Jurnal
Teknologi

Full Papers

EFFECTS OF *Avicennia marina* MANGROVE SEDIMENTATION ON WAVE ATTENUATION

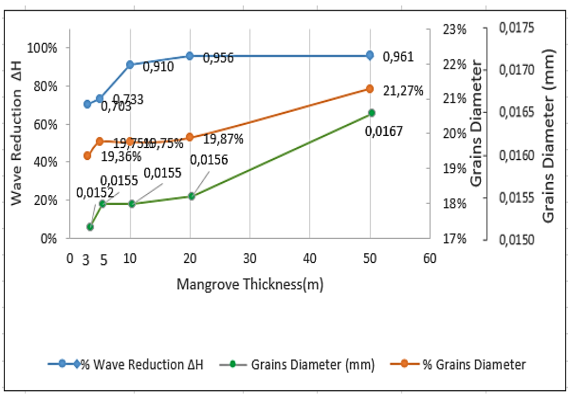
Ahmad Herison[a]*, Dietriech Geoffrey Bengen[b], Andius Dasa Putra[a], Yuda Romdania[a], Ari Sanjaya[a], Farah Diba Arief[a]

[a]Department of Civil Engineering, Faculty of Engineering, University of Lampung, Indonesia
[b]Department of Marine Science and Technology, Faculty of Fisheries and Marine Sciences, Bogor Agricultural University (IPB), Indonesia

Article history
Received
10 November 2022
Received in revised form
11 September 2023
Accepted
19 October 2023
Published Online
18 February 2024

Corresponding authors
ahmad.herison@eng.unila.ac.id

Graphic abstract



Abstract

Mangrove ecosystems protect coastlines from abrasion and erosion, dampen strong winds against oceans, and bind sediment periodically. The purpose of the study was to determine the effects of *Avicennia marina* sedimentation on wave attenuation. The employed methods in this research were spot-check, transect-squared, and laboratory test methods. The measurement of the wave data involved SBE 26 and RBRDuo T.D. They were carried out at 5 stations with thicknesses of 3 m, 5 m, 10 m, 20 m, and 50 m respectively. The percentages of the wave energy attenuation were 49.5%, 53.8%, 82.9%, 91.4%, and 92.3%, with grain diameter percentages of 19.36%, 19.75%, 19.87%, and 21.27%. The higher the percentage of wave attenuation, the smaller the percentage of grains, and vice versa. When a wave arrives, the energy is so large that each large particle of the sediment in the sea is brought back to the mangrove ecosystem. When the wave disappears, the released energy gets so smaller that only small particles are taken back to the sea. The conclusion of this study is that the diameter percentage of mangrove sediment was related to the percentage of wave attenuation. The greater the percentage of wave attenuation, the smaller the percentage of grains.

Keywords: Sedimentation, grains, mangrove, *Avicennia marina*, energy, waves

1.0 INTRODUCTION

Indonesia is a maritime country with a long coastline. In a coastal area, fresh water mixes with salt water, making this area rich in ecosystems with marine diversity where various marine and terrestrial lives co-exist [1]. Mangrove ecosystems growing on Indonesian coasts reach 3 million hectares, representing 23% of the world's mangrove ecosystems [2]. Ecologically, mangrove ecosystems act as coastal protectors from tsunamis and abrasion [3]. Waves in oceans are irregular and change frequently, causing changes in them and degrading coasts as part of the ecosystems [4].

Mangrove forests benefit the environment and coastal life significantly [5]. The damage to a coast is caused by the absence of breakwaters and wave attenuators, which leads to incoming waves directly striking the land and the potential for abrasion and other coastal damage [6].

In a mangrove ecosystem, a sedimentation process takes place. The sedimentation can reduce soil abrasion, the presence of high salinity, and the inundation circulation due to tides. This forest ecosystem has considerable ecological roles for living things, which are related to food resources, industry, and the prevention from floods and erosion as the ecosystem is able to attenuate waves and also holds recreational functions [7].

