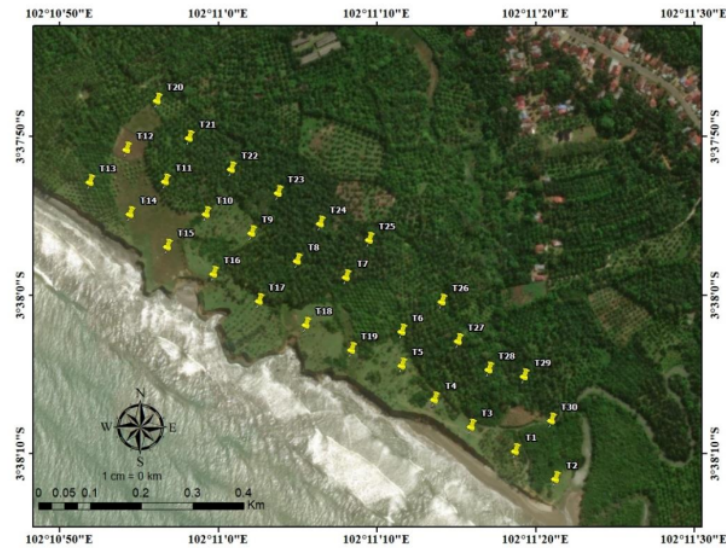


Figure 2. Microtremor data acquisition design in the study area.

Microtremor data processing uses several software including Geopsy, HV-Invers, 3D modeling and mapping software (Budi Legowo, Sorja Koesuma, 2018). Parameters sought in processing microtremor data include A_0 , f_0 , k_g and V_s (Ambarsari, 2017). The values of A_0 and f_0 are obtained using Geopsy software, by entering microtremor data records and then smoothing and windowing processes are carried out so as to get the results of A_0 and f_0 (N. I. Rahmawati et al., 2024).

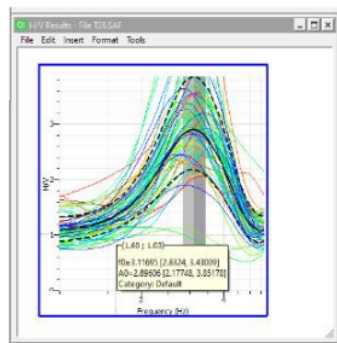


Figure 3. Data processing results using geopsy software.

The seismic susceptibility index (k_g) proposed by Nakamura (1996) is formulated in equation (1):

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

This k_g value is used to identify weak soil areas, calculate damage that may occur in areas of high seismic activity and calculate the vulnerability level (Ailing Kalyana Mita, Bambang Sunardi, 2023). The V_s value is obtained using the HV-Invers software by inputting the A_0 and f_0 values (Safitri et al., 2021). V_s values with soft materials or rocks will be lower than hard rocks because the shear wave velocity is directly proportional to the rock density (Edison et al., 2022). The important parameters produced by the HVSR method are natural frequency and amplification (Yogaswara & Kuncahyani, 2024) which can be formulated in equation (2).

$$H/V = \frac{\sqrt{(S-NS)^2 - (S-EW)^2}}{S-V} \quad (2)$$

Where H/V is the spectrum of H/V ratio spectra, $S - NS$ is the spectrum of the north-south horizontal component, $S - EW$ is the spectrum of the west-east horizontal component and $S - V$ is the spectrum of the vertical component (Refrizon et al., 2013).

Shoreline changes in a span of 12 years can be seen on Google Earth Pro (Dewi Citra, 2023), then the data obtained from Google Earth Pro is exported to mapping software to get the results of the shoreline change map, besides that 3D modeling is used using modeling software (Sari et al., 2022). 3D modeling results are obtained by inputting coordinate points, depths and V_s values that have been made in Excel software (Rusli & Mandala, 2020).

