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Assessing the optimal location for Sipora wave energy power generator site placement from a geological perspective

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Abstract. One of the potential sources of renewable energy in the Mentawai region is ocean wave energy. The western Sumatra sea has a wave energy potential of up to 20 kW/m. The wave energy potential modeling conducted by the Marine Geological Institute (P3GL) ESDM revealed that western Mentawai waters are locations that produce annual average wave energy of around 20 kW/m. The geological survey of the seabed for power generating wave energy turbine sites using acoustic equipment including the Echosounder Odec, SBP Stratabox, and Star Fish Side Scan Sonar. The mapping of the seabed allows for the identification of undersea morphology, slopes, structural elements, and seafloor objects. Ocean depth sounding and bottom surface imaging are used in this research to determine the placement of the turbine site from the wave energy generator connection grid. The existence of underwater corals and fluvial plain units, continental shelf with shallow seabed and a gentle slope with an average depth of 30 meters was recognized as the most important factor in determining the site's location in this research. Based on the weighting and scoring results, optimal locations for potential power plant sites are in coastal areas located in offshore near Batu putih coast.

Keywords: Mentawai, seafloor, wave, energy, Underwater, exploration, Geology

1. **Introduction**
The Bali action plan Joint Implementation (JI) was established at the 2007 COP-13 meeting in Bali, Indonesia, as an emission reduction mechanism through which developed countries could transfer emission reductions through joint projects to reduce greenhouse gas emissions and the rate of climate change in the country. The meeting's protocol became the government's basis for responding to global issues, with the Minister of Energy and Mineral Resources issuing Ministerial Regulation Concerning the Regulation of the Electric Power System Network, which requires PT PLN (Persero) to be able to optimize the potential for power generation from new and renewable energy sources. Offshore wave energy farms provide one of the best, new possibilities for clean, abundant, environmentally benign, and reliable energy generation. Wave energy is produced close to coastal population and does not require significant additional build out of transmission. The Sipora islands are known as the destination of endless surf breaks. Waves tend to be heavy hitters with some exposed sections of shallow reef. Consistent Indian Ocean swell to make it one of the most sought on earth. There are at least 22 villages that are part of the non-electrified village in Mentawai Islands [1]. The wave energy potential modeling conducted by the Marine Geological Institute (P3GL) ESDM revealed that western Mentawai waters are locations that produce annual average wave energy of around 20 kW/m[2]. Based on ESDM research and Sipora natural conditions, the Sipora offshore are most suitable for the use of wave energy.

1.1 Location
Tuapejat is the main village on the island, with a population of around 20,000 people, PT PLN still relies on inadequate diesel generators. Despite the fact that the electricity supply is limited, Tuapejat's electrical network installation is well connected. In order not to require a significant additional transmission, we decided to conduct a survei in Tuapejat, Sipora Utara (Figure 1).

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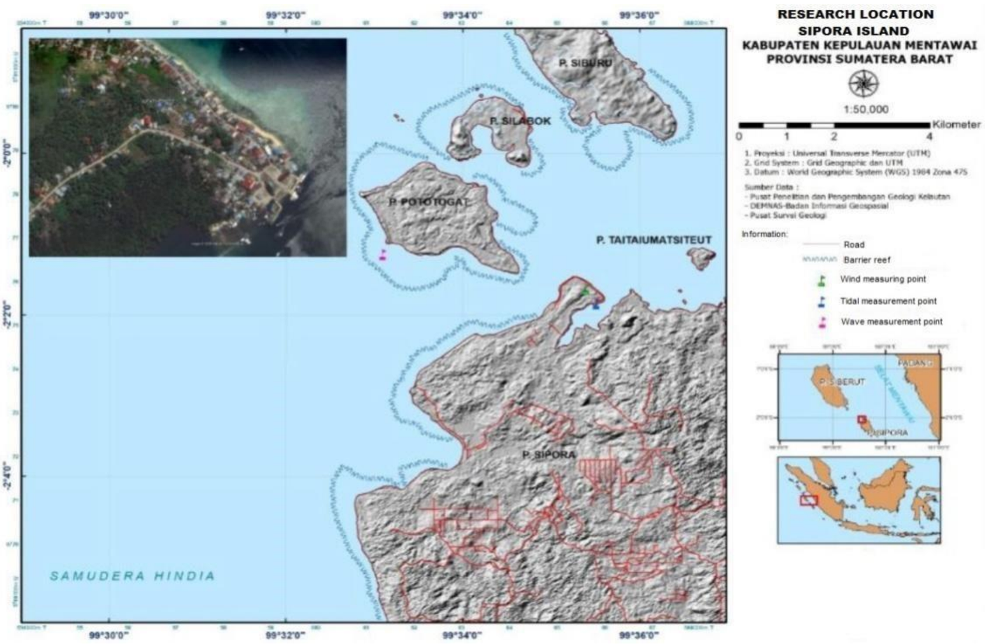

Figure 1. Study area are the world-famous surf destination located in Sipora island. As the largest island, the town and administrative center is also located on the island, precisely in Tuapejat city that located on the North side.

1.2 Equipment plan

The waves originally blow far from the coastline, due to the wind blowing on the surface of the water inducing the water particles to rotate and that rotation extends deep down below the surface. This rotational energy turns into elliptical energy and eventually backward and forwards. The mechanism was actually developed by a company called WaveRoller. The system was inspired by a professional diver, Rauno Koivusaari. While diving in a shipwreck and watching shipwreck hatch moves back and forth with the waves. This prototype approximately has about 10 square meters of steel panel fixed to the seabed via the floatable foundation. The equipment is planned to be deployed at around 15-20 m of water depth, where there is still strong wave energy coming in. It is submerged at a depth of around 20 m, so it is protected from extreme waves (Figure 2).

The system generates electricity by capturing the movement with a hydraulic circuit in a machinery room underneath the surface. That hydraulic energy we turn into electricity with a hydraulic motor, accumulator, and generator[3].

