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RESEARCH ARTICLE

The Geomorphological Factors and Its Implications for The Tidal Energy Installations in Java, Indonesia.

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Abstract

This study aims to place the tidal energy installation effectively in Indonesia based on geomorphological factors. The survey method was used to analyze the characteristics of beaches in Indonesia. Mathematical physics model was implemented to find the new formulas based on geomorphological factors. Tides are the result of gravitational attraction and the centrifugal effect, which is the drive In the earth-moon system, tidal generating forces are the resultant forces that cause tides, namely: the earth-moon system (FS) centrifugal force and the moon's gravitational force (FB). FS works in the center of the mass of the earth-moon system whose mass point is located on the 3/4 radius of the earth. The style of tidal generator caused by the moon can be calculated by combining Newton's universal gravitational law .The results of this study consist of $F = m\, a_c$, where the style of the tidal generator caused by the moon can be calculated by combining newton's universal gravitational law in equation and newton's second law of motion in Equation. The another results is $tan = \frac{h}{l}$, where the formula takes into account constants (K) based on slopes. The last result is the constants (K) for each land form starting on 0,00 untill 1,00. The north coast of Java is more suitable for tidal energy installations because the land form is dominated by alluvium plains of the quaternary age with a lower risk than the southern region of Java. The effectiveness of tidal energy installation depends on the characteristics of the land form. In alluvial plains, the quaternary age of the alluvial plains is more suitable than the hill form volcanic quaternary, tertiary volcanic, and tertiary holokarst.

Keywords: Geomorphological factor, tidal energy, Indonesia

1. Introduction

Most people in Indonesia meet their energy needs by using conventional energy. Conventional energy is energy that cannot be renewed (Unrenewable) and when used continuously it will run out, such as petroleum, natural gas, and coal. Conventional energy use not only has an impact on the crisis of energy shortages but also has an impact on the environmental crisis because its nature cannot be renewed (Wardhani et al., 2016). During the next 40 years (2010-2050), national energy demand is predicted to increase by 3.21% per year from 1,082.33 million SBM in 2010 to 3,289.44 million SBM in 2050 (Heyko, 2013). With the increasing need for energy, while fossil-based energy is certainly decreasing, there is a need for a substitution strategy for new and renewable energy sources.

NRE used is hydropower, solar power, waste, wind power, geothermal energy, and biomass. This EBT potential can in principle be renewed, because it is always available in nature. But in reality the potential that can be utilized is limited. The construction of a Hydroelectric Power Plant (PLTA / MH) is constrained by the availability of land, water, environmental and social availability. The construction of solar power plants (PLTS) is constrained by low technological efficiency and requires extensive land. The use of wind power is constrained by wind speed and low wind continuity. The potential for waste utilization is limited to large cities like Jakarta and Surabaya with small capacity. Meanwhile, other EBTs are on average constrained by costs and are still being developed on a small scale.

The limitations of the utilization of NRE make the value of NRE resources to date unable to replace the position of fossil energy resources as raw material for the production of electricity. This renewable energy is more appropriately referred to as additive energy, namely additional energy resources to meet the increase in electrical energy needs, and inhibit or reduce the role of fossil energy resources (Pramudji, 2002). Therefore there is still a need for more renewable energy, especially more predictable energy.

Indonesia is an archipelago with an area of about 60% of the territory of Indonesia. There is a lot of potential from the sea that is unknown so that it cannot be utilized. Indonesian people basically only know the potential of the sea in the form of various fisheries resources. The sea has a lot of potential for developing EBT. The sea can provide energy from the conversion of mechanical forces (wave energy and ocean current energy) or from potential forces (tidal / tidal energy and ocean heat).

According to Dronkers, (1969) sea tides is a phenomenon of the movement of the ups and downs of sea levels on a regular basis caused by a combination of gravitational forces and attractive forces of astronomical objects, especially by the sun, earth, and the moon. The influence of other celestial bodies can be ignored because the distance is further, and the size is smaller.

