International Journal of Advances in Applied Sciences (IJAAS)
Vol. 12, No. 4, December 2023, pp. 301~308
ISSN: 2252-8814, DOI: 10.11591/ijaas.v12.i4.pp301-308

Coastal vulnerability assessment using electrical resistivity tomography in Padang Betuah, Central Bengkulu

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Article Info

Article history:

Received Mar 10, 2023
Revised Apr 12, 2023
Accepted Jul 15, 2023

Keywords:

2D electrical resistivity tomography
3D electrical resistivity tomography
Abrasion
Coastal vulnerability assessment
Padang Betuah Beach

ABSTRACT

Abrasion disaster in the coastal area of Padang Betuah Beach has a high level of abrasion in Central Bengkulu. The local community utilizes abrasion in the coastal area as a tourist attraction and becomes local revenue in the research location. The location that becomes a tourist attraction is decreasing because the coastal area's land has been abraded. After conducting research using the electrical resistivity tomography (ERT) method in 2D and 3D, it was found that claystone dominated the coastal area at the research location with a resistivity value of 16-200 Ωm at a depth of 15-20 m. The coastal area in Padang Betuah Beach is composed of clay shale rocks (207-220 Ωm), and the depth is 2-14.8 m. Clay shale rocks are not abraded in stones with resistivity values >250 Ωm. This is caused by clay shale, which has low porosity, so it has a compact rock density. Seawater is identified at a depth of 21-63 m with a resistivity value of 2.225-10.2 Ωm. The depth of seawater determined follows the average height of the cliffs in the research location. The abrasion process can be slowed down by making jetties, water breakers, and mangrove cultivation.

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1. INTRODUCTION

Bengkulu Province is one of the provinces on the Island of Sumatra with a coastline of ±586 km, leading to the Indian Ocean [1]. The area in Bengkulu Province with a coastal area is Central Bengkulu Regency. Central Bengkulu Regency is the most vulnerable area to abrasion disasters and even ranks 70th in Indonesia as a district prone to extreme waves and coastal abrasion [2]. Abrasion has been prone to occur over the past 26 years, contributing to shoreline changes [1], [3]–[7]. The deterioration of the coastline in each research location can be classified as very severe damage criteria because the abrasion speed from the results of the abrasion speed study obtained >10 m/year [8].

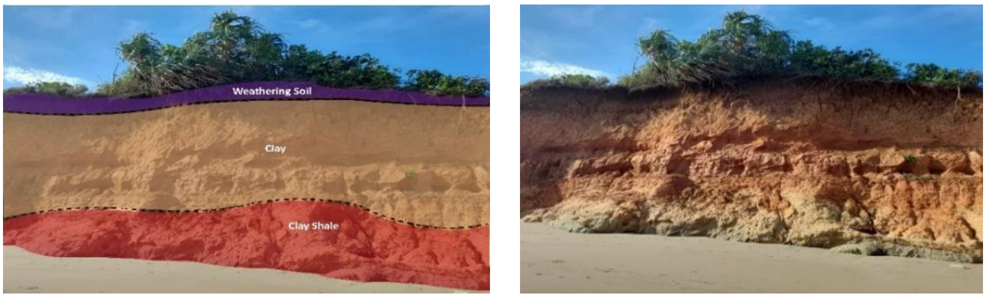
Coastal abrasion in Central Bengkulu can threaten the benefits of various coastal area resources for the surrounding community [9]. Resources in Central Bengkulu's coastal areas benefit the community, such as tourism, industry, and residential areas for residents [10]. Coastal abrasion in Central Bengkulu has damaged road facilities and residential houses and eliminated some coconut and oil palm plantations [11], [12]. Land erosion due to high waves has eliminated up to 40 m of coastal land area [13]. The loss of land due to abrasion is the main objective of this research to determine the ground that will remain after the entire coast is abraded.

Research conducted [1], [8], [14] generally revealed that the subsurface rock structure of abrasion-prone areas on the coast of Central Bengkulu varies greatly and is dominated by layers of clay, gravel, sandstone, sand, and weak rock structures that cause coastal cliffs to be easily abraded and eroded when hit by waves of seawater. The research covers almost all abrasion-prone areas in Central Bengkulu Regency, with the level of vulnerability in each area having a soft rock structure but has yet to provide 2D and 3D subsurface rock structure information. Previous research also did not provide information to see the subsurface structure that is prone to abrasion if the abrasion process continues and how to model the continuation of abrasion towards the mainland in 3D, so it is necessary to know the layer of soil/rock that will be abraded towards the mainland with an orientation perpendicular to the coastline. This abrasion process continues; therefore, the urgency in the Central Bengkulu coastal area is urgent and must be studied with geophysical methods. The geophysical method that can describe the subsurface rock structure in 2D and 3D in the coastal areas of Central Bengkulu is the geoelectric method. This method has been widely used in coastal area studies [15]–[19]. Electrical resistivity tomography (ERT) is a geoelectric method one of the geophysical methods that can determine the subsurface geological conditions based on the electrical properties of the constituent rocks [20]. Therefore, it is necessary to conduct research on the lithology and rock structure in the abrasion-prone area based on the rock resistivity value to determine the visualization of the lithology and subsurface structure in 2D and 3D so that it can determine the depth of the rock layer that will be abraded and model how far the abrasion will occur towards the land. The ERT method is robust and well-consolidated in near-surface geophysics surveys [21]. The study's results will analyze the resistivity value of rocks that do not have the potential to be abraded and know the types of rocks that are not eroded by seawater so that the material remains on the coast.

