

Application of Satellite Imagery and HVSR Method for Coastal Analysis in Nangai Beach, North Bengkulu

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Abstract

This research analyzes shoreline changes in the Nangai Beach area; North Bengkulu Regency using Satellite Image data and analyzes subsurface structures using the Horizontal to Vertical Spectral Ratio (HVSR) method. The main objective of this research is to identify shoreline changes along the Nangai Beach area that occur due to abrasion. Data were collected from 30 points, with a distance of ± 100 meters between each point. The research shows that the condition of the area is quite stable to vulnerable to the occurrence of abrasion disasters. Coastline changes were obtained using Satellite Image data from 2011 to 2023. Changes can be observed between points 17 and 35.63 meters, and at point 2, 33.87 meters. The Horizontal-to-Vertical Spectral Ratio (HVSR) method determines dominant frequency values and processes them through amplification to calculate the seismic vulnerability index, sediment layer thickness, and shear wave speed. These values are used to identify areas 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 . This research makes a significant contribution to abrasion disaster mitigation through a geophysical approach.

Keywords: Abrasion, Satellite image, HVSR, Microtremor, North Bengkulu

INTRODUCTION

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 and friends in 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.

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).

MATERIAL AND METHOD

The research was conducted from November 26, 2023 to May 31, 2024. The location of observation and data collection was carried out in the Nangai beach tourism area, North Bengkulu Regency. Figure 2 shows the administrative map of the research area.

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 3 is the design of microtremor data acquisition in the research area.

Microtremor data processing uses several software including Geopsy, HV-Invers, 3D modeling and mapping software (Koesuma *et al.*, 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 (Rahmawati *et al.*, 2024).



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

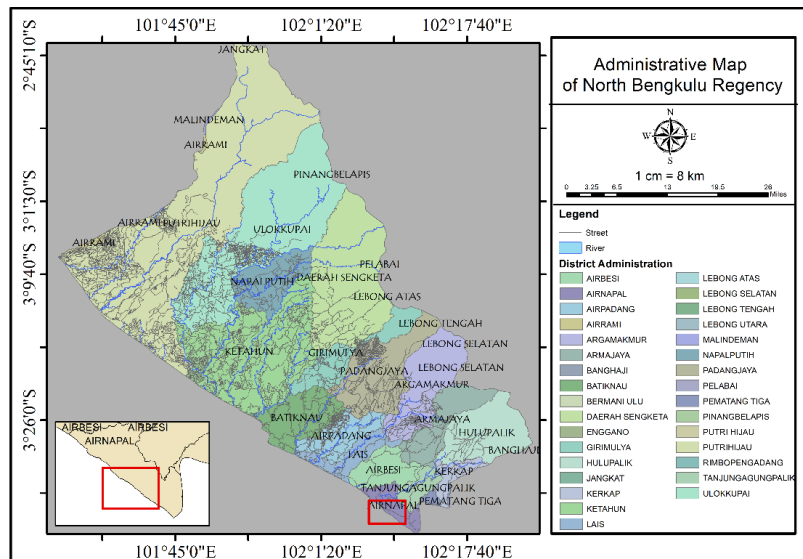


Figure 2. Administrative Map of North Bengkulu Regency

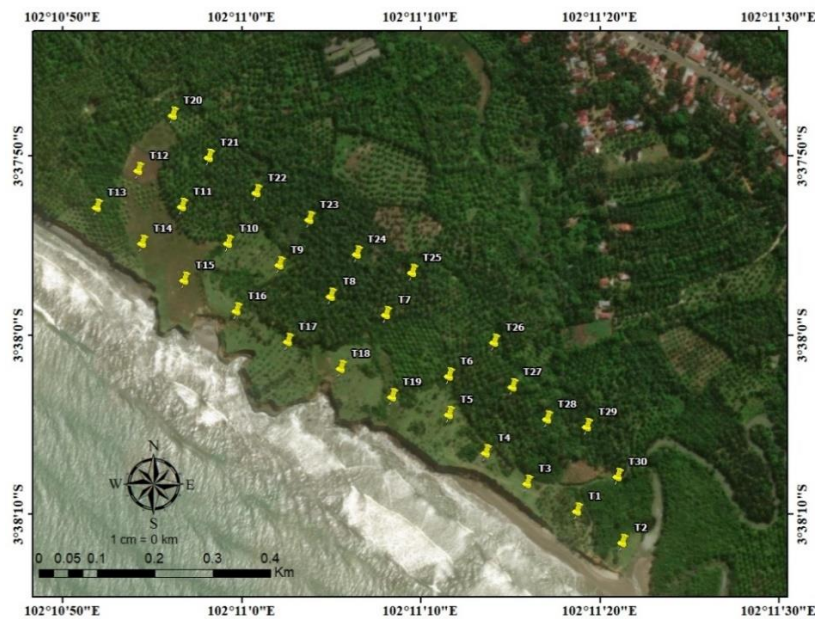


Figure 3. Microtremor data acquisition design in the study area.