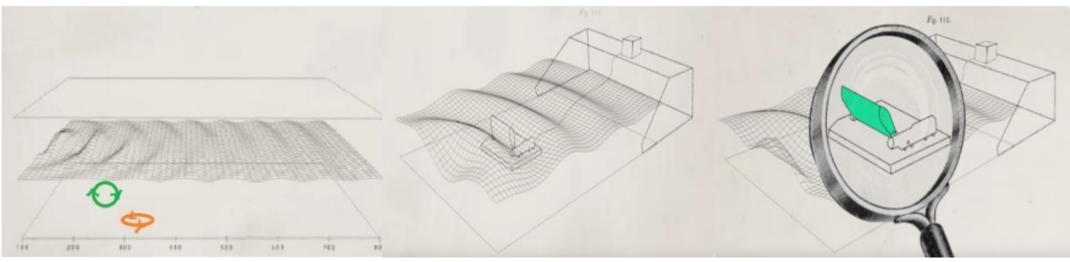

Figure 2. The device is installed underwater at depths of approximately 15 - 20 meters, which connects to a hydraulic motor that drives an electricity generator. The wave energy power plant's electrical output is subsequently connected to the electric grid through a subsea connection. [3]

1.3 Regional Geology

The basement rock of the sipora island is constituted of accreted oceanic crustal rocks mixed with with scoured metamorphic rock and the Paleogene deep-sea flysch sediments (Bancuh). The geodynamic framework suggests the presence of a magmatic arc province that migrated as a result of the compressional and strike-slip tectonic forces. During late Miocene, extensive stretching of the crust that was related to the eastwards migration of the subduction zone. This transtensional rifting brought about the input of sea water in the Mentawai basin, leading to the development of both continental and shallow-marine depositional environments. The sedimentary rock of the Mentawai Islands comprises clastic and carbonate rocks with lignite intercalation [4]. In the Sipora Islands, the sedimentary rock of the Mentawai Group was included into the Tolopulai, Maonai, and Batumonga Formations. The Early Miocene Tolopulai Formation was deposited within the shallow marine environment, probably as fore-reef, and overlain by the Maonai Formation. The later interfingers with the Batumonga Formation of Middle-Late Miocene - Pliocene age deposited within an inner littoral environment [5](Figure 3).

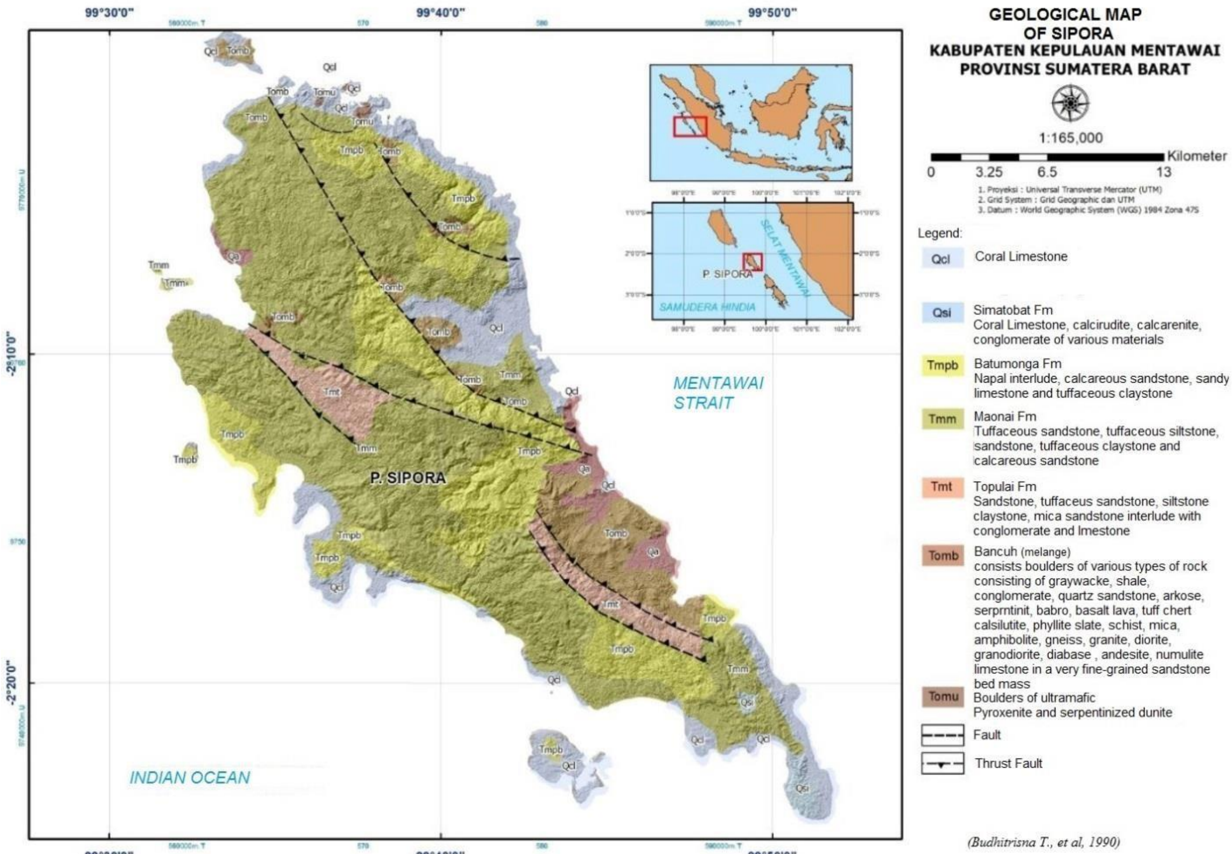

Figure 3. Geological Map of Pagai and Sipora[5]

2. Method

2.1 The coastal characteristics Mapping

The coastal characteristics were mapped out qualitatively according to the classification proposed by Dolan [6], which included lithology, beach slope, shoreline characteristics, and dominant processes. The objective of mapping the coastal characteristics is to understand in detail the characteristics of the beach, the process of accretion and abrasion in the study area. The results of the- mapping of coastal characteristics are used for determination of the landing point of the cable route transmission.

2.2 Sounding

Sounding is a process of gaining sea depth measurements simply using an Echosunder Single Beam Navison Reson 210. Data is retrieved graphically and digitally utilizing a recorder installed into the equipment. A signal transducer tool is put on the ship's left hull, at a depth of 1 (meter) meter below sea level.

The echosounder is triggered at 1 second intervals with a 10 cm reading accuracy. The depth data are corrected for the transducer position and the tides of the survey area, and the outputs are projected on a map of the research area's location, ultimately result in a map of sea depth.