The geological condition of the coast in Padang Betuah Beach is dominated by geological formation unit Qa (Alluvium formation), which consists of tidal marshland formed from Holocene sediments containing marine deposits, river and swamp deposits, and beach sand deposits. Detailed geological condition information is in Table 1. The Qa formation in the study area is exposed on the coastal cliffs as shown in Figure 1, Figure 1(a) shows the interpreted, and Figure 1(b) shows the uninterpreted.

Table 1. Geological formations at the research site [22]

Unit	Age	Code	Lithology	Distribution
Alluvium	Holocene	Qa	Boulders, pebbles, sand, mud, and clay	Distributed for the most part along significant rivers in the northeast and southwest of the area and locally along the Ketaun–Musikeruh fault zone.



(a) (b)

Figure 1. The stratigraphy of the coastal area of Padang Betuah Beach, (a) interpreted and (b) uninterpreted

2. RESEARCH METHOD

The abrasion phenomenon in this study was carried out in March-June 2022 on the coast of Padang Betuah, Central Bengkulu Regency, Bengkulu Province. Determination of the resistivity value by injecting current into the subsurface [23] at 12 voltages (V), and the main unit will record the rock response [24]. Geolistic measurements are in the form of a straight line stretch of 480 m long and using 48 electrodes, with an electrode spacing of 10 m perpendicular to the coastline.

The data acquisition technique uses a Wenner-schlumberger configuration. 2D measurements were carried out on one track with a line-shaped distribution of measurement points and 3D measurements as in the survey design in Figure 2. Illustration of datum points or quadrupoles in Figure 3. 2D measurement with 48 electrodes using the Wenner-schlumberger configuration [25]. The dense quadrupoles can obtain inversion results of rock-type resistance values resembling rock lithology conditions and high resolution. Figure 3(a) illustrates the survey design for getting 2D and Figure 3(b) illustrates the 3D subsurface cross sections.

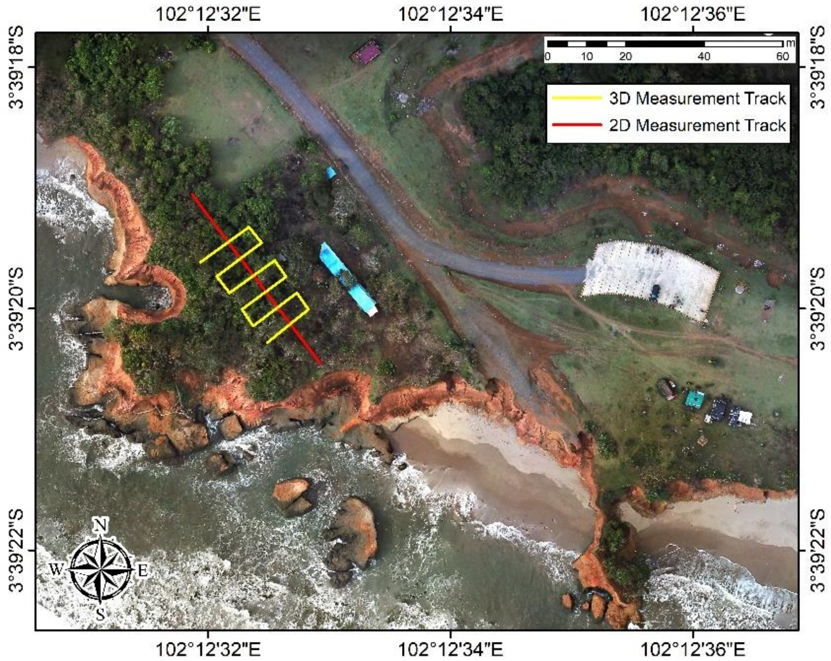
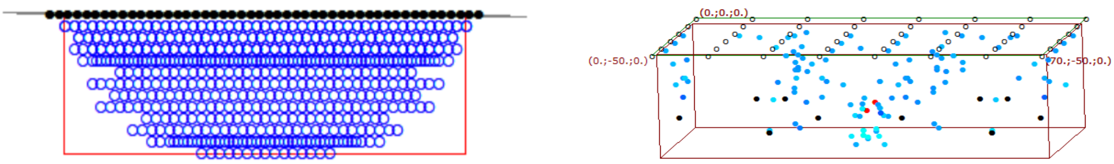