RESULTS AND DISCUSSION

geological conditions

According to the Bengkulu geological sheet map (Gafoer et al., 2007), Bengkulu Utara Regency consists of alluvium (Qa), andesite (T15n), rio andesite volcanic rocks (Qtv), diorite (Tmdi), bale formation (Tmba), bintunan formation (QTb), hulusimpang formation (Tomh), seblat formation (Toms), simpangaur formation (Tmps) and lemau formation (Tml). Figure 4 is a rock geology map of North Bengkulu regency, it can be seen on the Geology map that the rocks in the research area are composed of the bintunan formation (QTb), this formation consists of various conglomerate rocks, breccia, reef limestone, tuffaceous claystone, cobble and woody rocks.

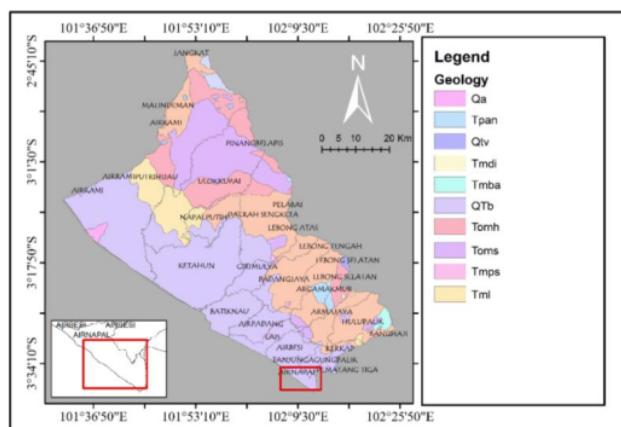


Figure 4. Geological map of North Bengkulu regency.

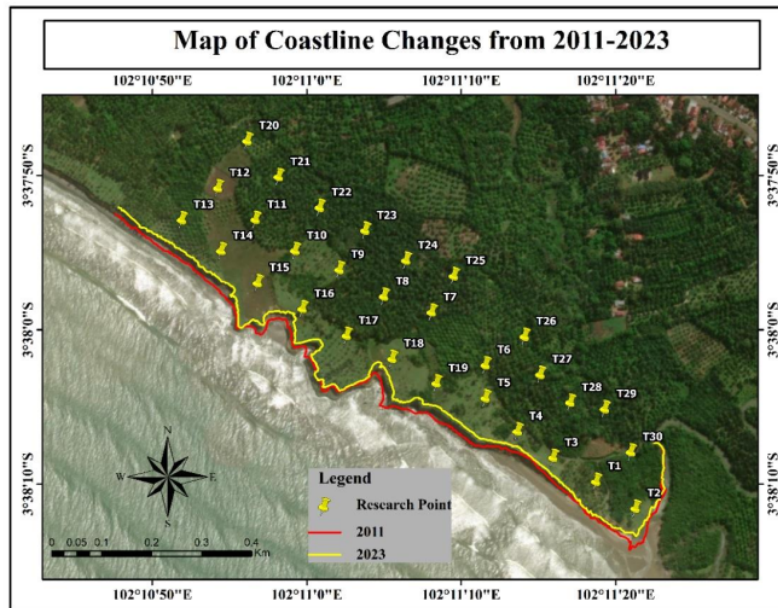


Figure 5. Shoreline change map from 2011 to 2023

The results of the analysis of shoreline changes in the study area from 2011 to 2023 show that abrasion occurs quite significantly for 12 years can be seen in Figure 5. At point 2 abrasion occurs along 37.25 meters, point 15 abrasion occurs along 38.69 meters, point 16 abrasion occurs along 24.32 meters, point 17 abrasion occurs along 39.12 meters, point 18 abrasion occurs along 38.39 meters and point 19 abrasion occurs along 30.34 meters. While point 30 shoreline changes occur the least, which is 0.35 meters, it can be seen in Table 1 that the average annual shoreline change is 1.88 meters/year. The average shoreline change per year can be seen in Table 1.

Table 1. Average annual shoreline changes in the Nangai beach tourism area.

Research Point	Change from 2011-2023 (m)	Average for each year (m)
1	8.12	0.67
2	37.25	3.10
3	9.10	0.75
4	11.00	0.91
13	18.11	1.50
14	17.14	1.42
15	38.69	3.22
16	24.32	2.02
17	39.12	3.26
18	38.39	3.19
19	30.34	2.52
30	0.35	0.02
Average		1.88

The correspondence between the two approaches between the vs value and the results of satellite image data found that the rocks are soft and very vulnerable to abrasion such as at points 2, 15, 16, 17, 18 and 19. The research area has a soft rock structure so that it cannot maintain the stability of the coastline, this is based on the geological conditions of the research area.