Mangrove forests themselves offer many positive effects on human life, including mangrove ecosystems protecting coastlines from abrasion and erosion. Mangrove forests are also resistant to strong winds coming from the sea and are able to withstand and bind sediment periodically to form new land [8]. Mangrove forests also have various biological functions as natural breeding areas for various types of terrestrial and marine biota with economic values.

Currently, in the protected forest area in Pasir Sakti District, East Lampung, there are 15 estuaries with numerous *Avicennia marina* mangroves. Before 2004, the coastal area of East Lampung was eroded by seawater, causing abrasion at an alarming stage. Mangrove forests are the best solution to overcome the high intensity of sea winds due to the spread of deforested coastal areas. In 2013, more than 1,000 hectares of mangrove forests were formed [9]. Due to the harmful impacts of sea waves, i.e. abrasion and erosion, the coastal area of East Lampung needs protection making use of mangrove ecosystems, which are very important to wave speed restoration. Mangrove ecosystems come with such economic potentials as ponds, housing, tourism, and renewable energy resources [10]. Additionally, the ecosystems are also beneficial in terms of oxygen production and carbon dioxide absorption [11, 12]. Given this, we can as well conserve coastal resources to improve communal welfare.

The ability of mangrove forests to attenuate wave energy depends largely on the composition of their mangroves [13, 14]. The *Avicennia marina* mangrove has a root system called breathing roots or pneumatophores, meaning the plant can grow in various tidal conditions. Its roots are able to help enhance sedimentation and speed up the process of the emergence of new land as a place for the breeding of mangrove seedlings [1, 15].

Many parts of the mangrove tree serve to withstand the wave reduction process, one of which is the substrate. *Avicennia marina* mangroves are suitable for areas with muddy sand substrates, especially the forefront of the beach with an inundation frequency of 30-40 times/month [16]. Mangrove ecosystems have the capability to capture sedimentary grains brought by incoming waves, which then settle as they are left behind when the waves leave, resulting in the creation of mangrove sedimentation [17]. During the sedimentation process, several forces affecting the process of moving sedimentary particles from the sea to land take place, namely the force of gravity, thrust, and buoyancy force [18]. Mangrove ecosystems are capable of breaking down and attenuating natural waves so as to keep the land behind them in addition to replacing the construction of mangrove forest breakwaters as an alternative environmentally friendly solution for sustainable coastal development [6]. This case study was aimed at determining the effects of *Avicennia marina* mangrove sedimentation on wave attenuation at Pasir Sakti Beach, East Lampung.

2.0 METHODOLOGY

2.1 Research Location

This study was conducted in a protected forest area with 15 estuaries in Purworejo Village, Pasir Sakti District, East Lampung Regency (see Figure 1). Within a radius of 50 m, 5 stations with mangrove thicknesses of 3 m, 5 m, 10 m, 20 m, and 50 m were examined using two wave gauges, i.e. SBE 26 (Sea-Bird Electronics) and RBRDuo TD [6].

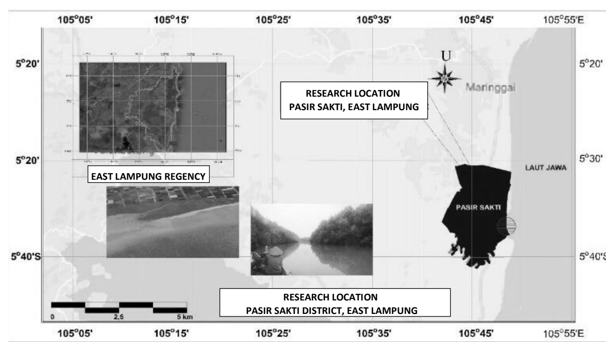


Figure 1 Location Map

2.2 Data Collection

The primary data in this study were those obtained from direct observation in the field, including (see Figure 2):

1. Wave data (50 m from the outer mangrove line).
2. Sludge samples (4 test samples from each station).
3. Measurement of the sludge depth at each station.
4. Measurement of the water depth at each station.

The secondary data were obtained from relevant agencies or not taken directly in the field, including the layout of the area as a reference map to find the stations under review.