2.3 Side Scan Sonar

Side Scan Sonar Starfish 900F used for imaging seabed objects and providing information on the shape and size of underwater objects. This method can provide quantitative information in the form of the amplitude value of the object or the bottom of the water. The purpose of this research is to visualize or map the bottom of the waters and classify sediments or objects on the seabed qualitatively and quantitatively, so that the unique signal characteristics of various substrates can be known.

2.4 seismic reflection (SBP)

Sub-bottom profilers Stratabox are usually composed of a single channel source that transmits sound pulses into the shallow sediments on the seabed. The sound pulses bounce off the sea floor and subsequent buried sediment layers according to differences in their acoustic impedance (hardness). Acoustic impedance is related to the density of the object and the speed at which sound travels through this material. The different times taken for this signal to be returned and recorded by the SBP indicate how deep the layers are below the seabed. The result of SBP data processing is a representation of the geological structure.

2.5 Seabed surface sediment sampling

Sampling of seabed sediments was carried out to determine the distribution of seabed sediments and as a side scan sonar image correction in the study area. This method is very important to determine the distribution of sediment as a sediment carrying capacity for wave power plant. Around Tuapejat offshore, Sampling of seabed sediment was carried out at 16 locations using a grab sampler.

2.6 Data processing

Data from sounding and SBP were corrected for transducer positions and tidal before being projected onto a map of the study area location. Depth data from sounding is processed using Surfer and Global Mapper to create contour shapes and three-dimensional morphology. Data from SBP were analyzed qualitatively using petrel software and side-scan sonar data is interpreted and classified qualitatively using the SonarPro software to determine the geometric shape and uniqueness of objects. Ocean depth sounding and bottom surface imaging also used in this study to determine the cable route transmission from the wave energy generator connection grid [7].

The main purpose are GIS analysis with raster-based spatial analysis is used to determine the location of the generator, assuming several parameters to get the best weight for determining the location.

3. Result

3.1 Coastal characteristics

Based on the type of lithology in the coastal area can be divided into four groups, reef limestone (Qcl), Tufaceus sandstone (Tmm), Ultramafic Boulder (Tomb) and Bancuh Melange (Tomb) (Figure 3)

Most of the mineral that composes the beach is from coral limestones (Qsi). The grain size of the coral limestones sand found on the beach is generally medium-coarse, greyish white in color, and contain few quartz minerals, lithic fragments, and mafic minerals. This type of sediment dominates the Pototogat island coast and the northwest coast of Sipora. Around the Jati beach exposed few melange rocks that underlie the island of Sipora, with a very weathered outcrop. The north side of the Sipora island is dominated by mangrove forests (Figure 4). The sediment that dominates this area is grey mud which is believed to have a high organic matter content. This beach is also strongly influenced by the tides of sea water which periodically stirs the sediment. The interaction of organisms with sediment and the high effect of water evaporation also greatly affects this coastal environment. The wave conditions on the north side mangrove beach is relatively calm so they are unable to carry the sediment to the deep waters on the high seas so the suspended sediment spread over a wide area of water. The slope and morphology of the study area can be devided into two categories. The north side of the Sipora island is dominated with hilly beach approximately occupies 30% of the study area. The slope is between 20 - 30 degrees, with high cliffs in some sections. The lowlands occupy about 70% of the Sipora island are coastal plains units with concave slopes, exogenous morpho-genesis (marine), 0–2% slopes, and land use for settlements, agriculture, and smallholder plantations. This type of morphology dominates the Pototogat island coast and the northwest coast of Sipora (Figure 4).

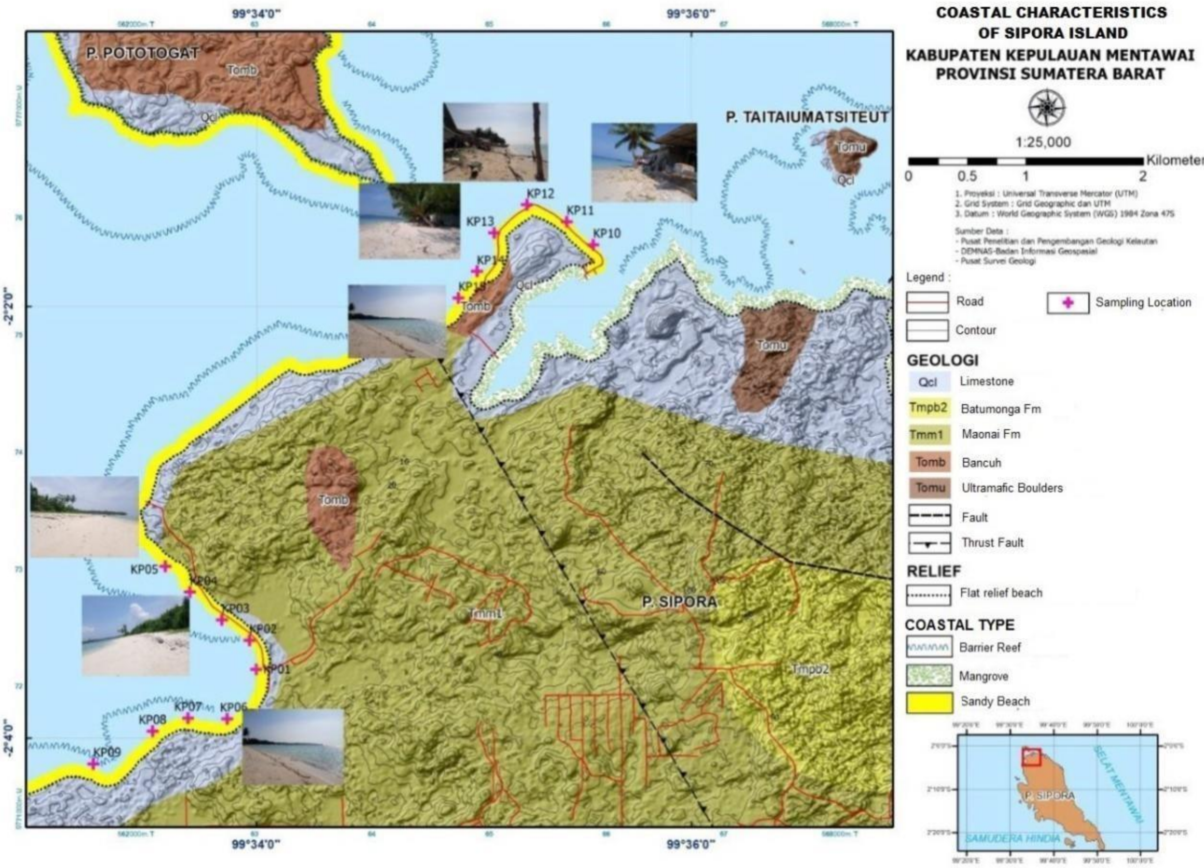

Figure 4. Coastal characteristics map of Sipora Island (Tuapejat-Pantai Jati-Mapadegat)

