ANALYSIS OF POTENTIAL ENERGY OF SEA WAVES IN SOUTHERN WATERS OF MALANG USING GEOGRAPHIC INFORMATION SYSTEMS APPROACH

Fahreza Okta Setyawan[1*], Aida Sartimbul[1], Mochamad Arif Zainul Fuad[1], Qoirunnisa Ussania[1], Fathurrosyid Hidayatullah[1], Nuril Annisa Haq[1]

[1]Marine Science Study Program, Faculty of Fisheries and Marine Sciences, Universitas Brawijaya, Malang, Indonesia
*Correspondence Email: setyawan.fos@ub.ac.id

ABSTRACT

Southern waters of Malang are one of the areas in the south of Java where some of its coastal areas have not been electrified. The purpose of this research is to determine the magnitude of wave energy potential in the waters of South Malang. The theoretical amount of wave energy is obtained through wave data processing (wave period, significant wave height, and wave direction) and the results are in the form of the wave energy value with the highest value in 2021 occurring in August with an average value of 40 kW /m - 50 kW/m while in 2022 the highest value occurs in July with an average value of 40 kW/m to 50 kW/m. The technical potential value of wave energy is calculated by adding the efficiency formula from AquaBuOY so that results with the highest technical wave energy potential value are obtained in 2021 in August with an average value of 40 kW/m - 50 kW/m while in 2022 the highest potential wave energy value occurs in July with an average value of 40 kW/m - 50 kw/m. Potential locations are determined based on theoretical and technical potential results and the suitability of placing AquaBuOY so that a station point that meets these criteria is obtained, namely at the 29, 30, and 34 where station 30 is the station that has the closest criteria to effectively installing buoys with the total theoretical energy is 4838.46 MW and technically it is 4354.61 MW in 2021 while in 2022 the total theoretical energy is 4387.95 MW and technically it is 3977.38 MW.

Keywords: *Wave energy potential, AquaBuOY, Geographic Information System*

1. INTRODUCTION

Energy potential is the amount of energy contained in a source entity natural resource, hereinafter known as energy resources. Information or the scale of the energy potential can be a consideration in assessing whether it is potential sufficient to be developed or managed to produce energy. Renewable energy is the future of the world's means of energy generation. It is possible to generate an enormous amount of energy through renewable means, ie. energy from the sun, energy from wind, geothermal energy, energy from the sea, energy from organic material and biofuels (Wilberforce et al., 2019). The conversion of marine energy resources (e.g., waves, currents) to electricity is at an early stage of development and, as a consequence of scientific and regulatory uncertainty (Polagye et al., 2020). Marine energy development efforts require increased support for resource exploration marine energy through survey activities to obtain data and information on how much energy content from sources in the sea. One of the exploratory activities that need to continue intensified is a survey activity for the measurement of sea energy in the waters that potential. With periodic surveys, ocean energy calculations can be carried out sustainably and the amount of marine energy potential can be updated from time to time.

According to the Wave Energy Center in collaboration with the Implementing Agreement on Ocean Energy System (OES), defines that ocean energy is energy that produced from several technologies that use energy sources from power waves, ocean currents, tides, ocean thermal differences (Ocean Thermal Energy Conversion) and differences in salinity (salt content) to generate electricity. Each oceanic energy source has a relevant potential for human applications; however, as shown in Table 1, sea waves and marine currents have the highest energy potential.

