Assessment of Mangrove as Natural Protection Buffer for Coastal Areas

by

Tuan Nurul Shakira Bt Tuan Mohd Shukri
14597

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
Civil

SEPTEMBER 2014

Universiti Teknologi PETRONAS
Bandar Seri Iskandar,
31750 Tronoh,
Perak Darul Ridzuan,
Malaysia.

CERTIFICATION OF APPROVAL

Assessment of Mangroves as Natural Protection Buffer for Coastal Areas

By

Tuan Nurul Shakira Bt Tuan Mohd Shukri
14597
A project dissertation submitted to the
Civil Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CIVIL)

Approved by,

____
(Assoc. Prof. Ahmad Mustafa Bin Hashim)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
SEPTEMBER 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

TUAN NURUL SHAKIRA BT TUAN MOHD SHUKRI

ABSTRACT

Mangrove forests have been reported to effectively lower the impact of tsunami, storm surge waves plus high and moderate waves especially after deadliest Ocean Tsunami 2004. Many parameters or aspects have been taken look on during previous studies by researches, scientist, lecturers and students to investigate the effectiveness of mangroves in dissipating waves optimally through physical and numerical conducts.

In this paper, a review on the effectiveness of mangroves in protecting coastal areas has been provided and the empirical researches have been conducted by analyzing few derived empirical relationships by previous researches and field measurement has been done in coastal mangroves system in Kuala Gula, Bagan Serai and Pantai Lekir, Lumut, Perak to validate the empirical relationships. The study areas consisted of bare mudflat, abruptly changing into muddy tidal flat overgrown with mangroves. Leveling staffs and measuring tapes were used to measure the wave height, water level and also the geometry of mangroves. The measurements were conducted in October 2014 where it is in the transition between two monsoons; the Southwest Monsoon and the Northeast Monsoon. Since there are few obstructions during the site measurement, only one place is used to validate the parameter which is in Pantai Lekir, Lumut, Perak.

For the effectiveness of the wave attenuation by the mangroves, equation by Bao's (2011) has been modified in to validate the wave attenuation in Kuala Gula. The structure of mangrove roots is not considered in the calculation. New coefficients obtained represent the mangrove roots structure.

Comparison between Darymple's formula and Raleigh distribution on wave energy dissipation has been made which shows big differences between the results of both equations which is about 90%.

ACKNOWLEDGEMENT

I would like to take this opportunity to acknowledge and thank everyone that has given me all the supports and guidance throughout the whole period of completing the final year project. Firstly, many thanks to the university and the Final Year Project coordinators, especially Dr. Raza that have coordinated and made the necessary arrangements.

I must also acknowledge the endless help and support received from my supervisor Assoc. Prof. Ahmad Mustafa Hashim throughout the whole period of completing the final year project. His guidance and advices are very much appreciated.

I would also like to thank the lab technicians in UTP, especially Mr. Meor, Mr. Idris and Mr. Zaid for their endless support in terms of the preparation of field visit and guidance during the site measurement. Their continuous support and help throughout the whole period of experiments are very much appreciated.

Finally, I would like to thank to my fellow colleagues for their help and ideas throughout the completion of this project.

Thank you.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLE

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

In the last two decades, natural coastal ecosystem as coastal protections has been considered by many parties as one of the mitigation measures against storm waves and also tsunami. Extensive researches have been carried out to study the performance of natural forest along coastal area after 2004 Indian Ocean Tsunami hit African and Asian countries especially along the western coast of Thailand and Sri Lanka were 230,000 people killed in the deadliest natural disaster. The coastal forests are able to withstand storms, winds and salt sprays. This has been proved by field observations, damages and satellite images, and it is supported by some semi-analytical and empirical approaches in both physical and numerical model [1].

A decade after the natural disaster happened the coastal areas are among the most densely and dominated places on earth as the areas have been associated with industries, agricultures and infrastructures. However, the areas are exposed to the risks of climate change and sea level rise. There have been growing calls for the consideration of natural coastal ecosystems role in coastal defense.