Based on the processing results, the values of f_0 , A_0 , K_g and V_s . In the research area can be seen in Table 2.

Table 2. Results of research data processing

Research Point	Latitude (Deg)	Longitude (Deg)	A_0	f_0 (Hz)	K_g
1	-3.63606	102.1886	2.7	4.5	1.6
2	-3.63655	102.1893	2.4	6.1	0.9
3	-3.63563	102.1878	3.2	3.1	3.4
4	-3.63516	102.1871	3.3	3.1	3.4
5	-3.63456	102.1866	3.1	7.2	1.3
6	-3.63397	102.1861	3.1	7.2	1.3
7	-3.63299	102.1856	2.6	4.3	1.5
8	-3.63283	102.1847	3.4	4.9	2.3
9	-3.63253	102.1836	2.8	5.4	1.5
10	-3.63205	102.1831	2.2	3.3	1.4
11	-3.63144	102.1824	1.9	3.4	1.0
12	-3.63060	102.1815	1.7	3.9	0.7
13	-3.63189	102.1813	4.1	5.2	3.3
14	-3.63205	102.1818	2.0	4.3	0.9
15	-3.63277	102.1828	2.2	3.9	1.2
16	-3.63306	102.1833	2.1	9.1	0.5
17	-3.63354	102.1841	2.4	8.8	0.7
18	-3.63394	102.1849	3.3	3.8	2.8
19	-3.63439	102.1857	2.3	5.3	1.0
20	-3.63002	102.1823	2.1	3.8	1.1
21	-3.63066	102.1828	2.7	4.8	1.5
22	-3.63078	102.1833	3.4	5.2	2.3
23	-3.63169	102.1841	3.9	4.8	3.2
24	-3.63220	102.1851	4.4	4.8	4.1
25	-3.63248	102.1860	2.6	4.9	1.4
26	-3.63308	102.1872	2.1	4.5	1.0
27	-3.63398	102.1877	3.3	5.8	1.9
28	-3.63519	102.1875	3.1	2.9	3.4
29	-3.63604	102.1894	4.5	3.7	5.6
30	-3.63555	102.1892	2.1	2.4	1.9

3

Dominant Frequency (f_0)

Based on the data obtained, the dominant frequency value in the study area has a value between 2.35-9.05 Hz. The research location is dominated by the dominant frequency (f_0) which has a medium value of 4.48-5.71 Hz shown in light green-yellow color can be seen in the figure 6.

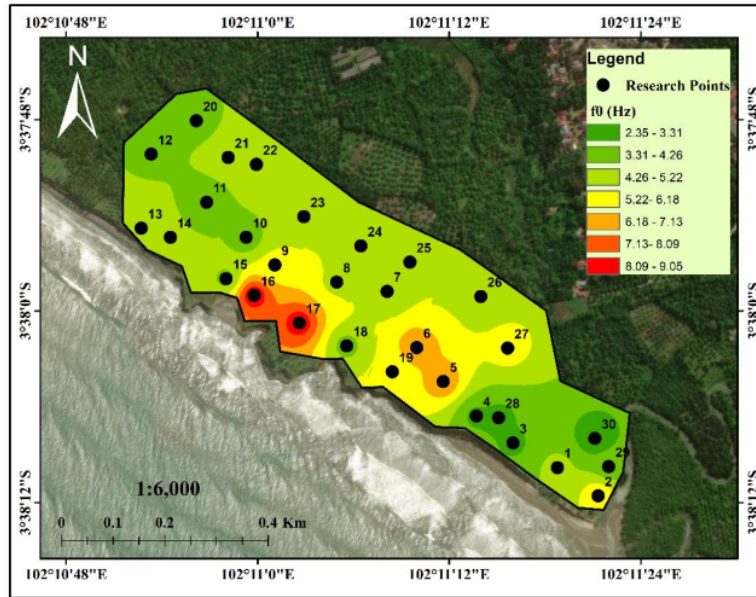


Figure 6. f_0 distribution in the study area

The soil classification for the study area at points 5, 6, 16 and 17 includes the type IV soil category whose classification consists of hard sandy rocks, gravel and other surface sediment thickness is very thin which is dominated by hard rocks (Ridwan, 2024). The following is a complete table 3 of rock classification based on microseismic natural frequency values in the study area. Knowing the soil classification based on microseismic natural frequency values can be seen in the Table 3.