Table 1. Potential Marine Energy Sources

Ocean Energy	Capacity (GW)	Potential Generation (TWh/y)
Tide	90	800
Marine currents	5000	50,000
Osmotic salinity	20	2000
OTEC	1000	10,000
Sea wave	1000-9000	8000-80,000

(Curto et al., 2021)

Sea wave is a form of marine energy due to the several forces acting on the water surface, such as the friction generated by wind, the Coriolis force (related to the Earth rotation), the celestial bodies attraction (tidal), or other unpredictable phenomena as earthquake and volcanic eruptions (tsunami) (Curto et al., 2021). Wave energy is one of the most concentrated renewable energy (much more concentrated when compared to many other types of renewable energy, such as solar, wind etc), and its resources are huge in many countries around the world (Sheng, 2019). However, ocean wave energy is a potential energy source that has not been widely developed, although some breakthroughs have been made. This wave energy is not only a great source of energy but can also be more reliable than most other renewable energy sources. Indonesia has the potential for marine energy spread in various places throughout Indonesia such as the southern part of Java and the western part of Sumatra are places that have large enough wave potential to be utilized for their energy because their areas directly face the Indian Ocean (Muhammad & Akbar, 2021).

In recent years, the Indonesian Ministry of Energy and Mineral Resources (ESDM) in collaboration with several research institutions in Indonesia have conducted a survey and research to find out about the potential of marine energy in several locations in Indonesia. This is proven by the existence of Indonesia's marine energy potential map that has been published in 2022. However, this result is considered not sufficient to represent all potential locations for marine energy in Indonesia. Meanwhile, East Java Province has no less than 79 small islands that are concentrated in the Madura Islands and a long coastline that covers the southern coast and north coast. The latest new energy potential on the south coast can be used as an energy source for electricity generation.one of which is in the waters of South Malang (Haryuda et al., 2019).

The south waters of east java has a characteristic wave height that is constant and above the average between 2.00 - 3.00 m per year (Isdianto et al., 2021). South Malang waters is one of the areas in the south of Java which borders the Indian Ocean, where some of its coastal areas have not been electrified. So this research was proposed to be carried out as an initial research to calculate and map the potential of wave energy in the waters of South Malang which can later be developed as a source of renewable energy for the coastal communities of South Malang. In detail, the objectives to be achieved in this research are to know the amount of wave energy in the waters of South Malang both theoretically, technical, and practical as well as to find out locations that have wave energy potential in the waters South Malang which can be further developed or researched.

2. METHOD

The research was conducted in the waters of South Malang, East Java Province. South Malang Waters is one of the waters facing the Ocean Indies which has extreme wave heights.

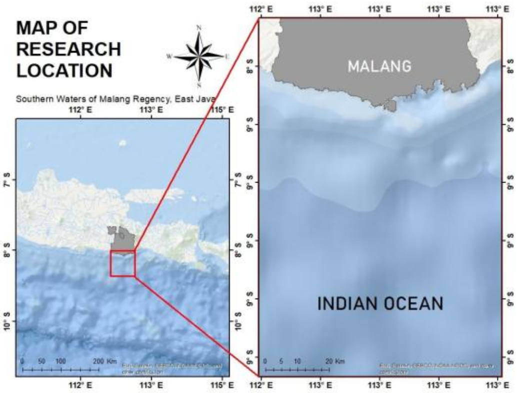

Figure 1. Research Sites

2.1 Preparation of Data

This stage includes preliminary studies, problem identification, site surveys as well as determining the data to be used. The focus of the literature used to support this research is on wave modeling and the equations used in the equation of wave energy and wave energy

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generation technology Aqua Buoy. In addition, in this stage a site survey is carried out to determine the area – areas in South Malang that have not been electrified. This stage is also carried out in preparation of data so that it can be processed. The data used in this study is in the form of modeling data that has been verified by satellite imagery which can be obtained through web page http://marine.copernicus.eu for a period of 1 year in 2022. Then the modeling data processed with the results in height, period and wave coming direction data in a monthly period. Based on these data, the calculation of wave energy is carried out using the wave energy formula to determine the theoretical wave potential. Then a calculation of the efficiency of wave energy conversion technology will be carried out to calculate the wave potential technically and added data on the depth of the southern Malang waters obtained from BIG data (Geospatial Information Agency) to calculate the wave potential practically. The results will be interpreted in the form of a potential map in a monthly period. For more details, the research flow is shown in Figure 2.