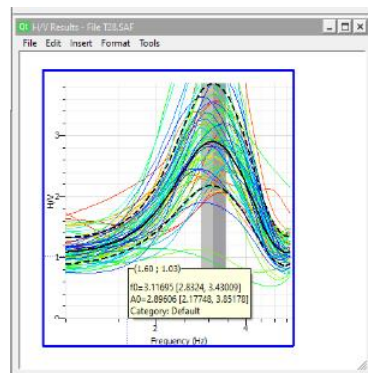


Figure 4. Data processing results using geopsy software.

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 (Mita & 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 the HVSr 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 (Setyowati *et al.*, 2024)

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

According to the Bengkulu geological sheet map (Gafoer *et al.*, 2007), The rocks in the research area consist of the Bintunan Formation (QTb) can be seen from the geological map of the rocks of the North Bengkulu area in Figure 5, this formation consists of various conglomerate rocks, breccias, reef limestone, tuff clay rocks, pumice rocks and woody rocks. Several studies show that areas with the Bintunan formation are susceptible to coastal abrasion, because the rocks in this formation have lithological characteristics that tend to be easily abrasive (Tarigan, 2016).

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 6. 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.

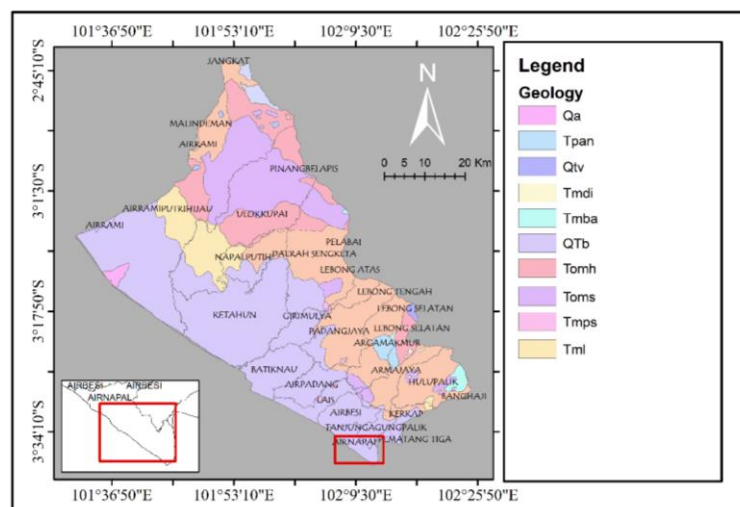


Figure 5. Geological map of North Bengkulu regency.

The correspondence between the two approaches between the v_s 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.

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 7.

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 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