The movement of water from tidal events can produce energy which can later be converted into electrical energy or other useful forms of energy. The first country to carry out this experiment was France, namely in the city of La Roche in 1966 (Shaikh Md. and Shaiyek Md., 2011). Tides move large amounts of water every day and their utilization can produce relatively large amounts of energy. The basic principle of tidal power plants is the dynamics of the movement of turbines that are installed technically at the confluence of river and sea estuaries, the utilization of potential energy from tides to low tide and vice versa used to drive the turbine (Sangari, 2012). Even though the use of tidal energy is currently not done commercially and only a few countries use it, the future projection is not impossible anymore in all countries, especially Indonesia. This can happen if all countries are able to see the potential in each region that can be used as an energy source for electricity generation (Sleiti, 2015).

Geomorphological factors greatly influence the conservation of tidal zones (Finotello et al., 2020). Delta is a landform that is not found on all beaches, so it needs to be considered in tidal energy studies. Geomorphological factors greatly affect vegetation around the coast (Crotty and Angelini, 2020). Exploitation of tidal energy is very high, but consideration of geomorphological and ecological factors must be prioritized (Catto, 2020). The conversion of coastal landforms is the main cause of environmental damage (Xu et al., 2019). Key factors related to coastal conservation are geomorphology and population density (Van Coppenolle and Temmerman, 2019). The erosion and sedimentation patterns on the coast are strongly influenced by geomorphological factors (Emery et al., 2019). There is a non-linear relationship between sea level rise, tides, and geomorphic changes (Palmer et al., 2019). A few researchers focused on relationship among the geomorphological factors such as land form of beach, type of erosion, and type of depositon with a analysis of tidal energy installations. There have been limited studies concerned on impact of tidal energy to environment based on geomorphological factors especially in tropical region such as Indonesia. Therefore, this research intends to analyses a the geomorphological factors and its implication to tidal energy installations in Indonesia.

The development of tidal energy is strongly influenced by geomorphological factors. The geomorphological process between one place and another will be different. The difference consists of differences in intensity and differences in landforms (even with the same forming forces). The intensity of geomorphological processes and differences in landforms depend on (1) climate, (2) topography, (3) proximity to subduction, (4) lithology and (5) environmental changes.

The influence of climate on land formation can be seen from weathering of rocks, soil color, depth of soil, and type of vegetation. Weathering of rocks will often occur in landscapes that have high rainfall. This can be proven by the presence of rock outcrops that undergo structural changes in a short time (miocene to holocene period). Climate greatly influences tidal dynamics on a beach. Climate change will also deform the marine landform.

The effect of topography on land formation is that there is a difference in geomorphological process patterns caused by high differences, slope and relief of a region. High differences between one place and another place will result in the two places having a causal relationship. A higher place is one of the causes of deformation of landforms for places located below it, for example the increase of floodplains in the downstream area is due to the increasing intensity of erosion in the upstream. The tidal region is associated with the deposition of material carried from the land. Deposition dynamics will affect the presence of tidal energy.This study aims to place the tidal energy installation effectively in Indonesia based on geomorphological factors.

2. Methods

The survey method was used to analyze the characteristics of beaches in Indonesia. The beach sampling was conducted purposively by considering the distribution and similarity of lithological characteristics and watersheds. Observation sheets are used as instruments to observe land around the coast. Table 1 was used to identify topographic types, vegetation, and organic content.These 3 factors are associated with coastal vulnerability if used as a tidal energy installation.

Table 1. topographic types, vegetation, and organic content

Factor	Lower	Higher
Organic Content	Highly organic	Low organic
vegetation	Treed with groundcover	No Cover
Topography	Flat	Steep

Field observations are used to observe the geomorphological and stratigraphic processes of the region. Furthermore, the mapping of areas related to the characteristics of watersheds is done using global mapper softwareTides are the result of gravitational attraction and the centrifugal effect, which is the drive towards the center of rotation. Newton's gravitational law states that in a system of two masses m1 and m2 there will be an attractive force of F between the two which is proportional to the mass multiplication and inversely proportional to the square of the distance expressed by Equation (2.1).

$$F = G\frac{m_1 m_2}{r^2} \qquad (2.1)$$

where G is the general gravitational constant of magnitude 6,67 x 10^{-11} Nm^2/kg^2 (Abdjul, 2010).