2.3 Hydrometer Analysis

The hydrometer analysis aimed to find out the size divisions of fine soil grains. The benefit of this test is the comparison between soil properties obtained from the *Atterberg* boundary test to determine soil activity [20]. The basis for the calculation is Stokes' law whose provisions are:

1. Soil grains are considered to be balls, while in reality, this is not the case. To overcome this, an equivalent diameter is measured, i.e. the diameter of a fictitious sphere composed by the same material and having the same deposition speed as the actual soil grains.
2. The place where soil grains settle is semi-infinite and is only reviewed by one grain, while in fact, the place is infinite and grains affect each other. It is handled by taking only a relatively small amount of soil, 50 grams in 1 liter. For this reason, the above objection can be ignored.
3. The referred specific gravity is the average specific gravity. As a matter of fact, the specific gravity of each soil grain does not equal the average. In this study, the specific gravity was regarded as the same.

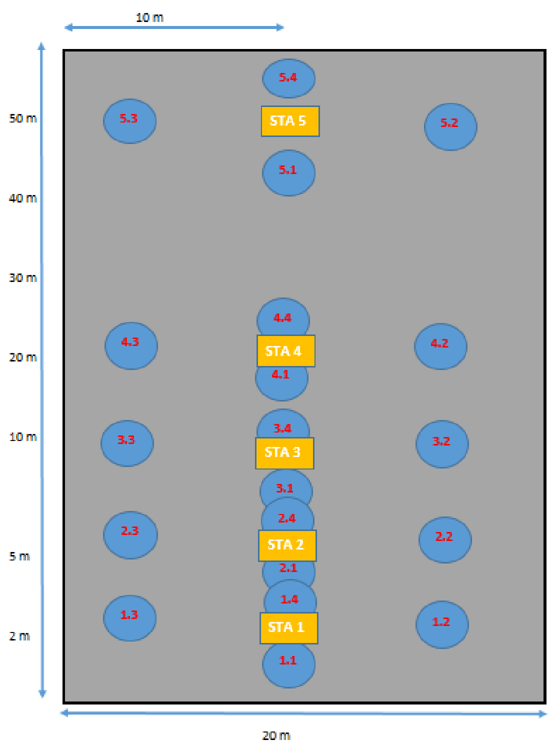


Figure 2 Research Point Scheme Sediment

Here is the calculation:

$$\% \text{ finer} = \frac{Rc \times a}{Ws} \times 100\% \qquad (a)$$

Where:

a = Correction Factor $= \frac{1,65 \times Gs}{2,65 \times (Gs-1)}$

Rc = Correction of hydrometer readings (Ra- C0 – Ct)
Ra = Actual hydrometer readings
C0 = *Zero correction*
Ct = Temperature correction
Ws = Dry Weight of Soil (gr)

$$D = K\sqrt{\frac{L}{t}} \qquad (b)$$

$$K = \frac{\sqrt{30\eta}}{g\,(Gs-Gw)} \qquad (c)$$

Where:

D = Grain diameter (mm)
L = Effective depth (cm)
t = Elapsed time (minute)
K = Constant
η = Viscosity of akuades (poise)
Gs = Specific gravity of oil
Gw = Specific gravity of water
g = gravity (m/s^2)

2.4 Sediment Data Collection Equipment

The implements involved in this study were [6]:

1. PVC tubes were used for sludge samples. Each PVC tube was 4 inches long with a diameter of 40 cm. The number of tubes varies depending on needs. In this study, the number of tubes was 20.
2. Rubber covers were used to seal the bottoms and tops of the tubes for leakage reduction.
3. GPS was involved to map and find out sampling points in remote areas such as mangrove forests.
4. Wood served as a tool to measure the soil and sludge depths at the research site.
5. Roll meter for measuring the circumference and area at the research site.
6. Paint for marking test tubes to avoid confusion.
7. Snorkeling equipment for better visibility in water when taking sludge samples.
8. Stationery for recording research results in the field.
9. First-aid kit for immediate medical treatment in case of incidents in the field.
10. Plastic containers for storing research items susceptible to water.
11. Duct tape for attaching sample containers to caps for air leakage reduction.
12. Life jacket for safety equipment at the research site as it was located by the sea.
13. Lightings for data collection at night.