Considering their widespread distribution and ability to live in saline environment, mangrove forests have been the mitigation measures for years and being increasingly used as part of broader coastal protection strategies. Literally, the term mangrove has shown the strength of its own physical. The term comes from combination of Portuguese and English words, which are *mangue* for “tree” and grove for “a stand of trees”. Mangroves are important for various flora and fauna species. They can be found in tropical and subtropical areas with high degree salinity especially along marine shorelines where tidal amplitudes, winds, temperatures and anaerobic soil conditions exist. According to [2], mangroves have their own special ability to adapt with salt water where they use reverse osmosis to prevent roots from absorbing salt, but only freshwater. They also use salt-secreting gland in the leaves to excrete salt from the tree if some salts are partially absorbed by the roots.

Mangrove forest can be varying into several types based on its hydrological conditions which are fringe mangroves, riverine mangroves, basin mangroves and dwarf mangroves, meanwhile the main types of mangrove aerial roots can be divided into stilt roots, pneumatophres, knees roots, and plank roots.

Many researchers have proved that mangroves are able to dissipate surface wave energy, reduce wave height and decelerate water flow. This upstanding mangroves vegetation shown that wave can be attenuate where the seabed is stabilized and energy load is reduced in dikes [3] . Mangroves can tolerate with underwater ecosystems such as sea grass and coral reef communities for coastal protection, thus this will minimize the soil erosion and act as natural buffer. The World Conservation Union (IUCN) has proved that, mangroves saved lots of lives and properties where only two people died in the village covered with mangroves, meanwhile 6000 people died in the village without similar vegetation in Sri Lanka [4]. Studies show mangroves able to absorb between 70-90% of the energy of the wave normal. Several organizations established by the non-governmental organization Global Environment Centre based in Malaysia come out with Coastal Greenbelt Initiative to exchange experience and resources between groups involved in coastal restoration in response to the tsunami event [5].

In Malaysia, 2% of the total land area is comprises with mangrove forests which is about 641 886 hectares, where 57% can be found in Sabah and 26% in Sarawak and the remaining 17% in Peninsular Malaysia. About 441,092 ha or 69% have been gazette as forest reserves which consist of 112 mangrove forests in the country. These reserves forests are declared as the part of the country’s Permanent Forest Reserve (PFE), which is managed sustainably for both production and protection by the Forestry Department.