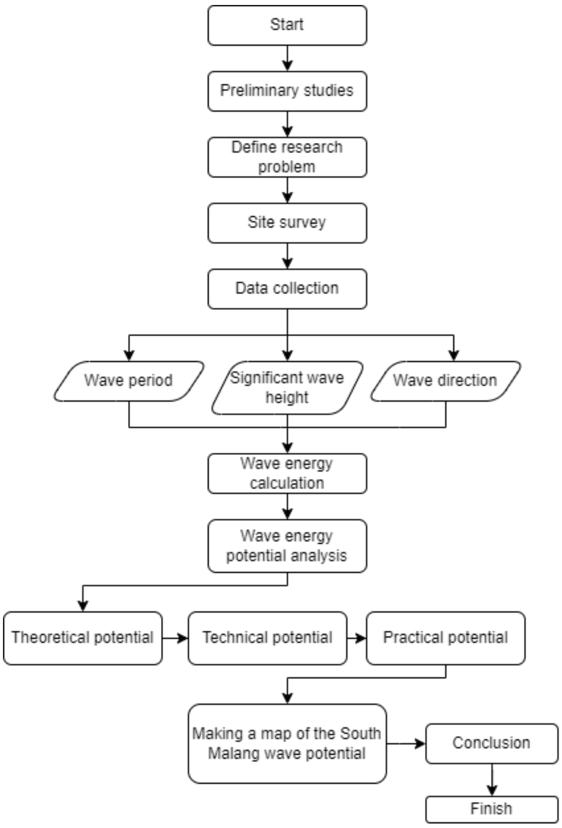

Figure 2. Research Flow

2.2 Data Analysis

The stage of data analysis is divided into three processes, namely theoretical potential calculations, technical potential calculations and practical potential calculations. In the process of calculating the theoretical potential, the data used includes significant wave height data, period waves and wave direction data. The data is processed on Ms. Excel and proceed with calculations using the wave energy formula according to the following equation:

$$P \approx \frac{\rho g^2}{64\pi} Hs^2 Te \quad (1)$$

After obtaining the wave energy value, an interpolation process in ArcGIS will be carried out based on the theoretical wave energy value which will later be used as a theoretical wave energy map and calculate its power.

Meanwhile, for the calculation of technical potential, the data used is wave energy data and wave converter technology efficiency data. In this research AquaBuOY is used, one of the wave energy converters (WEC) which has an efficiency level of up to 25%. The theoretical wave energy value from the previous calculation will be multiplied by the technological efficiency (AquaBuOY) and the results will be interpolated which will then be used as a map of technical wave energy and its power will be calculated.

Then for practical potential calculations, the data used is energy data technical wave and bathymetry data. The bathymetry data is used to look at water depth in South Malang where this data has high enough resolution. This will later be used as a parameter to determine the location for making a practical wave energy map as well as from the map it will be calculated its power.

In making a map of the location of wave energy in South Malang, the data used are wave energy maps that have been made before. This location map is the result of an overlay of several previous maps in order to obtain a location that is feasible to be developed for the utilization of wave energy in South Malang waters.

3. RESULT AND DISCUSSION

3.1 Validation Results

The data validation process is carried out by looking for the RMSE value between the main data and comparative data. Validation was carried out at the same four stations between the Global Ocean Wave Analysis and Forecast data and the Global Ocean L 4 Significant Wave Height from Nrt Satellite Measurements data. The time frame used in this process is 2 years from January 2021 to December 2022. The results of the RMSE values can be seen in Table 1.