The gravitational force varies directly with mass, but is inversely proportional to the square of distance. In line with the law above, it can be understood that even though the mass of the moon is smaller than the mass of the sun but the distance of the moon to the earth is much smaller, so that the attraction of the moon to the earth has a greater effect than the sun on the earth. The gravitational pull draws seawater toward the moon and the sun and produces two gravitational tidal bulges at sea. The latitude of tidal protrusion is determined by declination, which is the angle between the earth's rotation axis and the moon and sun's orbital plane.

The moon-pulling force causes the formation of a shared mass center system (barycenter), where the earth and moon surround the center of the mass. The revolution of the earth towards the center of mass causes the formation of a centrifugal force towards the outside of the rotary axis. In the earth-moon system, tidal generating forces are the resultant forces that cause tides, namely: the earth-moon system (FS) centrifugal force and the moon's gravitational force (FB). FS works in the center of the mass of the earth-moon system whose mass point is located on the 3/4 radius of the earth. The following are earth-moon-sun astronomical data:

Earth mass (ME) = 5.98 x 1024 kg
Month mass (MM) = 7.35 x 1022 kg
Sun Mass (MS) = 1.99 x 1030 kg
The radius of the Earth (RE) averages = 6.37 x 106 m
Moon radius (RM) = 1,738 x 106 m
Sun radius (RS) = 6.96 x 108 m
The distance of the earth - the moon from the center to the center (dEM) = 3.844 x 108 m
Earth distance - sun from center to center (dES) = 1,496 x 1011 m (Tipler, 1998).

The center of mass of the earth-moon system (CM) can be calculated using Equation (2.3) below :

$$CM = \frac{m_m x_{em}}{m_m + m_e}$$

$$CM = \frac{(7{,}35 \times 10^{22})(3{,}844 \times 10^{8})}{(7{,}35 \times 10^{22}) + (5{,}98 \times 10^{24})}$$

$$CM = \frac{28{,}2534 \times 10^{30}}{605{,}35 \times 10^{22}}$$

$$CM = 0{,}04667 \times 10^{8}$$

$$CM = 4667 \times 10^{3} m$$

$$CM = 4667\ km$$

So, the center of mass of the earth-moon system lies at a distance of 4667 km from the center of the earth. The style of tidal generator caused by the moon can be calculated by combining Newton's universal gravitational law in Equation (2.1) and Newton's second law of motion in Equation (2.4), so that the centripetal acceleration of a_c can be obtained from Equation (2.5) from the center of the earth in the earth system -month.

$F = m\ a_c$ (2.4)

$$M_E a_c = G\ \frac{M_E M_M}{{d_{EM}}^2}$$

$$a_c G\ \frac{M_M}{{d_{EM}}^2} \quad (2.5)$$

The tidal generation force from the moon also considers the acceleration at a point close to the moon or called the sublunar point (P1) and the opposite point or called the antipode point (P2) as in Figure 2.5. When the moon is at the apogee point and the earth is in its perihelion, the ratio of the force of this tidal generator becomes:

Moon apogee distance = 4.055 x 108 m

Moon perigee distance = 3,633 x 108 m

The distance of the earth's perihelion = 1.470568 x 1011 m

Earth's aphelion distance = 1.515448 x 1011 m

$$\frac{F_{D,S}}{F_{D,M}} = \frac{M_S}{M_M}\frac{{d_{EM}}^3}{{d_{ES}}^3}$$

$$\frac{F_{D,S}}{F_{D,M}} = \frac{1{,}99\ \times 10^{30}}{7{,}35\ \times 10^{22}}\frac{(4{,}055 \times 10^{8})^3}{(1{,}470568 \times 10^{11})^3}$$

$$\frac{F_{D,S}}{F_{D,M}} = \frac{1{,}99\ \times 10^{30}}{7{,}35\ \times 10^{22}}\frac{(66{,}67646638 \times 10^{24})}{(3{,}180206597 \times 10^{33})}$$

$$\frac{F_{D,S}}{F_{D,M}} = \frac{13{,}26861681\ \times 10^{55}}{23{,}37451849\ \times 10^{55}} = \frac{0{,}56}{1}$$

When the moon is at the perigee point and the earth is at aphelion, the ratio of the force of this tidal generator becomes:

$$\frac{F_{D,S}}{F_{D,M}} = \frac{M_S}{M_M}\frac{{d_{EM}}^3}{{d_{ES}}^3}$$

$$\frac{F_{D,S}}{F_{D,M}} = \frac{1{,}99\ \times 10^{30}}{7{,}35\ \times 10^{22}}\frac{(3{,}633 \times 10^{8})^3}{(1{,}515448 \times 10^{11})^3}$$

$$\frac{F_{D,S}}{F_{D,M}} = \frac{1{,}99\ \times 10^{30}}{7{,}35\ \times 10^{22}}\frac{(47{,}95083714 \times 10^{24})}{(3{,}48035157 \times 10^{33})}$$

(2.3)

$$\frac{F_{D,S}}{F_{D,M}} = \frac{9{,}542216591\ \times 10^{55}}{25{,}58058404\ \times 10^{55}} = \frac{0{,}37}{1}$$

So, from the calculation above, it can be seen that the influence of the sun on tidal forces ranges from 37% to 56% of the force caused by the moon.

3. Results and Discussion

The amount of energy available from tides is by using dams, depending on the volume of water collected.Tidal DAM Scheme could be seen at the figure 1.

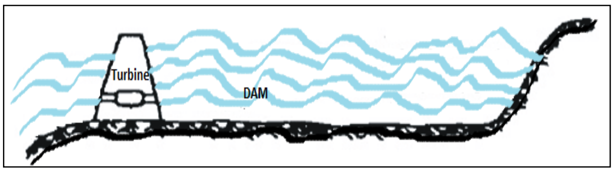

Fig. 1 Tidal DAM

The collected water provides potential energy (Ep) in Equation (2.14) to drive a turbine or generator system.

Ep = m g h (2.14)

where m is mass, g is the acceleration of the earth's gravity, and h is the change in altitude.

If the water contained in the dam has a volume (V), density (ρ) and mass (m), then

m = ρ V (2.15)

and if the pool area is A and the maximum height (tidal range) is h, then the volume of dammed water is

V = A h (2.16)

The V value in equation (2.16) is substituted to Equation (2.15), will produce

m = ρ A h (2.17)

Then equation (2.17) is substituted to Equation (2.14), so that

Ep = ρ A h g h (2.18)

The stored sea water will decrease in height from h 'to 0. The average change in height is 0.5h. Then the potential energy in Equation (2.18) becomes:

Ep = ρ A h g 0,5h

Ep = 0,5ρ g h2 (2.19)

If it is assumed that the maximum tide occurs every 12.4 hours, and the turbine operates only when the water is released, the potential energy for 2 times per day is:

Ep total in 1 day = (24/12,4) 0,5 ρ A g h^2

=0,968ρ A g h^2 (2.20)

If ρ seawater is 1025 kg m-3 and g = 9.81 N / kg, then:

The total ep in equation (2.20) becomes

Ep total in 1 day = (0,968)(1025)(9,81) A h^2

=9731 A h^2 (2.21)

Because in 1 day there are 24 x 3600 seconds, and Power = Energy / Time, then:

Power= (9731 A h^2)/((24) (3600))

Power=0,113 Ah^2 (2.22)

From Equation (2.22), it can be seen that power depends on the square tidal range (h^2). So the greater the range of tides, the greater the electric power that can be produced.