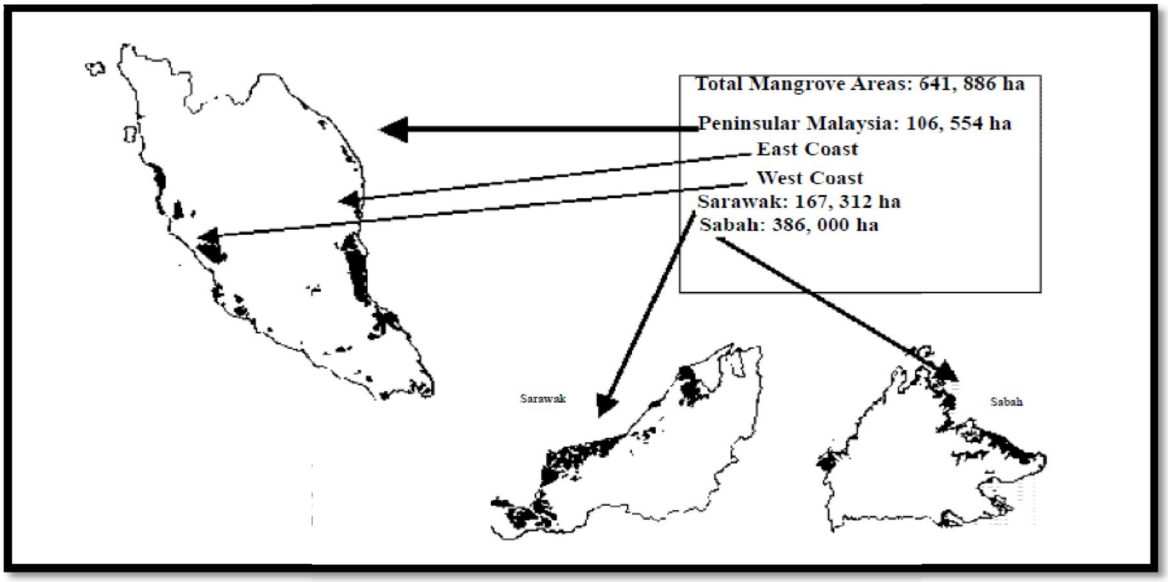


Figure 1.1 Distribution of mangroves forest in Malaysia

Figure 1.2 Distribution of mangroves forest in the world where 1000 Landsat scene using hybrid supervised & unsupervised digital image classification techniques was used. (Source: [6])

In this research, the main focus will be on the characteristics of the mangrove which are the age, species, bandwidth and the forest density as the physical parameters. In term of hydraulic parameters, this will be investigated as well.

According to [7], the wave attenuation in mangrove forests depends on the vegetation and also the hydraulic conditions. Roots, trunk and canopies influenced by variation of vegetation parameters, which are the most important and significant will be trunk diameter, density and vegetation height. However, how optimally it is dissipated has not been discussed in his paper.

1.2 PROBLEM STATEMENT

Most of the coastal areas in west coast of Peninsular Malaysia were badly damaged due to tsunami incident in 2004. However, the areas covered with mangrove forest just received slight impact compare to the area without mangroves forest. Since then, many researches have been conducted to prove that mangroves are able to protect the coastal area by dissipation wave energy and heights. Many parameters or aspect have been taken look on during research. Species of mangrove, ages of mangroves, density, width of forest and others have been focused to study the performance of mangroves in wave attenuation. These parameters have been studies by physical and numerical experiments to make comparison. However, study on parameters for optimum measures is still not fully understood and this study is conducted to ascertain influencing parameters for optimum wave dissipation so that future plantation of mangroves can be well-managed and efficient.

1.3 OBJECTIVES

Below are the objectives of this study;

- To provide a critical and intensify review on the effectiveness of mangroves in protecting coastal areas and to obtain optimum parameters where wave optimally dissipates.

- To achieve empirical relationship between results of past studies on certain parameters. From here, optimum parameters can be obtained where it can dissipate waves optimally according to particular area and investigate the pattern and to validate the assumption of generalizing structural dimensions of mangroves with different ages.

- To produce a mangrove management tools that can be used in analyzing the wave attenuation by mangroves.

1.4 SCOPE OF STUDY

This study focuses on mangrove fraction and data that have been produced by previous study to obtain optimum parameters where attenuation of wave is optimally effective. The common species that will be studied is *Rhizophora species and Avicennia species*, where it is widely found in Asia. Information on mangroves will be focused on up-to-date data. Surveying and observations, including collecting data will be conducted during field measurement.

This study is divided into 3 main phases. Firstly, the available information and knowledge about the mangroves vegetation and the wave actions is studied and reviewed where analysis is conducted by focusing on many physical aspects and different approaches available in understanding the wave attenuation by the mangrove forest. Secondly, the field observation and measurement works related to the mangrove tree parameterization have been conducted and analyzed based on typical characteristic of vegetation.

Afterwards, validation and verification can be made from the obtained data that is used to conduct empirical research and analysis to obtain empirical relationship and comparisons.