Table 3. Soil classification based on f_0 values (Setyowati et al., 2024).

Soil classification Type	Soil classification Kind	Frequency Natural (Hz)	Kanai classification	Description	Location	Color
IV	I	6.667-20	Tertiary or older rocks. Consists of Hard sandy rocks, gravel and others.	The thickness of surface sediments is very thin, dominated by hard rocks.	5, 6, 16 and 17	  
III	II	4.0-6.667	Tertiary or older rocks. Consists of Hard sandy rocks, gravel and others.	Surface sediment thickness falls into the medium category 5-10 m	1, 2, 7, 8, 9, 10, 11, 12, 13, 14, 15, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27 and 29	  
II	III	2.5-4.0	Alluvial rocks, with a thickness of	The thickness of surface sediments is	3, 4, 28, and 30	

			more than 5m. Consists of sandy hard clay, loam and others.	categorized as thick, about 10-30m.
I	IV	< 2.5	Alluvial rocks, formed from sedimentation of detrital soil, mud and others. Depth ≥ 30m.	Surface sediment thickness is very thick

Amplification Factor (A_0)

The maximum amplitude value is the result obtained from microseismic data processing the value is called the amplification factor. The distribution of A_0 values in the research area can be seen in Figure 7.

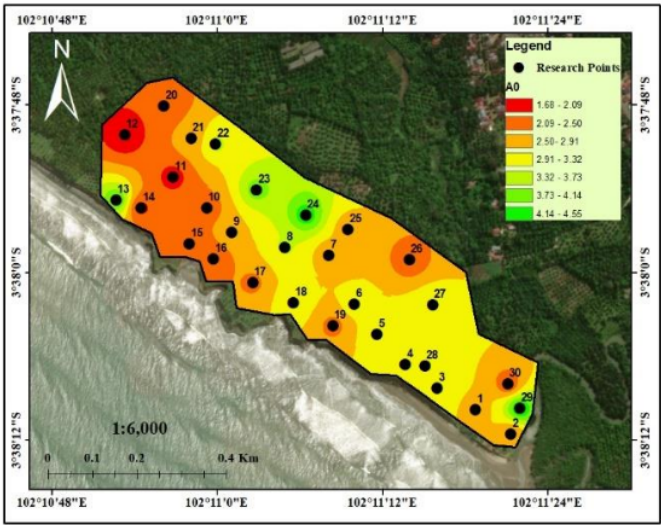


Figure 7. Distribution of A_0 values in the study area.

Based on the data obtained, the amplification value in the study area is categorized as low to medium because according to Table 4, the classification based on the amplification value is in the range of 1.68-4.55.

Table 4. classification based on amplification values (Tanjung et al., 2019).

zone	Classification	Value A_0	Location	Color
1	Low	$A_0 < 3$	1, 2, 7, 9, 10, 11, 12, 14, 15, 16, 17, 19, 20, 21, 25, 26, and 30	

2	Medium	$3 \leq A_0 < 6$	3, 4, 5, 6, 8, 13, 22, 23, 24, and 29	
3	High	$6 \leq A_0 < 9$		
4	Very High	$A_0 \geq 9$		

Indeks Kerentanan Seismik (K_g)

The seismic susceptibility index is useful for detecting weak zone areas, the amplification factor is obtained from processing the data of vibration amplitude measurements in the horizontal and vertical directions (Refrizon et al., 2013). If the sediment layer in an area is thin, the seismic vulnerability value of the area is high. The seismic susceptibility value in the research area is mapped according to the measurement point, as shown in Figure 8.