The dominant factor affecting the configuration most of the north Sipora and Patotogan island coastline is marine processes. This is because this area is an overwash area, which has higher energy. The slope of the beach ranges from 2–6%. This shows that the wave energy in this area is quite high, because the steepness of the beach slope is directly proportional to the wave energy [8]. Currents and waves are estimated to be coming from the west, southwest, south, and southeast. Waves can generate energy to form beaches, creating currents and sediment transport in a perpendicular direction and along the coast and cause forces acting on coastal structures [9]

Overall, we discovered two types of beaches as a result of the coastal characteristics mapping, there are sandy beaches and mangrove beaches. The sandy beaches are characterized by the presence of coral reef terraces near shore with fairly coarse white loose sand consisting of coral debris and shell fragments and few mafic minerals from reworked melange in front of the beach, while the the north side of the Sipora island is dominated with hilly beach and mostly covered by mangroves (Figure 3). This type of beach has shallow, clear, and inundated calm water conditions so that coral reefs can develop well, as well as several other marine biotas (locally and in small quantities), especially fish and seaweed. This is due to the presence of a wide and shallow coral terrace in front of the beach, which serves as a barrier against the crashing waves. Based on the data above, the best proposal for the placement of the cable line transmission landing point is the northwest coast of Sipora.

3.2 Seabed surface sediment

Seabed sediments were taken from 15 locations using sample grabs at a depth of 10 meters to 40 meters. Sampling of seafloor sediments was performed at 16 sample locations and only one location contained sand samples at M20-08. the other samples were only fragments of coral reefs and mollusk shells fragments with grain size granules to gravel. The results of megascopic descriptions can be seen in Table 1. Samples M20-8 consisted of medium-coarse sand, brownish white, poorly sorted, moderately angled, contain few quartz minerals, lithic fragments, and mafic minerals.

As a result, nearly the entire feasible area is covered with coral. In this case, only 20 percent of the study area is covered with sand (Figure 5)."

Table 1. List of Samples, and description

No. Samples	Coordinate (DD)	Description
M20-01	02.061352 /99.566660	Coral, red, brown and white coral reefs and mollusk shells fragments, granules to gravel
M20-02	02.058995 /99.566172	Coral and mollusk shells fragments, granules to gravel
M20-03	02.057558 /99.563961	Coral and mollusk shells fragments, granules to gravel
M20-04	02.055352 /99.561528	Coral, red, and mollusk shells fragments granules to gravel
M20-05	02.052489 /99.559621	Coral, and mollusk shells fragments, granules to gravel
M20-06	02.065159 /99.564449	Coral and mollusk shells fragments, granules to gravel
M20-07	02.065149 /99.561445	Coral and mollusk shells fragments, granules to gravel
M20-08	02.066131 /99.558701	Medium-coarse sand, brownish white, poorly sorted, moderately angled, contain few quartz minerals, lithic fragments, and mafic minerals
M20-09	02.068680 /99.554173	Coral and mollusk shells fragments, granules to gravel
M20-10	02.028561 /99.592453	Coral and mollusk shells fragments, granules to gravel
M20-11	02.026810 /99.590458	Coral and mollusk shells fragments, granules to gravel
M20-12	02.025491 /99.587373	Coral and mollusk shells fragments, granules to gravel
M20-13	02.027655 /99.584880	Coral and mollusk shells fragments, granules to gravel
M20-14	02.030637 /99.583553	Coral and mollusk shells fragments, granules to gravel
M20-15	02.032701 /99.582147	Coral and mollusk shells fragments, granules to gravel

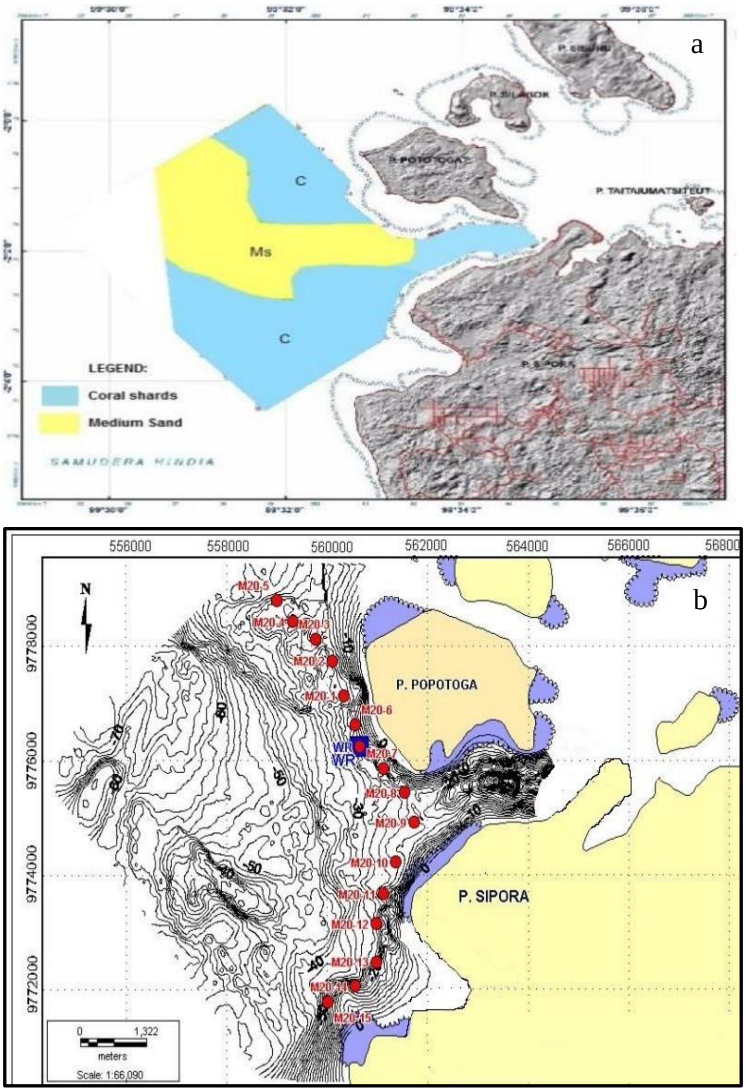

Figure 5. a.) Sediment distribution and b.) sampling location

3.3 Seafloor Morphology & Bathymetry

The integrated sounding data produces a sounding fix point in the form of coordinates, latitude (X) and longitude (Y), as well as the depth value (Z). The result of bathymetric measurements was corrected with tidal MSL.