Table 2. RMSE Value Calculation of Significant Wave Height

Station	Longitude	Latitude	RMSE Value
1	111.000	-11.000	0.19
2	113.000	-11.000	0.20
3	111.000	-9.000	0.18
4	113.000	-9.000	0.19

Based on the calculation of the significant wave height RMSE values at four different stations in the South Malang area, the results were between 0.18 - 0.20 m. The lowest RMSE value is at station 3 of 0.18 m. Based on previous research conducted by (Verdyansyah et al., 2021), it shows that the RMSE value between significant wave height data output from the SWAN model compared to data on altimetry satellites has a range of 0.10 - 0.45 m. When compared with this study, the RMSE values obtained are not far adrift.

3.2 Significant Wave Height

Significant wave height, H_s, is the average height of the top one-third waves in a wave group. H_s has usage for many purposes, ranging from coastal studies, maritime transportation, ocean energy utilization, to offshore engineering and operations (Wurjanto et al., 2021).

The research observation point map is shown in Figure 3 as follows.

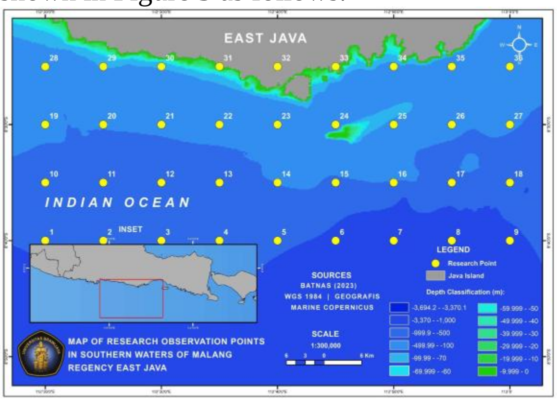

Figure 3. Map of Research Observation Point

In determining the point of wave energy potential, mapping is used based on the energy of the waves generated in several sub-districts including Donomulyo, Bantur, Gedangan, Sumbermanjing, Tirtoyudo, and Ampel Gading Districts. The sampling point area is measured as far as 50 km from the coastline. Making a sampling point measured 50 km from the coastline is considered that this includes taking into account variables such as cost and effectiveness of energy distribution.

The following is the result of wave data processing in the form of a significant wave map and wave direction in 2021 and 2022 in Figure 4 and Figure 5.

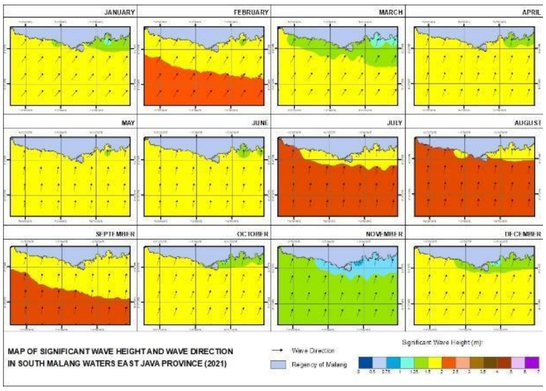

Figure 4. Map of significant wave heights in Southern Malang waters 2021

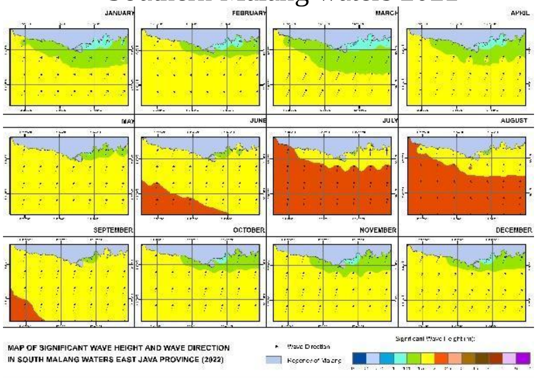

Figure 5. Map of significant wave heights in Southern Malang in 2022

Based on the mapping of significant wave heights in the waters of South Malang, East Java Province in 2021 and 2022, the waters area of South Malang is dominated by significant wave heights of 1.5 m - 2 m marked with a yellow color observed throughout the month. The range of significant wave heights is included in the Moderate Sea category (1.25 m - 2.5 m) based on the WMO Sea State Code (2023). Water areas close to land with a distance of less than

10 km have wave heights of 1.25 m to 1.5 marked in green which are included in the moderate sea criteria. Areas with significant wave height values with a distance of more than 10 km from the coastline have a higher value range of 1.5 m to 2 m marked in yellow which is included in the Moderate Sea criteria and 2 m to 2.5 m marked in brick red which includes in the Rough Sea criteria.