Figure 2. Research sites in Padang Betuah Beach



(a) (b)

Figure 3. Quadapole geoelectric data are shown, for (a) 2D measurements and (b) 3D measurements [26], [27]

The data obtained from the field has the file extension *.tsv. This file contains the V, current (I), rock density (ρ), and standard deviation (σ) values for each measurement datum point. The measurement data at the research location is input in the inversion process and minimum standard deviation correction. The data processing results are followed by the interpretation of the best model results provided by the software. The software used for the inversion process and producing 3D cross-section models is ERTLab and ViewLab software. This software also provides facilities to perform and convert 3D into 2D models by performing cross-sections on particular axes. Through this software, we can interpret rock types in depth. 2D and 3D models can identify the type of rock layer below the surface based on specific color differences or color contours. ERTLab 2D and 3D cross-section resistivity values are matched with the study area's geological conditions so that the subsurface layer type can be known based on the interpretation of ERT data and with the help of rock resistivity by Edge [27].

3. RESULTS AND DISCUSSION

The ERT method is one of the geophysical methods that can describe minerals under the earth's surface [20]. The ERT method shows the subsurface structure in an apparent lithological heterogeneity and geological structure [28]. The 2D model obtained is the result of inversion, which will match the field measurement data with the model provided by the software shown in Figure 4. The interpretation of the 2D model results can be seen in Table 2. The field measurement data is modeled using (1) and (2) [29]. 2D modeling using (1) and 3D modeling using (2):

$$\nabla.\left(\sigma\nabla\hat{G}\right) + k_y^2\hat{G} = \frac{-\delta(x-x_s)}{2} \quad (1)$$

$$\nabla.\left(\sigma\nabla G\right) = -\delta(x - x_s) \quad (2)$$

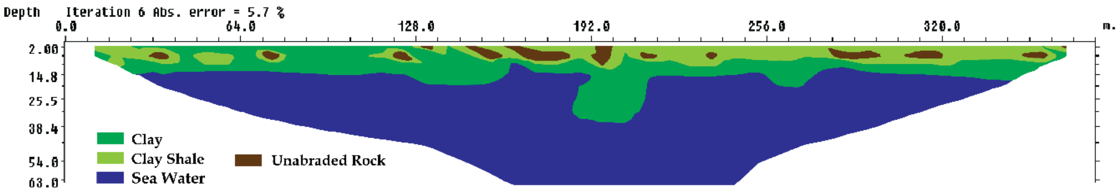


Figure 4. 2D modeling of the research site

Table 2. 2D measurement results of coastal vulnerability in the research site

Lithology	Thickness (m)	Resistivity (Ωm)
Clay shale	2-14.8	207-440
Clay	15-20	16-200
Sea water	21-63	2.25-10.2

Geoelectric method measurements will analyze the resistivity value of rocks that contain water and have high porosity, and the resistivity value will be calculated compared to relatively compact rocks [30]. Rock pores will be filled with fluid, and empty pores will be filled according to the conditions that dominate in the subsurface [31]. Areas near the sea will cause these highly porous rocks to infiltrate seawater and settle into it. The conditions at the study site are dominated by seawater because the study is located in the coastal area, and the rocks will be sedimented continuously according to the sea conditions at Padang Betuah Beach. Rocks that continue to undergo sedimentation cause the characterization of the supporting rock to be different from its original state [32]. Ongoing sedimentation involves the mechanical breakdown of materials due to the rush of seawater that has force and pressure [15], [33]. This process occurs gradually, with rocks in the coastal area eroded perpendicular to the land. Rocks that continue to be corrupted by seawater, causing the land to be completely eroded, and remaining clay shale rocks with resistivity values >200 Ωm. Clay shale rock remains and is not eroded because this rock has a low priority compared to other rocks. Clay shale has rock properties that are more compact than other rocks, so its porosity is low, and it is not sedimented by seawater. This clay shale rock is a dry stone whose constituent materials have strong bonds, so external factors do not easily overturn the material [34].