Table 2 show that the erosion that occurs on a beach will affect to the quantity of material carried by the river currents. These materials can threatening with the existence of tidal energy installations. A Beaches with high erosion sensitivity will be affected by tidal energy damage. The formation of a landscape is largely determined by the geomorphological process. The geomorphological process is a process that is strongly influenced by the formation of the earth's surface. The power can be exogenous energy (wind, water, glaciers, or human intervention) and endogenous (tectonic and volcanic) power. Every power, will cause a different influence on the land it forms. The formation of the land will affect the physical and natural economic conditions of the surrounding community.

Table 2. Distribution of geomorphologcal process in Java

Region	Topography	Geomorphological process	Organic Content of Soil	Vegetative Cover (%)	Stratigraphy
Jakarta	Flat	Splash erosion	Low	Low	Mostly aluvium
Cirebon	Sloping	Sheet erosion	High	Moderate	Mostly aluvium
Semarang	steep slope	Sheet and Riil Erosion	Low	Low	Mostly aluvium
Surabaya	Steep	Riil Erosion	Low	Moderate	Mostly sandstone-carbonate
Yogyakarta	very steep	Gully erosion	Low	Moderate	Carbonate- aluvium
Situbondo	Flat	Splash erosion	High	Moderate	Mostly sandstone-carbonate
Jember	Flat and steep	Sheet erosion	High	Moderate	Mostly aluvium-volcanic
Malang	Flat and steep	Sheet erosion	High	Moderate	Mostly aluvium-volcanic
Cilacap	Flat and steep	Splash erosion	High	High	Mostly aluvium-volcanic
Sukabumi	Flat and steep	Splash erosion	High	High	Mostly aluvium-volcanic

Table 2 show that the distribution of beaches in Indonesia with a various forms of beaches based on slopes is in desperate need of tidal energy installations. The lithology is the configuration of the host rock that is the foundation of a region. Litology is very influential on various types of landform deformation because each type of rock has different characteristics. In addition, host rock is also an ingredient for soil formation. The lithology of each region varies, giving rise to different land forms, for example in areas with sedimentary rocks, the area will have a relatively sloping landform, flat and many floodplains. Figure 2 shows that the northern part of Java is an area that has the same geomorphological watershed characteristics. It also causes the same coastal geomorphological conditions. Jakarta, Cirebon, Semarang, Surabaya, Situbondo are areas that are easy to exploit with flat landforms. Surabaya and Situbondo have similarities in stratigraphic aspects which are dominated by sandstone and carbonate. Tidal energy installations in the north coast of Java must consider aspects of conservation of landforms that characterize the region, including deltas and abrasion vulnerability.The geomorphological characteristics of the north coast are different from the south coast. Jember, Malang, Yogyakarta, Malang, Sukabumi have land forms that are difficult to exploit, so the potential for damage to the region is lower. The dominant stratigraphy is old alluvium and volcanic with many active faults so that the land is more steep. Delta landforms are generally not found, while the potential for abrasion is also low, so the tidal energy installation consideration in the south coast region is not the same as the north area. Figure 2 shows that the entire northern coast of Java has a flat topography. This is due to the dominance of the quaternary alluvium plains and anticlinal hills which are tertiary in age.