Mapping the highest average significant wave height in 2021 is in August of 2.41 m marked in brick red (2 m - 2.5 m) while the lowest average significant wave height is in November of 0.89 m marked in navy blue (0.75m - 1m). Mapping the highest average significant wave height in 2022 is in July of 2.42 m marked in brick red (2 m - 2.5 m) while the lowest average significant wave height is in April of 1 m marked in blue tosca (1m - 1.25m). This is in accordance with research (Ginanjar et al., 2020) which states that the average wind speed conditions in the West Season (December, January, February) and the East Season (June, July, August) are higher than the Transitional Season I (March, April, May) and II (September, October, November). Wind speed conditions affect the height and direction of the waves. The location of the southern waters of Java is directly opposite the open sea (Indian Ocean) so that it can produce consistent wave heights. The minimum value of wave height that can be used as alternative energy is 1.6 m. However, if the wave height in the waters is quite large and constant, such as in the waters of Southern Java, the electricity generated tends to be stable (Pratomo & Soebari, 2020).

3.3 Wave Energy Potential

The following is the result of theoretical wave energy calculations in 2021 and 2022 shown in Figure 6 and Figure 7.

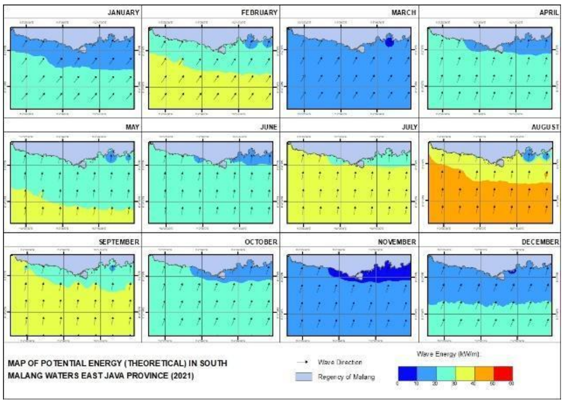

Figure 6. Map of energy potential (theoretical) in Southern Malang in 2021

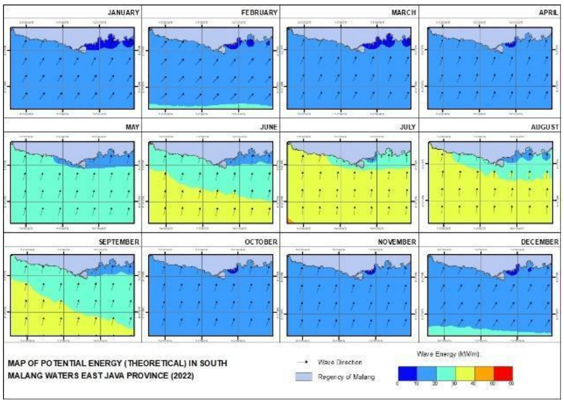

Figure 7. Map of energy potential (theoretical) in Southern Malang in 2022

The highest theoretical energy potential mapping in 2021 is in August with an average wave energy of 40 kW/m - 50 kW/m marked in orange while the lowest theoretical energy potential is in November with an average wave energy of 4.7 kW/m - 10 kW/m is marked in dark blue. The highest theoretical energy potential mapping in 2022 is in July with an average wave energy of 40 kW/m - 50 kW/m marked in orange while the lowest theoretical energy potential is in January with an average wave energy of 5.86 kW/m - 10 kW/m is marked in dark blue.