2.5 Sediment Data Collection Equipment

The following are the implements involved in the collection of sediment data:

1. Hydrometer for the determination of the suspension specific gravity.Set of multiple-size

sieves with caps at the top and the bottom. The following numbers represent the sizes [19]:
  a) No. 10 (2.00 mm)
  b) No. 20 (0.85 mm)
  c) No. 40 (0.425 mm)
  d) No. 60 (0.250 mm)
  e) No. 140 (0.106 mm)
  f) No. 200 (0.075 mm)
2. Scales with a precision of 0.01 gram.
3. Cylindrical glass with a capacity of 1,000 cc, diameter of 2,5 inches = 6,35 cm, and height of 18 inches = 45,7 cm with a volume mark of 1,000 cc on the inside at a height of 36 cm from the base.
4. Porcelain cups and a grinder with a rubber head or was wrapped in rubber.
5. Suspension stirrer.
6. 0-50 ℃ thermometer.
7. Stopwatch for the calculation of trial time.
8. Bath with an adjustable constant temperature, which was especially needed when the air temperature was not constant enough.
9. Distilled water
10. Dispersive material (reagent) in the form of a glass of water (sodium silicate) or Calgon (sodium hexametaphosphate).
11. Shaker sieve (vibrator sieve).

2.6 Sedimentation Data Collection within the Mangrove Field

Sludge samples obtained from the field were processed into data at Civil Engineering Soil Laboratory, University of Lampung. The hydrometer analysis aimed to determine the distribution of soil grain sizes. The hydrometer analysis is a method for calculating the distribution of soil sizes based on the soil sedimentation in water, commonly called sedimentation test [19]. The examination is carried out by analyzing the sediment with a hydrometer. The following are the steps of the hydrometer test:

1. The sludge obtained from the land was drained and would be used as a test object.
2. Placing the soil sample in a glass tube (with a capacity of 250 cc). Pouring 125 cc of prepared water and reagent solution. Mixing and stirring until all the soil mixed with water. Letting the soil soak for 16-24 hours.
3. Pouring the mixture into the stirrer. Making sure that there were no granules left or lost by rinsing them with distilled water and pouring the rinse water into the appliance.
4. Immediately transferring the suspension to the cylindrical glass for sedimentation, making sure that no soil was left behind by rinsing and pouring rinse water into the cylinder. Adding distilled water so that its volume reached 1,000 cm^3.
5. Giving the second cylindrical glass filled with distilled water and reagent solution only in addition to the cylinder containing the suspension so that it was the same as the solution for the first cylinder. Floating the hydrometer in the second cylinder during the trial.
6. Closing the cup filled with suspension with a rubber cap (or with your palm). Shaking the suspension by repeatedly flipping it vertically for 1 minute so that the grains at the bottom floated evenly in the water. This flip was done about 60 times. Placing the cylinder so that it stood on the table. Running the stopwatch as the cylinder stood on the table and this was the initiation time to complete T=0.
7. Taking hydrometer readings at T=2; 5; 15; 30; 60; 250 and 1,440 minutes (after T = 0). About 20 or 25 seconds before each reading, the researchers took the hydrometer from the second cylinder, immersed it carefully and slowly in suspension until it reached the estimated depth of the scale. When it read, the researchers released it, but did not shake it. Then, at the right time, the researchers read the scale indicated by the peak of the meniscus water height = R1 (reading correction). After the reading, immediately taking the hydrometer slowly, moving it to the second cylinder, and reading the hydrometer scale = R2 (reading correction) in the second cylinder of water.
8. Observing and recording the temperature of the suspension by dipping the thermometer after each reading of the hydrometer.
9. After the last hydrometer reading (T = 1, 440 minutes), pouring the whole suspension into the No. 200 sieve, not leaving any granules behind. Washing it with clean water until the running water under the filter was clear and no finer grain remained.
10. Disposing of the remaining soil sample somewhere, then drying it in the oven (at a temperature of ±110^{o} C).
11. Cooling, weighing, and recording the obtained dried soil mass = B1 grams.
12. Sifting this soil with a sieve.
13. Weighing and recording the mass of the remaining part of the soil on each sieve. Checking whether the mass of each part was equal or close to the mass before filtration.
14. Performing the steps above for each test sample obtained from the field.