Data selection for Interpretation is related to the target location which aims to find out the bottom profile of the seabed. The basis of picking on stratabox data is based on the analysis model seismic facies[10]. In this study, the direction of the trajectory underwater morphological data collection is more focused on the location of the tool placement static ocean wave meter with the direction of trajectory southwest - northeast and vice versa.

The coastal parts of Sipora Island and Pototagat Island have relatively high subsurface relief, reaching a depth of approximately 40 m. From the SBP records, the rock that forms the base of the island and seabed sediments cannot be separated. This indicates that the stratabox acoustic waves cannot penetrate the layers on the seabed surface, making it difficult to identify the sediment layers below the seabed surface. The shape of the underwater morphology is a result of tectonic formations working in the study area. The sediment layer at the bottom of the subsea surface is rework material from the bedrock where the relative thickness is not visible in the stratabox recording results because the accoustic energy does not penetrate the hard rock.

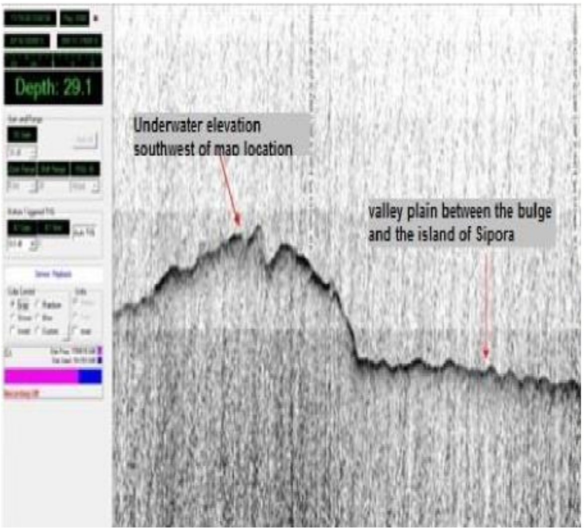

Figure 6. SBP records of seafloor the morphology show subsurface elevation in the Southwest of the study area.

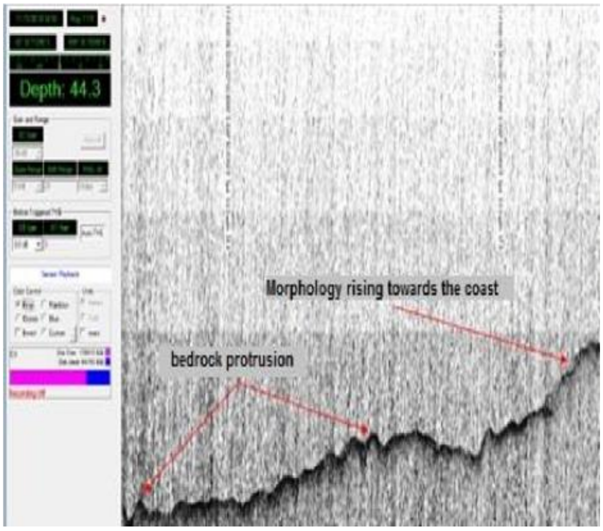

Figure 7. SBP records in the Northwest of study area, the appearance of the slopes towards features the coast with a depth of 35 meters and shows the bedrock protrusion morphology.

Bathymetric data show that the morphology of the Sipora seabed is graded starting from a depth of -15 m near the shoreline and getting deeper into the open sea to a depth of -60 m (Figure 4). The coastline pattern relatively follows the pattern of the north to south shoreline, the contour pattern begins to change and there is a wide valley plain up to a depth of 7 meters. In the northeastern area, the contour pattern mapping forms an oval circle with a depth of -35 meters which is the morphology of the protrusion of the bedrock (Figure 7), on the southwest side the depth gets deeper to -60 meters and slopes back towards the coast. The west side coast of Mapadegat, there is height morphology in the middle of the sea with a height of about 10 m from the seabed which is estimated to be hard rock (Figure 6). The condition of the seabed surface in the study area shows a steep morphology in the form of coral reefs and shallow basins but it appears flat in other areas and only steep away from the coast. Based on these results, the submarine power line corridor is included in the topography of the continental shelf or continental shelf with a depth value of up to -30 meters. This matches up to [11] statement that the continental shelf is a shallow seabed with a gentle slope and a steep slope with an average depth of 30 meters.

Tectonic events are primarily responsible for differences in the topography of the seabed surface. Moreover, oceanographic factors such as waves, and tides also affect recent geological processes. Based on the measurement results, the distribution of the slope of the depth contour pattern is described in the form of color gradations. The redder the color, the steeper the slope (Figure 9). On the map can be shown from east to west, to a depth of -30 meters from the shoreline. The contour pattern is relatively loose, showing the morphology of the seabed coastline with moderate relief, and a gentle slope to the open sea with a slope of 2^o to 8^o.