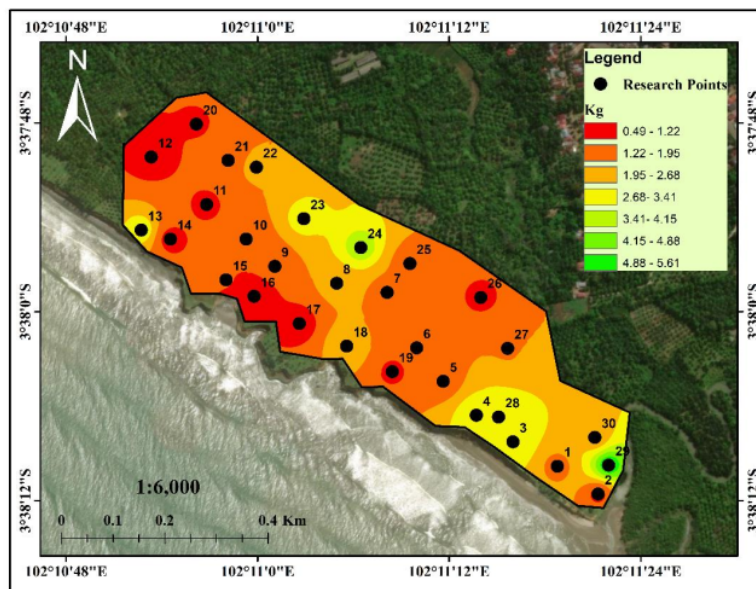


Figure 8. Distribution of k_g values in the study area

Based on the data obtained, it can be seen that the seismic susceptibility value in the research area is classified as low to medium (Table 5), this shows that the area has a fairly thin sediment layer thickness value indicated by green to medium shown by orange-red color.

Table 5. Seismic vulnerability values (Yogaswara & Kuncayani, 2024).

Zone	classification	Value K_g	Location	Color
1	Low	$K_g < 3$	1, 2, 5, 6, 7, 8, 9, 10, 11, 12, 14, 15, 16, 17, 19, 20, 21, 22, 25, 26, 27, and 30	

2	Medium	$3 < K_g < 6$	3, 4, 13, 18, 23, 24, 28 and 29	
3	High	$K_g > 6$		

Vertical Spectral (*Vs*)

Based on the mapping results (Figure 9) the shear wave velocity (*Vs*) shows that the bearing capacity of the soil is low because the soil calcification is rated 186.83 m/s-595.87 m/s which is the soil or rock in the area is medium soil to soft rock.

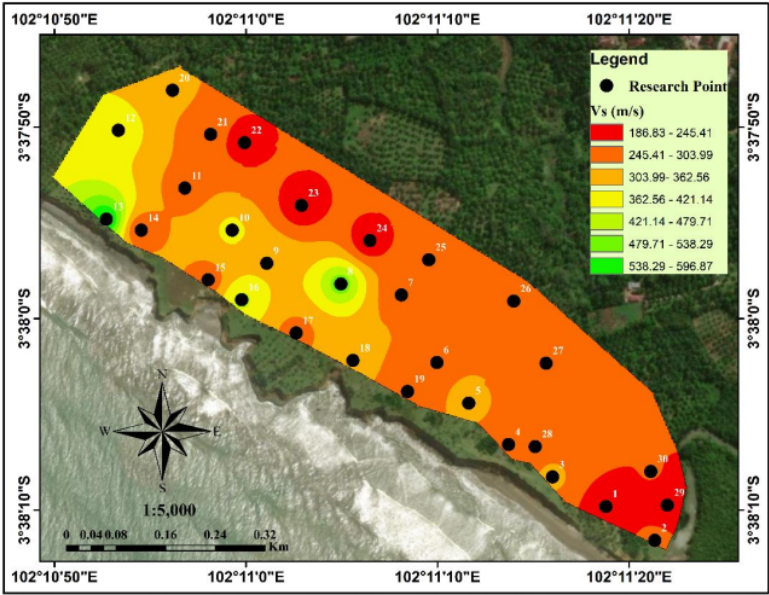
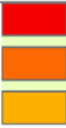


Figure 9. Distribution of *Vs* values in the study area

The classification of rocks in an area can be known through Table 6.