The benefit of this test is the comparison between soil properties obtained from the *Atterberg* boundary test to determine soil activity [20].

3.0 RESULTS AND DISCUSSION

Mangrove sedimentation measurement was carried out using wood to determine the depths of sludge and water and closed PVC tubes were used to take sludge samples at the predetermined points.

3.1 Wave Data Processing Results

The weakening of wave energy was the difference in energy between the incoming and leaving waves in the mangroves. The following is the wave energy formula used to calculate wave attenuation [15].

$$E = \frac{1}{8}\rho g H^2 \qquad \text{(d)}$$

Where:

E = Energy wave (J/m²)
ρ = Density of sea water (kg/m³)
g = Acceleration due to gravity (m/s²)
H = Wave height (J/m²)

As for the weakening of the wave energy at each thickness, it can be concluded that the greater the thickness of the mangrove, the greater sea waves wet it (see Table 1).

Table 1 Wave Data Calculation Results

No	Distance	E Average Wave Coming (SBE)	E Average Wave Leaving (RBR)	E Average Wave Attenuation (J/m²)
1.	3 m	1,1277	0,0989	0,5653
2.	5 m	1,3792	0,0974	0,7485
3.	10 m	1,5964	0,0129	1,3389
4.	20 m	1,7596	0,0034	1,6115
5.	50 m	1,7428	0,0027	1,6125

Source: (Herison *et al.*, 2017)

3.2 Hydrometer Analysis Processing Results

Following the hydrometer analysis, a weight of ±50 g of the tested soil sample was taken from each test sample (see Table 2).

Table 2 Hydrometer Analysis Results

STA	3 m	5 m	10 m	20 m	50 m
Average Moisture Content (%)	89,34	86,75	88,59	81,96	79,9
Average Specific Gravity	2,2691	2,2691	2,2691	2,2691	2,2691
Average Temperature (°C)	28	29	28	28	26
K Value	0,01264	0,01249	0,01264	0,01264	0,01291
Granule Diameter (mm)	0,0152	0,0155	0,0155	0,0156	0,0167

3.3 Wave Attenuation Percentages by ΔE

In Figure 3, the percentage of wave attenuation at a mangrove thickness of 3 m was between 60%-78%, at 5 m between 65%-82%, at 10 m between 82%-96%, at 20 m between 93%-98%, and at 50 m between 94%-98% [6].

Sedimentation is an important element to wave resistance since the accumulation of sediment brought and then settling along with that on the coast further inhibits the wave rate (Figure 4).

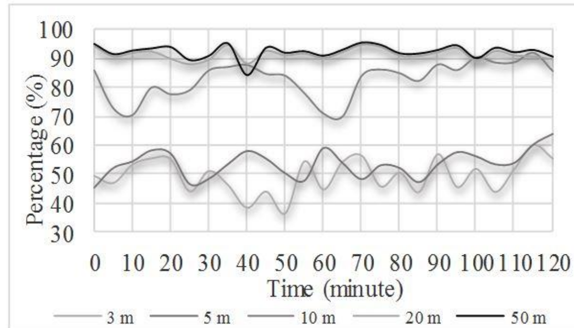


Figure 3 Percentages of wave attenuation by ΔE.
Source: (Herison *et al.*, 2017)

3.4 Relationship between the Grain Diameter and the Percentage of Attenuation by ΔE

Mangrove thickness has the ability to absorb different wave energy. In this study, at a distance of 5m, with an increase by 0.39% in the percentage of the sedimentary grain diameter, it was able to dampen 73.25% of the wave height. With a relatively small increase in the distance, from 5 m to 20 m, although the average grain diameter ranged from 0.0155-0.0156 mm, the dampened wave height was up to 95.6%. At a distance of 50 m, the total dampening rate of the wave height was 96.1% with a grain percentage of 21.27% (see Figure 4). Table 3 presents the overall final data of the study [6].