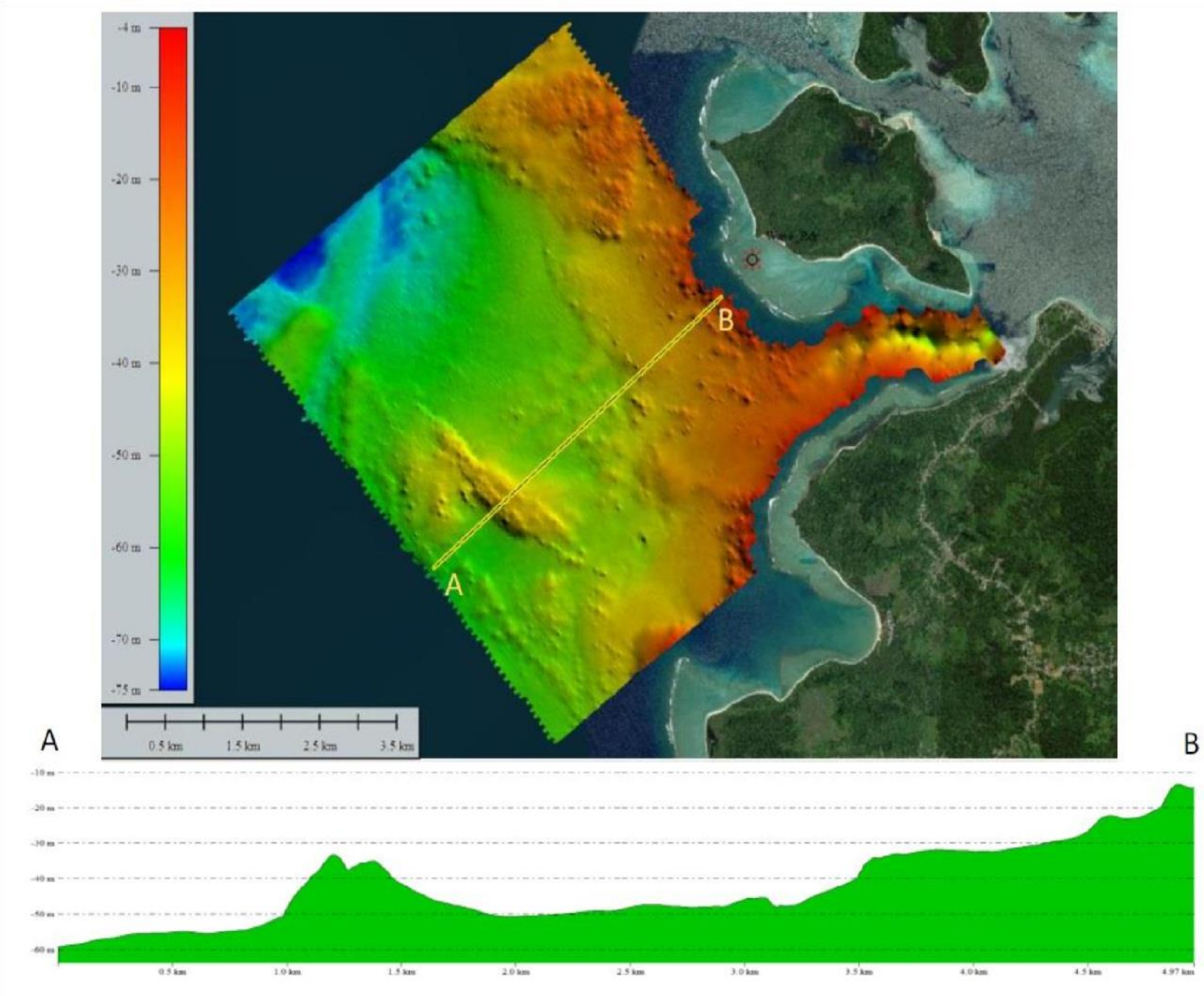

Figure 8. A-B cross-section of Sipora seabed morphology shows the presence of underwater elevations in the Southwest of the study area.

The slope of the seabed is visualized in the cross section line A-B'. The cross-sectional image of the seabed depth from A to B shows the morphology of the height in the middle of the seabed which is estimated to be hard rock (Figure 8). Based on the map cross-section the morphology of the seabed slopes off the coast and gets higher towards the coast. The morphology can be interpreted that the wave run-up will be higher reaching coastal areas due to morphology that is increasingly rising towards the coast.

Furthermore, the current flow will be higher towards the beach due to the presence of straits or gaps narrow between the two islands of Sipora and Pototogat, as well as the area where the waves break in the bay, which will also be higher towards the shore. A slope of more than 6 degrees will pose a risk to the burial plow [12] The seabed slope is also of great concern in the cable burial installation (Figure 9).