Then a technical calculation of the wave energy potential is carried out by entering the calculation formula for the efficiency value of AquaBuOY and the results are obtained in the form of a technical wave energy potential map in Figure 8 and Figure 9.

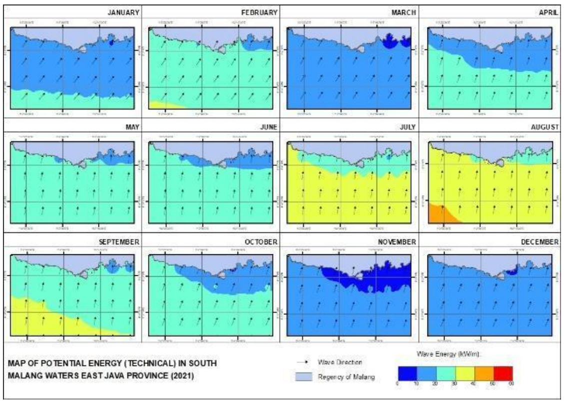

Figure 8. Map of energy potential (technical) in South Malang in 2021

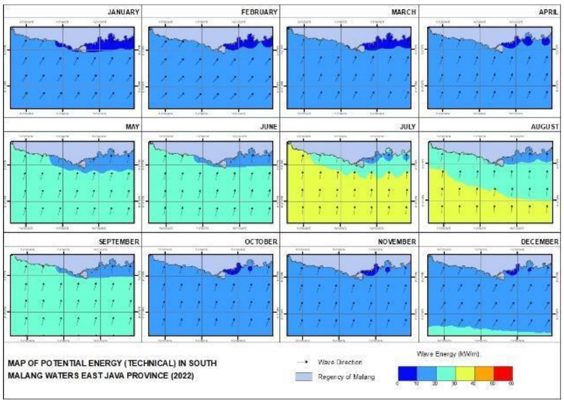

Figure 9. Map of energy potential (technical) in South Malang in 2022

Mapping the highest technical energy potential in 2022 is in August with an average wave energy of 40 kW/m - 50 kW/m marked in orange while the lowest technical energy potential is in November with an average wave energy of 4.22 kW/m - 10 kW/m is marked in dark blue. The highest theoretical energy potential mapping in 2022 is in July with an average wave energy of 40 kW/m - 50 kW/m marked in orange while the lowest theoretical energy potential is in January with an average wave energy of 5.27 kW/m - 10 kW/m is marked in dark blue.

Theoretical and technical mapping of energy potential has a difference for the average yield of energy that dominates in a water. This can be seen from the theoretical potential in August 2021 which is dominated by orange with an energy potential of 40 kW/m - 50 kW/m while the technical potential for August 2021 is dominated by yellow with an energy potential of 30 kW/m - 40 kW /m. The difference from the theoretical and technical potential value is due to the value based on the efficiency of the tool used to calculate the technical potential. In this research, the efficiency of the tool is 90% which is assumed to meet the criteria for optimal tool installation characteristics.

3.4 Amount of Energy

The results of energy processing are in the form of theoretical and technical energy values that can be utilized in the waters of South Malang which are shown in Table 2.

Table 3. Wave Energy Value

No	Years	Wave Energy Value (MW)	
		Theoretical potential	Technical potential
1	2021	1502.733324	1352.459992
2	2022	1319.172735	1195.951119

The total energy that can be produced in South Malang Waters uses 36 sample points which are assumed to represent the condition of the waters in the area. The theoretical potential for 2021 and 2022 is 1502733.324 MW and 1319172.735 while the technical potential for 2021 and 2022 is 1352459.992 MW and 1195951.119 MW. The amount of energy produced is based on the potential value multiplied by the length of the coastline in South Malang of 149 km (Mukhtasor et al., 2014).