Table 6. Classification of Rocks Based on *Vs* Value of Soil and Laboratory Investigation Results SNI 1726 (Arisona et al., 2023).

Site Classification	Shear wave velocity <i>Vs</i> (m/s)	Location	Color
Hard Rocks	$Vs \geq 1500$		
Rocks	$750 < Vs \leq 1500$		
Very dense soil and Soft Rock	$350 < Vs \leq 750$	8, 10, 12, 13 and 16.	

Medium Soil	$175 < V_s \leq 350$	1, 2, 3, 4, 5, 6, 7, 9, 11, 14, 15, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29 and 30.	
Soft Soil	$V_s < 175$		

Permodelan 3D

Reconstruction of 3D shear wave velocity (V_s) data is obtained by combining all V_s data into the same frame (Sungkowo, 2016). Visualization of the 3D model is made by 3D V_s Imaging values formed from microseismic measurement points (Buanawati, 2018). The 3D model for the hard soil rock layer (Figure 10.a) is separated from the hard rock layer (Figure 10.b).

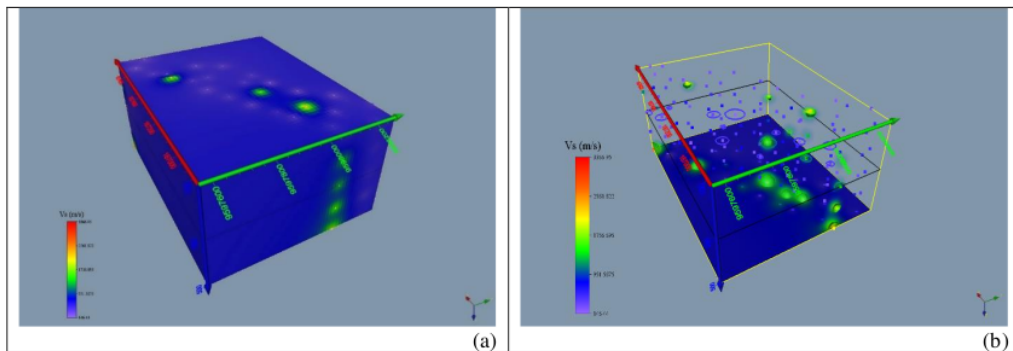


Figure 10. (a)Three-dimensional modeling (b)Volumetric modeling of the three-dimensional

Based on the reconstruction of 3D Microtremor data at point 1 to point 30, it explains that the dominant research area has a soil classification with medium soil (indicated in blue) between the values of $175 < V_s \leq 350$ soft rock (indicated in green and yellow) identified at V_s values between $350 < V_s \leq 750$.

CONC LUSION

Based on the results of the study, it was found that the biggest shoreline change occurred at sites 15, which experienced a change of 38.69 meters. The biggest change occurred at sites 15 experiencing a change of 38.69 meters long with tertiary or older rock types. Consists of Hard sandy rocks, gravel and others. Based on the results of the study, the f_0 value in the study area ranges from 2.35-9.05 Hz, indicating the classification of soil types I and III. The analysis shows that the area falls into the category of moderate vulnerability to abrasion risk. Notably, the highest values of amplification and seismic vulnerability index were observed at sites 11 and 12, where V_s values were found to be inversely proportional to k_g values. V_s values ranged from 186.83-596.87 m/s, corresponding to soft, medium and hard soil classifications. These findings provide a preliminary geophysical and geological picture of the seismic conditions in the Nangai beach tourism area of north Bengkulu district. Abrasion is also influenced by the energy of large ocean waves hitting the angle of the beach formed between the wavefront at breakup and the shoreline, the slope of the water bottom, the type and size of sediment deposited, and the morphological shape of the shoreline. The safe coastal area is at point 30 because the slope is not too steep and is not hit by large waves even though point 30 is classified as a medium soil type. In terms of mitigation strategies, it is important to integrate these findings to avoid development around the Nangai beach tourism area, the study area is recommended as a tourist spot without permanent development.

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