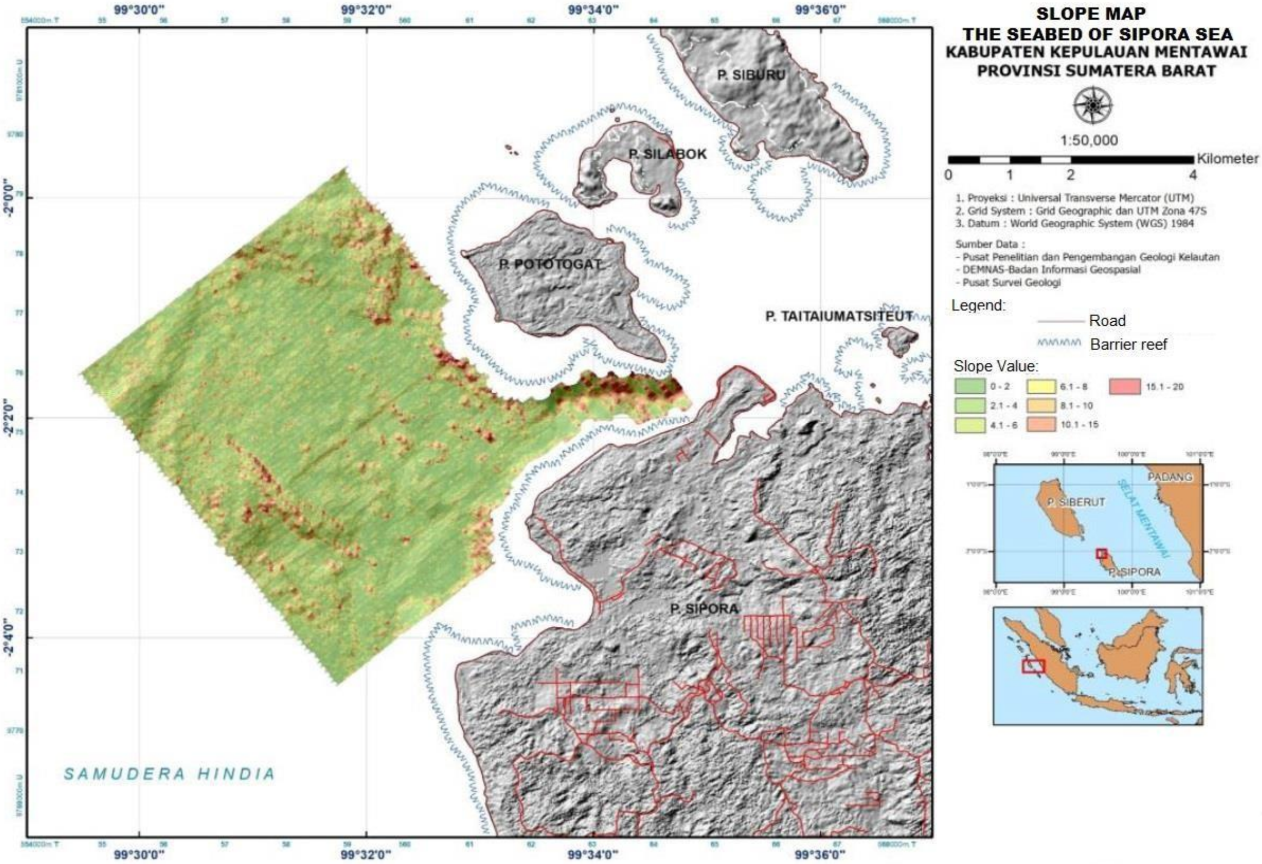

Figure 9. The slope map of the Sipora seabed shows the difference in the slope indicated by the color gradation

3.4 Seabed image

Side-scan sonar mapping obtained identification of rocks and sediments on the seabed. The side-scan sonar recording on the track in the southeastern region of the trudy area shows the presence of coral and sand sediments showing a ripple mark sediment structure.

The morphological characteristic of the seabed shows that the distribution of sand and coral sediments with diameters of up to 3 metres dominates the seabed of the study area in the strait (Figure 10). Coral colonizes or rests on a bed of hard rock that lies beneath the two islands.

Hard rock or coral features are interpreted as elongated boulder shapes with bright and shadowy saturation hues and a large and clustered texture pattern. The type of sand sediment is interpreted to be in the form of small grains with a fine texture pattern and has bright saturation hue.

The appearance of the seabed texture in the visualization of side-scan sonar data appears to have rougher and smoother parts. When compared to the appearance of a fine texture with a dark color intensity representing areas of low backscatter, coarse texture produces a bright backscatter signal.

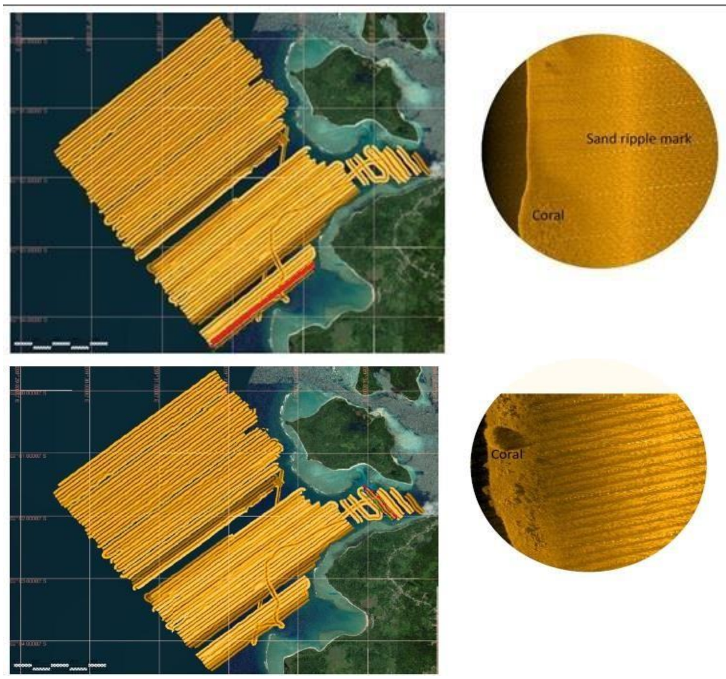

Figure 10. SBP and Side-scan sonar trajectory map showing the appearance of coral and sand ripple mark in the side scan sonar image

4. Analysis

GIS (Geographical Information System) modeling with raster-based spatial analysis is used to determine the location of the power plant, by assuming several parameters in order to obtain the best weight or assessment when deciding where to locate the power plant.

A total of four (criteria), including wave factor, lithological factor, slope factor, and coastal characteristics were adapted to evaluate sites for wave power generator (Table 2). The turbine should be installed in an area with a gentle slope and a topography of no more than 10%. Areas that have unstable topography should not be used as locations.

Table 2. List of constraint criteria, threshold values, and conformity mapping

Criteria	Application Model	Description
Annual Average Wave Energy Potential Map[2]	Constraint and suitability mapping	the places that received more than 15 kW/m per year are considered as potential sites. The higher the value, the higher the priority.[2]
Depth	Constraint and suitability mapping	The generator must be located between 15 to 25 meters [13].
Slope	Constraint and suitability mapping	The generator must be placed on a gentle slope in the range of 0-10% [14]
Types of seabed sediments	Constraint and suitability mapping	The recommended sediment as a base for water structures is sand (Soil parameters properties requirements for on-bottom

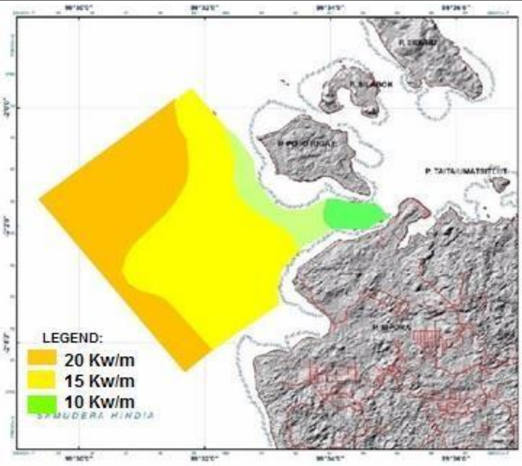

Figure 11 Annual Average Wave Energy Potential Map shows the highest average potential is 20 kW/m and the lowest is 10 kW/m. The higher the value, the higher the priority[2].