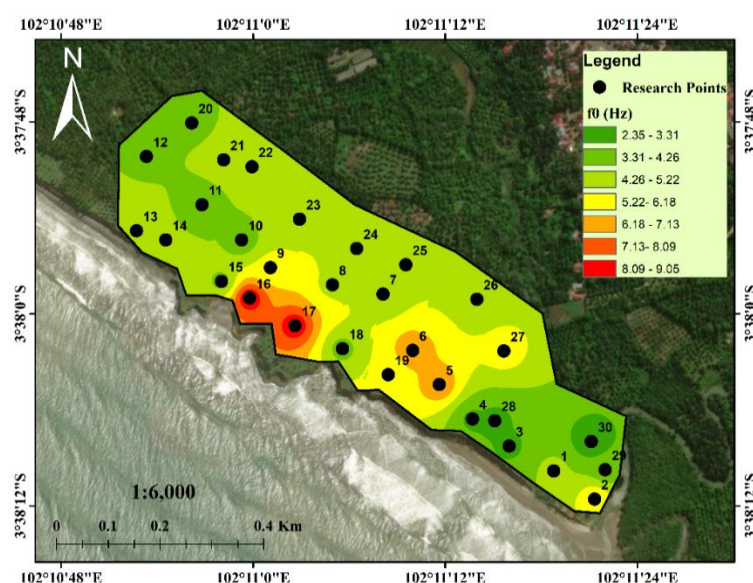


Figure 7. f_0 distribution in the study area

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

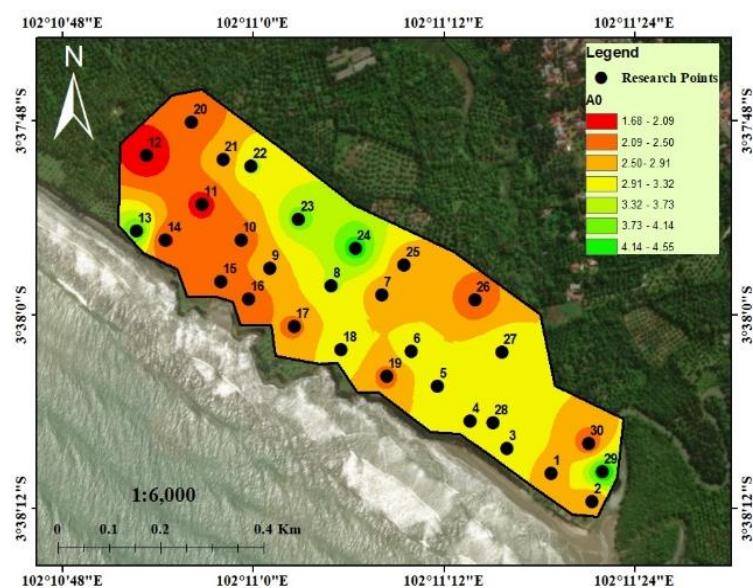
**Figure 8.** Distribution of A_0 values in the study area

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

Soil classification		Frequency Natural	Kanai classification	Description	Location	Color
Type	Kind	(Hz)				
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 more than 5m. Consists of sandy hard clay, loam and others.	The thickness of surface sediments is categorized as thick, about 10-30m.	3, 4, 28, and 30	
I	IV	< 2.5	Alluvial rocks, formed from sedimentation of deta, top soil, mud and others. Depth $\geq$ 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 8. 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.

Soft soil tends to have a high amplification factor, while hard soil will have a high amplification factor. In the research, the average beachfront area or at points 3, 4, 5, 6, 8, 13, 22, 23, 24 and 29 is in the medium soil classification, so development should not be carried out in the area to avoid abrasion.

Seismic Susceptibility Index (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 9.

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.

Areas that have low K_g values are areas that have thick sediment layers, which means that points 1, 2, 5, 6, 7, 8, 9, 10, 11, 12, 14, 15, 16, 17, 19, 20, 21, 22, 25, 26, 27, and 30 are areas that are safe from seismic vibrations.

Vertical Spectral (V_s)

Based on the mapping results (Figure 10) the shear wave velocity (V_s) 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.

The classification of rocks in an area can be known through Table 6. Very dense soils and soft rocks such as at points 8, 10, 12, 13 and 16 will be prone to moderate amplification of waves while soils with medium soil classification such as at points 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 will vibrate more easily when waves arrive because the soil is less rigid than the classification of very dense soils and soft rocks.

3D Modeling

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 11.a) is separated from the hard rock layer (Figure 11.b).

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 $350 < V_s \leq 50$.

The four parameters of microtremor analysis results of dominant frequency, amplification factor, seismic vulnerability index, and vertical spectral ratio show that the ground conditions at the site are quite stable to vulnerable to coastal abrasion. Special attention is needed in the planning of building structures to avoid resonance and minimize the impact of local amplification.

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

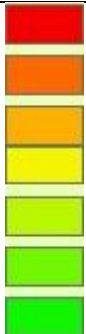
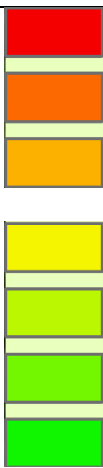
Zone	Classification	Value A_0	Location	Color
1	Low	$A_0 < 3$	1, 2, 7, 9, 10, 11, 12, 14, 15, 16, 17, 19, 20, 21, 25, 26, and 30	
2	Medium	$3 \leq A_0 < 6$	3, 4, 5, 6, 8, 13, 22, 23, 24, and 29	
3	High	$6 \leq A_0 < 9$		
4	Very High	$A_0 \geq 9$		

Table 5. Seismic vulnerability values (Yogaswara & Kuncahyani, 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	$K_g > 6$		