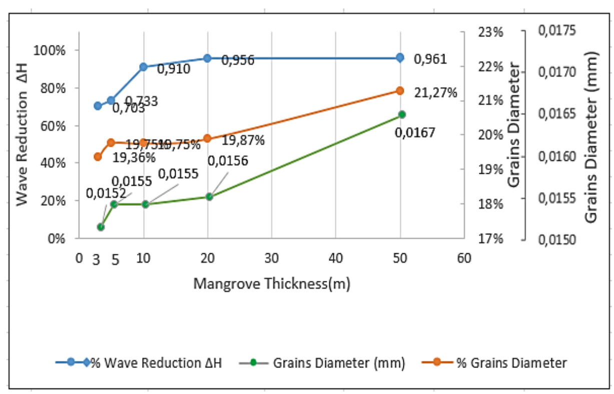


Figure 4 Relationship between the grain diameter and the percentage reduction in ΔE

3.5 The Relationship between Sludge and Water Depth and Mangrove Thickness

Avicennia marina mangrove roots can help the sediment binding process and speed up the process of new soil emergence and are able to grow in various tidal conditions [20] so that they can be found almost all over the coasts of Indonesia, especially in protected areas.

Sludge is the planting medium of the *Avicennia marina* [11], which contains many nutrients and has different grain sizes at each location, and water is also an important part of the mangrove ecosystem. Therefore, sludge and water have an important relationship.

Table 3 Overall final data

Station	STA 1 (3 m)	STA 2 (5 m)	STA 3 (10 m)	STA 4 (20 m)	STA 5 (50 m)
Attenuated Wave (ΔE)	60-78	65-82	82-96	93-98	94-98
Water Depth (m)	0,6	0,4	0,2	0,09	0,05
Sludge Depth (m)	1,40	1,35	1,25	1,10	0,95
Sludge Granule Diameter (mm)	0.0152	0.0156	0.0155	0.0155	0.0167
Percentage of Sludge Granule Diameter (%)	19,36	19,75	19,75	19,87	21,27

Referring to Figures 5 and 6, the depth of sludge and the depth of water at each station were related in the way the height of sludge was in line with the level of water and vice versa. The depths of sludge and water affected the volumes of water and sludge at each station. So, the deeper the sludge was, the higher the volume and the water level were.

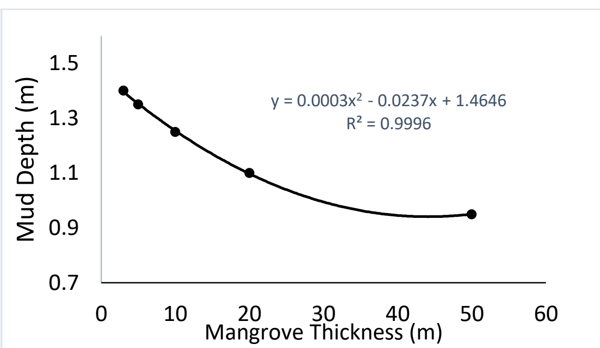


Figure 5 Relationship between the depth of sludge and the mangrove thickness

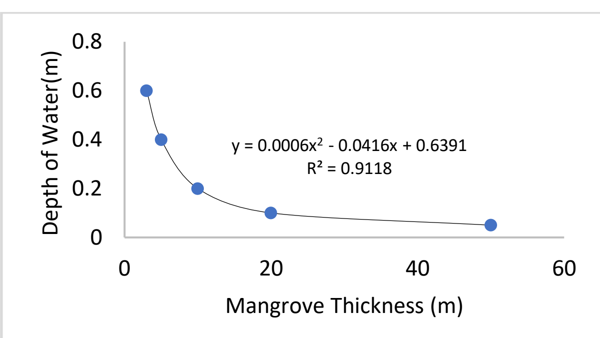


Figure 6 Relationship between the depth of water and the mangrove thickness

The higher the thickness of the mangrove, the lower the water level, due to the distance and occurring dampening process, and the less deep the soft sludge as the substrate had dried up from the infrequent submergence in water. So, it is safe to infer that the thicker the mangrove, the greater the wave attenuation.