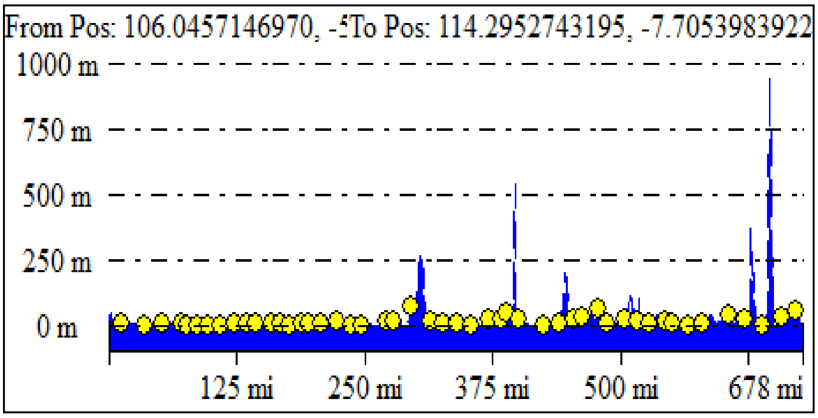

Fig. 2 North Java Topography

The southern part of Java is dominated by tertiary-aged landforms with a radius close to the subduction zone. This can be seen from the topography which is steeper than in northern Java. Therefore, the tidal energy installation is more in line with the characteristics of the north coast of Java because the geomorphological characteristics are not at risk of deformation of the landform. In addition, the karst areas of the southern part of Java and the tertiary volcanic mountains are areas that must be optimally conserved compared to the alluvium plains in the north. The topography of southern Java can be seen in Figure 3.

During the high tide, the sea level is higher than the water level in the reservoir, its height is almost to the top of the dam, as shown in Figure 1. The reservoir is filled with water from the ocean by passing through a tunnel in which there is a water turbine that is connected directly to the electricity generator. Because of the flow of water that passes through the tunnel, the turbine in the tunnel will rotate turning the generator so that electricity is generated. This continues until the reservoir water level is almost the same as the water level outside the reservoir. Figure 4 shows the very different distribution of coastal topography between northern Java and southern Java.