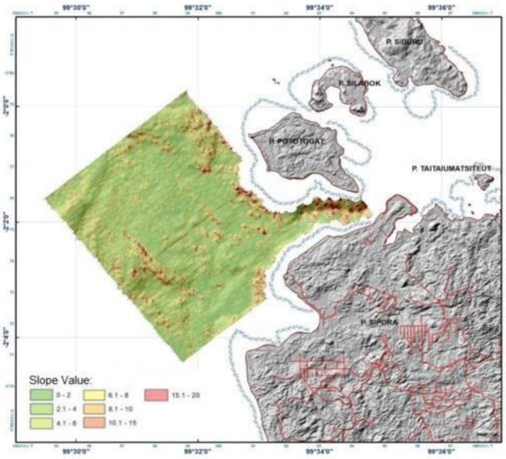

Figure 12 The slope map of the Sipora seabed shows the difference in the slope indicated by the color gradation. The generator must be placed on a gentle slope in the range of 0-10%.

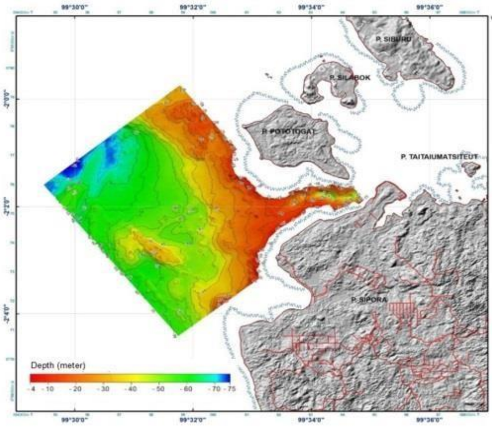

Figure 13 Bathymetric Map shows subsurface elevation features indicated by the color gradation. The generator must be located between 15 to 25 meters.

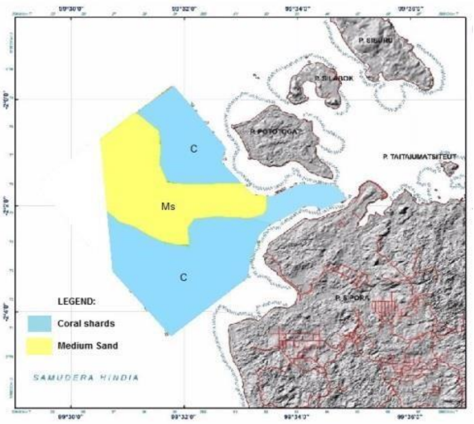

Figure 14 Sediment distribution map shows distribution of coral and sand. The recommended sediment as a base for water structures is sand.

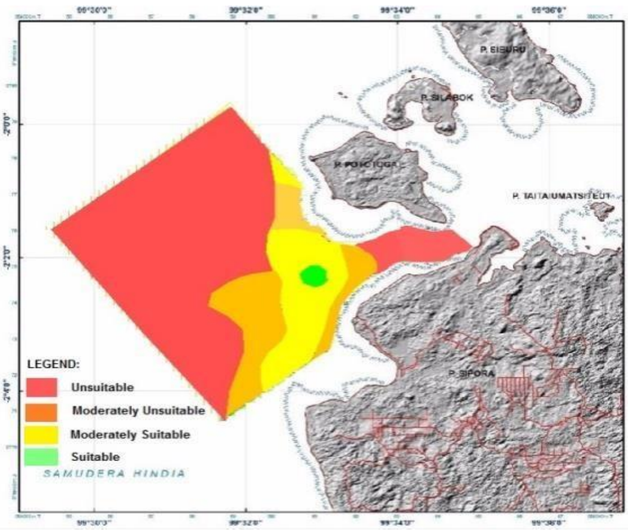

Figure 15 Suitability map based on weighting and scoring results.

The weights and standardized suitability maps are then combined to produce the overall suitability score. As a result, nearly the entire feasible area (77 percent of total area) is labeled "Unsuitable". In this case, 21.1 percent of the region is deemed "moderately suitable." Only less than 2% of the region is deemed "suitable”. Within this particular zone, the average depth of the coastal waters, the topography of the seabed, suitable sediment characteristics and the relatively reasonable wave energy potential (Figure 11) presuppose that the implementation of the wave energy system is practically achievable. Based on the weighting and scoring results, suitable locations for potential power plant sites are identified, including in coastal areas located in offshore near batu putih coast can be seen on the map above (Figure 15) the green color on suitability map shows the most suitable location with a depth of approximately 20 meters with estimation of annual average wave energy potential 15 kW/m.

5. Discussion and Conclusion

Subbottom profiling and side scan sonar data show that geological phenomena such as sloping plains on the high seas and a slight elevation of limestone exist at the study site.
Underwater morphology is a tectonic formation that works in the study area and is generally composed of hard and rigid rocks with a reflection pattern at the top and no reflection at the bottom. This is due to the fact that the rocks observed in the survey area are generally in the form of the Mentawai forearc's basement.
Bathymetry around the survey site is generally less than 100 meters. While the morphological contour pattern of the seabed beach with moderate relief is obtained with a slope of 10º to 20º, towards the open sea reaching 2º to 8º.
Based on the weighting and scoring results including wave factor, lithological factor, slope factor, and coastal characteristics suitable locations including in coastal areas located in offshore near batu putih coast with a depth of approximately 20m with estimation of annual average wave energy potential 15 kW/m. One of the most important value in the use of the GIS tools in that they constitute a distinctive information integration and management system that allows to gather, analyze, represent and facilitate the management and interpretation (qualitative and quantitative) of spatial and attribute information in a far more effective, rapid and integrated way. Additionally, it makes good use of the enormous capacity of spatial data in a single work environment for the fusion and review of various information layers, extraction of relevant data and ongoing information updating to enrich the system, compared to other types of manual methodologies and traditional map interpretation techniques used before. Such advantages allow us to handle several scenarios and generate map during the planning stage, before any decision is made on actions to take. Furthermore, these allows us to handle the assessment in quantitative way, providing us greater real-world approximation validity and less subjectivity in the analysis and selection of criteria.

6. Implication

Regarding the incorporation of overlay and weighting techniques, the advantage of this methodology is that it is integrated in GIS as a relatively common tool for a number of investigations as reported here is worth mentioning, where there are several factors and variables that influencing in the occurrence of a given fact, phenomenon or objective and there are several points of view in the decision-making process. Knowledge from these efforts will ensure that, as commercial-scale wave farms are developed, work is performed within a framework of understanding regarding associated effects on disaster risk, durability, and environmental sustainability at local and regional levels.

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