3.6 The Relationship between Sludge Grains and Mangrove Thickness

The grain size at each station was a different variation. This was related to the depth of sludge. The grain size depended on the sludge depth at the station. The deeper the sludge, the bigger the grain size (see Figure 7).

The grain size increased in accordance with the thickness of the mangrove (0-50 meters), so it is inferable that the greater the thickness of the mangrove, the bigger size the grains were of. As a result of the motion of these waves, sediment moved towards the mainland and vice versa. Various large sedimentary particles were trapped and left in the mangroves when heading to the land, resulting in variations of grain sizes between the edge of the mangrove ecosystem and land.

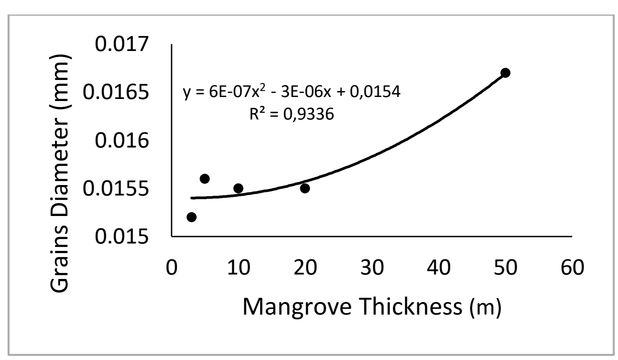


Figure 7 Relationship between the grain diameter and the mangrove thickness

4.0 CONCLUSION

The conclusion of this study is that the diameter percentage of mangrove sediment was related to the percentage of wave attenuation. The greater the percentage of wave attenuation, the smaller the percentage of grains.

Taking the results into consideration, it is logical to deduce that the diameter percentage of the sediment in the mangrove is related to the percentage of wave attenuation, the lower the grain diameter percentage is, the greater the degree of attenuation becomes, the less varied the granules in the range of 3-10 m are, and the lower the percentage gets, the bigger granules are found, and the increase in attenuation is relatively small in the range of 10-50 m.

Waves come with great energy so that all the large sedimentary particles in the sea are brought back to the mangrove ecosystem, and when the waves leave, the energy is getting less and less so that only small grains are taken from the ecosystem to the sea.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

Acknowledgement

This research would not have been carried out well without the help of various parties. For this reason, the researchers would like to express their deepest gratitude to the University of Lampung, Simlitabmas Dikti and Navy for providing cooperation at its best in this research.

Reference

[1] Noor, Djauhari. 2011. *Geology for Planning*. Yogyakarta: Graha Ilmu. https://scholar.google.com/scholar?hl=id&as_sdt=0,5&cluster=13510118345989738783#.

[2] Giri, C., Ochieng, E., Tieszen, L. L., Zhu, Z., Singh, A., Loveland, T. Duke, N. 2011. The Status and Distribution of the World's Mangrove Forests using Earth Observation Satellite Data. *Global Ecology and Biogeography*. https://doi.org/10.1111/j.1466-8238.2010.00584.x.

[3] McIvor A, Möller I, Spencer T, Spalding M. 2012. Reduction of Wind and Wave Waves by Mangroves. *Natural Coastal Protection Series.* Coastal Research Unit, Department of Geography, University of Cambridge, UK.

[4] Rev. Aditya Nugraha, Baskoro Rochaddi, Azis Rifai. 2015. Bathymetric Studies and Reduced Land in the Coastal Area of Tugu Semarang. *Journal of Oceanography*. 4(2). UNDIP. Semarang. https://ejournal3.undip.ac.id/index.php/joce/article/view/8390.

[5] Gumilar, I. 2010. Sustainable Mangrove Forest Ecosystem Management Strategy. Case Study in Indramayu Regency), Bogor. Dissertation: Bogor Agricultural Institute.