Based on the characteristics of the buoy installation, it is effective to plant it at a depth of approximately 50 - 70 m with a distance of 2 - 8 km from the coastline. Potential points that approach the criteria for installing Buoys are at Station 29, Station 30, and Station 34 as shown in Figure 10 and detail of the values in Table 3.

Table 5.Potential Point Values

Station point	Station 30	Station 29	Station 34
Depth (m)	93.21	100.61	118.68
Coastline length (km)	17.94	16.98	16.69
Distance from shoreline (km)	1.50	3.90	5.30
Total Theoretical Energy Amount in 2021 (MW)	4838.46	5207.03	3193.08

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Station point	Station 30	Station 29	Station 34
Total Theoretical Energy Amount in 2022 (MW)	4387.95	4717.99	2782.79
Total Technical Energy Amount in 2021 (MW)	4354.61	4686.33	2873.77
Total Technical Energy Amount in 2021 (MW)	3977.38	4273.65	2522.08

Based on the details in table 3 of the three stations, the result is that the station that has the closest criteria for effectively installing buoys is located at station 30. In 2021 the total theoretical energy is 4838.46 MW and technically it is 4354.61 MW with a monthly significant wave height value of 1.69 m. Whereas in 2022 the total theoretical energy is 4387.95 MW and technically it is 3977.38 MW with a monthly significant wave height value of 1.65 m. Areas that are not covered on the map can become potential points if the criteria for installing buoys are considered.

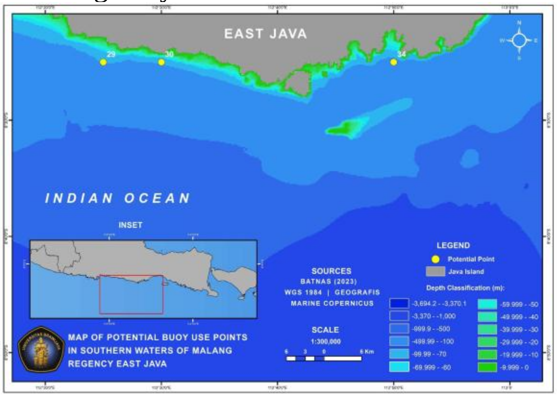

Figure 10. Potential Point

4. CONCLUSION

Based on the research performed, it can be concluded as follows:

1. The theoretical amount of wave energy is obtained through wave data processing including wave period data, significant wave height data, and wave direction data so that the results are in the form of the wave energy value with the highest value in 2021 occurring in August with an average value of 40 kW /m - 50 kW/m and the lowest value is in November with an average energy value of 4.7 kW/m - 10 kW/m while in 2022 the highest value occurs in July with an average value of 40 kW/m to 50 kW/m and the lowest value in January with an average value of 5.86 kW/m - 10 kW/m. The technical potential value of wave energy is calculated by adding the efficiency formula from AquaBuOY so that results with the highest technical wave energy potential value are obtained in 2021 in August with an average value of 40 kW/m - 50 kW/m and the lowest value in August November with an average wave energy value of 4.22 kW/m - 10 kW/m while in 2022 the highest potential wave energy value occurs in July with an average value of 40 kW/m - 50 kw/m and the lowest value is in January with an average wave energy value of 5.27 kW/m - 10 kW/m.
2. Locations that have wave energy potential are determined based on theoretical and technical processing results as well as the suitability of placing AquaBuOY where this wave energy converter is effective at a depth of 50 - 70 m with a distance of 2 - 8 km from the coastline so that a station point that meets these criteria is obtained, namely at the 28, 29, and 33. The station that has the closest criteria for effectively installing buoys is located at station 30 where in 2021 the total theoretical energy is 4838.46 MW and technically it is 4354.61 MW with a monthly significant wave height value of 1.69 m while in 2022 the total theoretical energy is 4387.95 MW and technically it is 3977.38 MW with a monthly significant wave height value of 1.65 m.

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