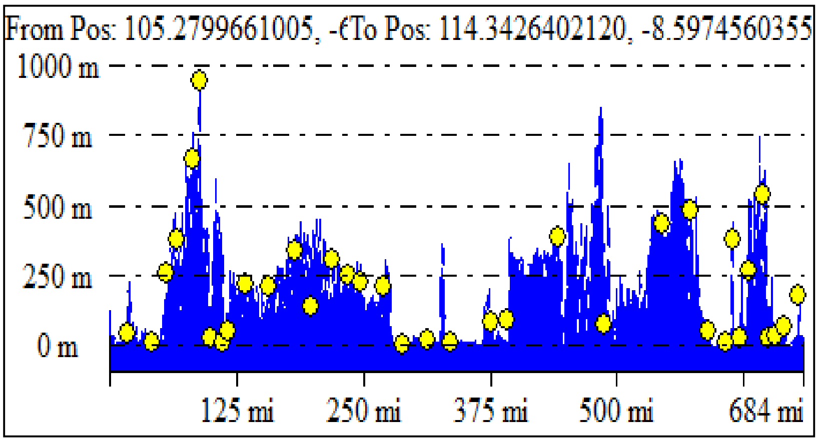

Fig. 3 South Java Topgraphy

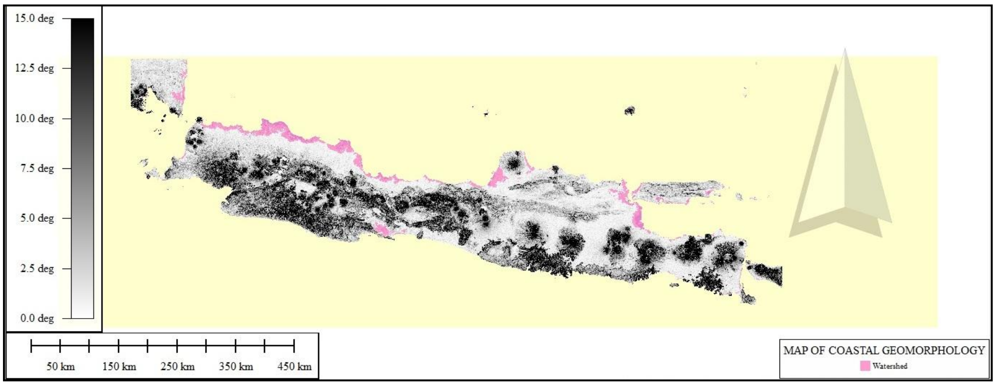

Fig. 4 Map of Coastal Geomorphology

Tidal conditions in the waters of the archipelago are determined by tidal propagation from the Pacific and Indian Oceans as well as coastal morphology, and complex aquatic bathymeries in which there are many shallow straits, troughs and seas, and deep seas. The condition of these waters forms a diverse tidal pattern. An area is said to be suitable for implementing tidal power plants if they meet a minimum tidal range of 2 m, a minimum current velocity of 2 m / s, and a sea structure that affects the magnitude of tides (Sangari, 2012). Changes in land use in coastal areas will affect the intensity of sedimentary transport, inducing stabilization of the landform, vegetation characteristics (Marrero-Rodríguez et al., 2020). The distribution of human activity in coastal areas is influenced by geomorphological factors (Yi et al., 2020). Preliminary observations of the coast must be carried out with the aim of maintaining environmental quality (Scherelis et al., 2020). Tidal energy site selection must consider the characteristics of coastal resources (Mejia-Olivares et al., 2020). The development of transportation in coastal areas is greatly influenced by geomorphological factors (Oliveira et al., 2020). Tidal energy could potentially slow down the sediment transport rate (Deng et al., 2020).

According to Wyrtki (1961), tides in Indonesia are divided into 4, namely: (1) Single daily tides (Diurnal Tide), are tides which only occur once and one time recedes in one day. This type of tides is found in the Karimata Strait, (2) Double daily tides (Semi Diurnal Tide), are tides that occur twice and twice as lows, which are almost the same height in one day. This type of tides is found in the Malacca Strait to the Andaman Sea. (3) Tidal mix of single daily inclines (Mixed Tide, Prevailing Diurnal), is a tidal which every day occurs one pair and one time recedes but sometimes with two pairs and two times low tide which is very different in height and time. This type of tides is on the South Coast of Borneo and the North Coast of West Java. (4) Tidal mixture of double daily inclines (Mixed Tide, Prevailing Semi Diurnal), is a tidal that occurs two pairs and twice recedes in a day but sometimes there is one tide and one time receding by having a different height and time. These types of tides are on the South Coast of Java and Eastern Indonesia.

Indonesia, with an area of almost 60% of the total area, has the potential to implement alternative tidal technologies. Especially with the stretch of East-West along 5,150 km and the stretch of North to South 1,930 km has positioned Indonesia as the country with the longest coastline in the world. In the rainy season, wind generally moves from the North West with the content of moisture from the South China Sea and the Bay of Bengal. In the West season, sea waves rise from the usual around Java. The territory of Indonesia which is an archipelagic country has narrow straits that limit its islands. In addition, there are also quite a lot of bays and peninsulas which experience daily ups and downs that have the potential to be explored by energy. This makes it possible to utilize tidal power, as a renewable energy resource needed by humans.

According to tidal recording data issued by the Hydro-Oceanographic Service of the Indonesian Navy (TNI AL), Indonesia has 90 tidal stations spread from Sabang to Merauke. Of the many tidal stations there are many tidal stations which have differences in tide and low tide exceeding 2.5 m. Based on these conditions, it is possible for Indonesia to utilize tidal power as a source of electricity generation.

4. Conclusion

The north coast of Java is more suitable for tidal energy installations because the land form is dominated by alluvium plains of the quaternary age with a lower risk than the southern region of Java. North Java is an area that is still developing by the presence of exogenous forces on its alluvial plains, so that land rehabilitation can be carried out. The effectiveness of tidal energy installation depends on the characteristics of the land form. In alluvial plains, the quaternary age of the alluvial plains is more suitable than the hill form volcanic quaternary, tertiary volcanic, and tertiary holokarst. Land forms in southern Java are more suitable for conservation because of the high vulnerability of holokarst (underground river damage) and tertiary volcanic mountains where there is no pyroclastic (high weathering) deposition process.

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