[6] Herison, Ahmad., Y. Romdania., D G Bengen and R Alsafar. 2017. Contribution of Avicennia marina Mangroves to Wave Reduction for the Benefit of Abrasion as an Alternative to Beach Building (Case Study in Lampung Mangrove Center, East Lampung Regency). *The IRES - 268th International Conferences on Engineering and Natural Science (ICENS)*. Bangkok. http://www.iraj.in/journal/journal_file/journal_pdf/13-425-152034191121-26.pdf.

[7] Arifin, Muhammad Yusuf, Soenarjo, Nirvana, Suryono, Chrisn Adi. 2019. The Relationship between Suspended Sediment Deposition and Mangrove Density in Romokalisari Waters, Surabaya. UNDIP. https://ejournal3.undip.ac.id/index.php/jmr/article/view/24850.

[8] Kariada, Nana. 2018. *Mangrove Ecosystems.* UNNES. Semarang http://lib.unnes.ac.id/33810/1/PDF_EKOSISTEM_MANGROVE.pdf.

[9] Yuliasamaya, Darmawan, Arief, Hilmanto, Rudi. 2014. *Changes in Mangrove Forest Cover on the Coast of East Lampung Regency.* Faculty of Forestry, University of Lampung. Buoyant. http://jurnal.fp.unila.ac.id/index.php/JHT/article/view/439.

[10] Ghufran, M. and Kordi, K.M. 2012. *Mangrove Ecosystem: Potential, Function, and Management.* Rineka Cipta. Jakarta. https://books.google.co.id/books/about/Ekosistem_mangrove.html?id=4XJPMwEACAAJ&redir_esc=y.

[11] Nybakken, J. W. 1992. Marine Biology; An ecological approach. Marine Biology: An Ecological Approach: Eidman M, D. G. Bengen and Koesoebiono, M. Hutomo and Sukristijono. Pt. Gramedia Main Library. Jakarta. https://elibrary.dephub.go.id/opac/detail-opac?id=2139.

[12] Nababan, E. J. K. 2016. Social Capital on the Management and Preservation of Mangrove Forests in Labuhan Maringgai District, East Lampung Regency. Thesis. University of Lampung. Bandar Lampung.

[13] Alongi, D. M. (2008). Mangrove Forests: Resilience, Tsunami Protection, and Response to Global Climate Change. Estuary. *Coastal and Shelf Sciences*. 76: 1-13.

[14] Tanaka, N., Sasaki, Y., Mowjood, M. I. M., Jinadasa, K. B. S. N., Homchuen, S. 2007. Coastal Vegetation Structure and Its Function in Tsunami Protection: The Recent Indian Ocean Tsunami Experience. *Ecol Landscape. Eng*. 3: 33-45.

[15] Herison, Ahmad, Kusmana, Cecep, Nurjana, I Wayan, Ardianto, Luky. 2014. Wave Weakening using Mangrove Avicennia marina as a Waterfront Construction Element. *Asian Journal of Scientific Research.* 7(2): 162-175. https://scialert.net/fulltext/?doi=ajsr.2014.162.175.

[16] Bengen, D G. 2004. *Coastal and Marine Ecosystems and Natural Resources and their Management Principles.* Center for the Study of Coastal and Ocean Resources. IPB. Bogor.

[17] Thomascik, T., Mah, A. J., Nontj, M. K., Mossa. 1997. *Indonesian Marine Ecology. Part Two*. Ecology Series Indonesia. Periplus Edition (HK) Ltd https://opac.perpusnas.go.id/DetailOpac.aspx?id=528708

[18] Tampubolon, S. 2010. Sediments in Muara Aek Tolang Pandan North Sumatra. Thesis of Marine Science UNRI Pekanbaru.

[19] Indonesian National Standardization Agency (SNI 3423:2008). 2008. *How to Test Soil Grain Size Analysis*.

[20] Adha, Idharmahadi. 2008. Soil Mechanics Practicum Guide. Bandar Lampung. https://scholar.google.co.id/scholar?hl=en&as_sdt=0,5&cluster=11575354741218500255.