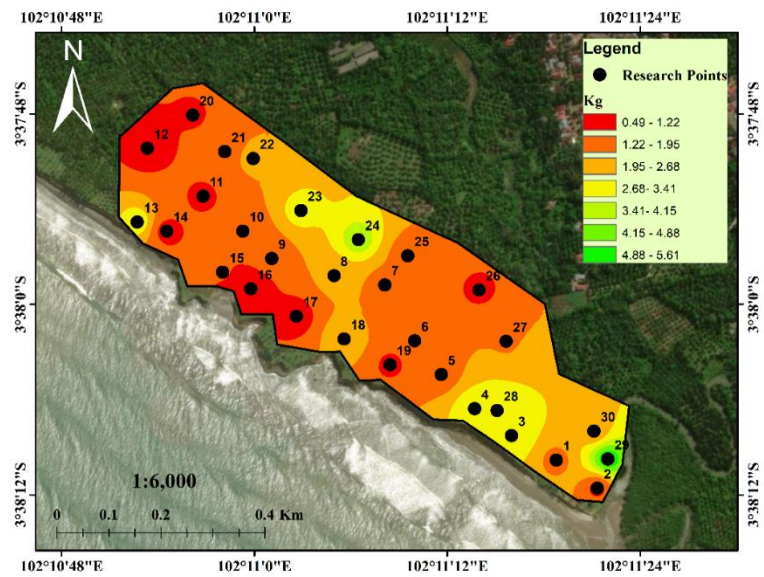


Figure 9. Distribution of k_g values in the study area

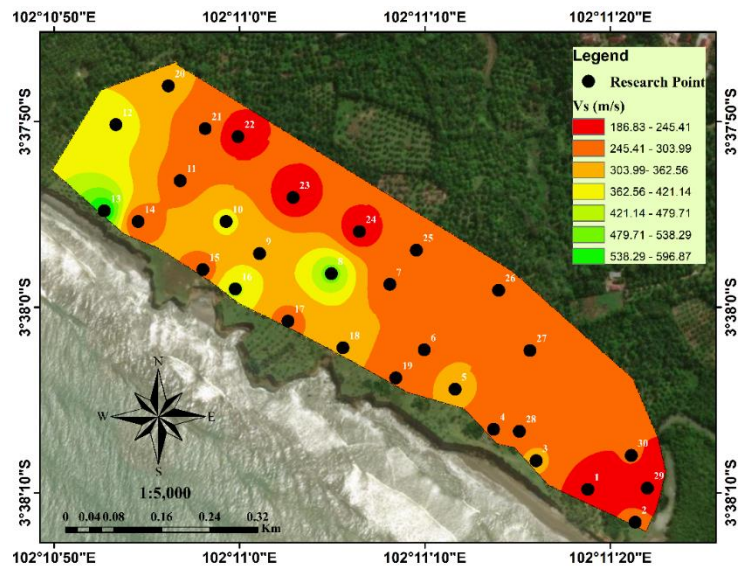


Figure 10. Distribution of V_s values in the study area

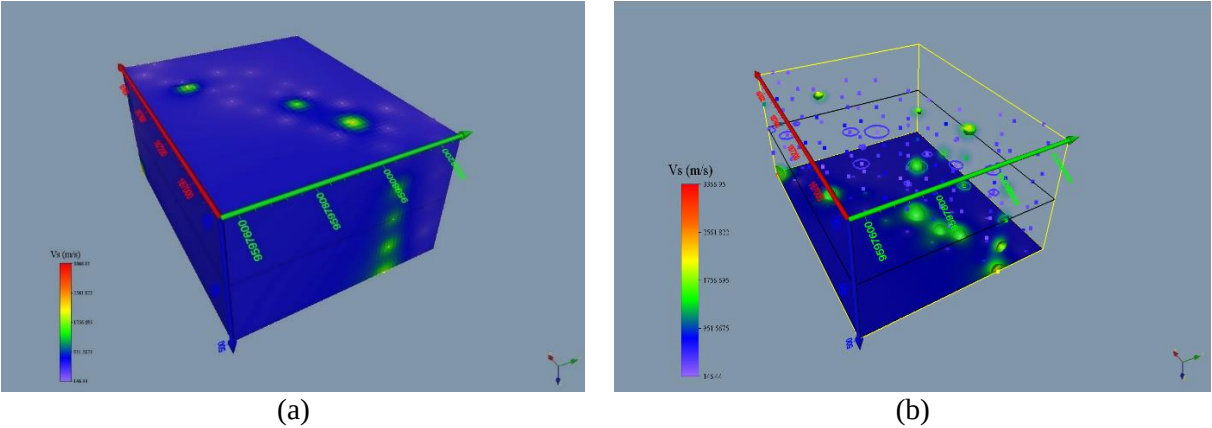


Figure 11. (a)Three-dimensional modeling (b)Volumetric modeling of the three-dimensional

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 Vs (m/s)	Location	Color
Hard Rocks	$V_s \geq 1500$		
Rocks	$750 < V_s \leq 1500$		
Very dense soil and Soft Rock	$350 < V_s \leq 750$	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	$V_s < 175$		

CONCLUSION

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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