Claystone dominates the coastal cliffs on Padang Betuah Beach. Claystone has a resistivity value of >15 Ωm, and the material is mixed with sand. If exposed to prolonged heat, this claystone will easily experience cracking and has impermeable properties to water [35], [36]. Its cracking nature causes the claystone material to be quickly eroded by seawater and collapse due to the splitting of the claystone material. This condition causes the land dominated by claystone to have a high potential to be lost due to the abrasion process in the coastal area. The coastal regions of Betuah Beach must have special treatment by the government to inhibit the abrasion process. If not given special treatment, it can reduce the land used by local people to make money and damage government facilities such as crossroads and others.

Identification of seawater, the main factor in abrasion with geoelectric methods, will calculate a relatively small resistivity value of <10 to <10-Ωm. The small resistivity value of seawater is caused by its electrolyte nature [37]–[39], so the resistance value is small when injected with electric current [15], [40]. Seawater in the 2D cross-section accumulates in the sand layer with refined grains, so it has a high porosity that can store seawater in large volumes. The 3D model of the study site displays the distribution of materials that make up the study site at Padang Betuah Beach. The 3D modeling (Figure 5) focuses on the remaining clay shale rocks if the study area is abraded.

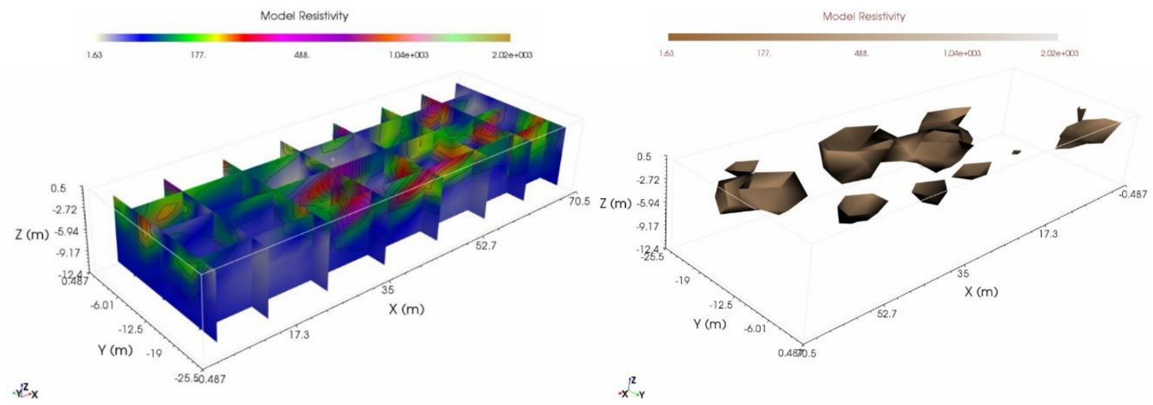


Figure 5. 3D modeling of the rocks that will remain if the study area continues to experience abrasion

The 3D model in Figure 5 shows the rocks that will remain if there is continued landward abrasion. Climatological and geological factors influence this condition in the research area, affecting seawater and the rock structure of the coastal zone [5], [7], [10], [41]–[43]. This modeling displays the subsurface condition of the research location with a resistivity value of >250 Ωm in the form of clay shale. this rock is not homogeneously distributed in the coastal area, so the land conditions are inserted in an abstract and undefined form. The landscape's shape in Padang Betuang Beach's coastal area is unique and exciting. Factors that influence this research location to have a unique landscape shape are caused by abrasion, which has been explained in the previous explanation.

4. CONCLUSION

Abrasion in the coastal area of Padang Betuah Beach is dominated by layers of clay, clay shale, and seawater that accumulate in fine-grained sand. The 3D modeling results show that the remaining rock layer is clay shale, with a resistivity value of >250 Ωm. This study shows that the research site is not homogeneous and has an abstract landscape. The shape and distribution of the remaining rocks at the research site are depicted in 3D modeling. Supporting factors for continuous abrasion are caused by geological and climatological factors in the coastal area. The condition of abrasion that occurs massively in Padang Betuah Beach is a significant concern in geohazard in Bengkulu Province. The results of our research can refer to the construction of jetties and water breakers, which can be studied further in the field of Geotechnical science. Conventional activities can slow abrasion, such as reclaiming land on the coast with mangrove cultivation. Recommendations on each element cannot be assessed how much efficiency in preventing abrasion disasters at Padang Betuah Beach, so it is necessary to research the handlers that will be applied objectively.

ACKNOWLEDGEMENTS

The authors are grateful to the Institute for Research and Community Service (LPPM), University of Bengkulu, for the research grant "Unggulan FMIPA UNIB Tahun 2022" with contract number (5704/UN30.15/PP/2022). The authors also thank the Physics Laboratory, University of Bengkulu, for providing equipment (Multi-Channel Resistivity meter MAE X612-EM 48 Channels) and software (Res2Dinv, View Lab 3D, and ERT LAB 64) during this research.

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