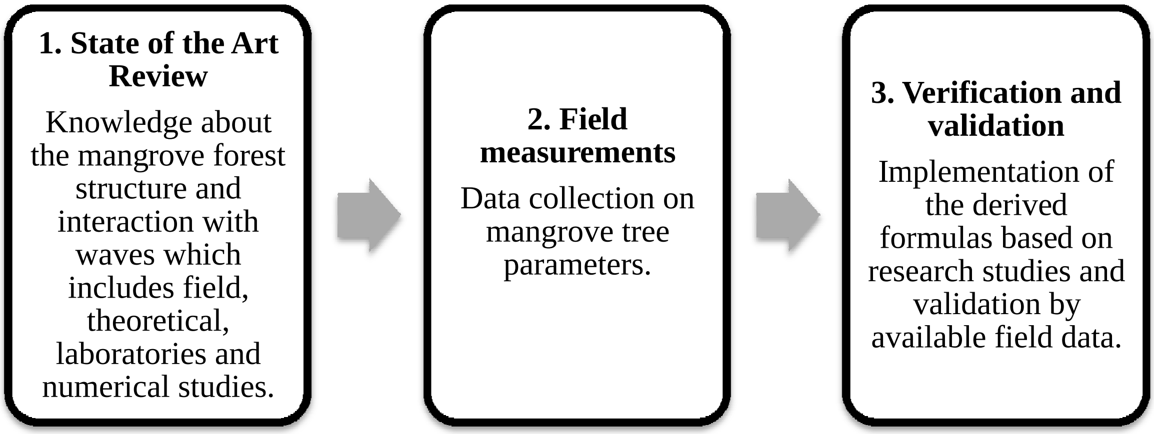


Figure 1.3 Steps in conducting empirical research

1.5 RELEVANCY AND FEASIBILITY OF PROJECT

For many years, after tsunami hits Asian countries, many researches have been conducted to investigate mangroves forest as wave dissipater from tsunami and strong winds. Mangroves also have been one the mitigation measure to protect Malaysia coastal area against erosion. However, in order to maintain this mitigation, lots of considerations need to be taken look on in term of cost, effort and effect on aquatics animals. Based on survey, the cost of mangrove seed can reach about RM 6.00 per tree of different species with different characteristics and the cost keep increasing with economic development in the country. Therefore further research should have been conducted and proved before it can become a much reliable solution.

This project is mainly purposed to obtain empirical relationships so that optimum value can be obtained to investigate the effectiveness of mangrove forests in dissipating wave at different condition and geometry parameterization. This study will cover approximately about 10 months (2 semesters) timeframe and knowledge from Coastal Engineering course to complete this study.

CHAPTER 2

LITERATURE REVIEW

2.1 BENEFITS OF MANGROVE

According to [1], mangroves are among the most commonly considered coastal forest as natural protection against tsunami and strong waves. Their habitats can be found in estuaries and lagoon, but some of mangrove species are also capable in adapting to open sea environments. This has been proven by studied of [8] where about 15 countries have the largest mangrove areas.

Table 2.1 Countries with areas of mangrove forest

Country	Mangroves (1000 ha)	Global percentage (%)
Indonesia	4250	30
Brazil	1376	10
Australia	1150	8
Nigeria	970	7
Malaysia	641	5
Bangladesh	611	4
Myanmar	570	4
Vietnam	540	4
Cuba	530	4
Mexico	525	4
Senegal	440	3
India	360	3
Colombia	358	3
Cameroon	350	2
Madagascar	327	2

According to [2], mangroves also benefits in protect coastal area and its ecosystem by protecting the water quality by trapping sediments from seawater. They also are able to minimize erosion by stabilizing the soil, lower the wave velocity and spreading seawater over large area. They also act as protection for coastal habitats whereby migration of various species takes place and also cover them form predators and extreme climate which essential in both ecological and biological system. For nature lovers, mangroves forest gives them pleasant and aesthetical value where mangrove preserves protects and restores the value of a coastal area.

On the other hand, mangroves also act as coastal protection from hurricanes and typhoons, and they help remove pollutants before they enter adjacent coastal waters. Mangroves functions as home to many types of biodiversity by providing link between marine and terrestrial ecosystem. This kind of ecosystem replenishes the population of fishes, offers refuge and nursery ground for crabs, shrimps and juvenile fish. Moreover, they provide prime nesting and migratory sites for thousand species of birds, monkeys, turtles and lizards which they use mangroves wetlands as their habitat [4].

In term of commercial, mangroves help in reducing poverty where they provide fuel-wood, aquatic products, shellfish species, medicinal herbs, poles for fences and posts. This has been supported by [4] where contribution of mangroves products to the income poor income category is estimated to be 42% using the market value in Sri Lanka. It has been stated in the study conducted by IUCN that the value of shoreline protection by mangroves is about US$ 392.5 per hectare of mangroves.

Shown below is the economic value of mangroves by [4].

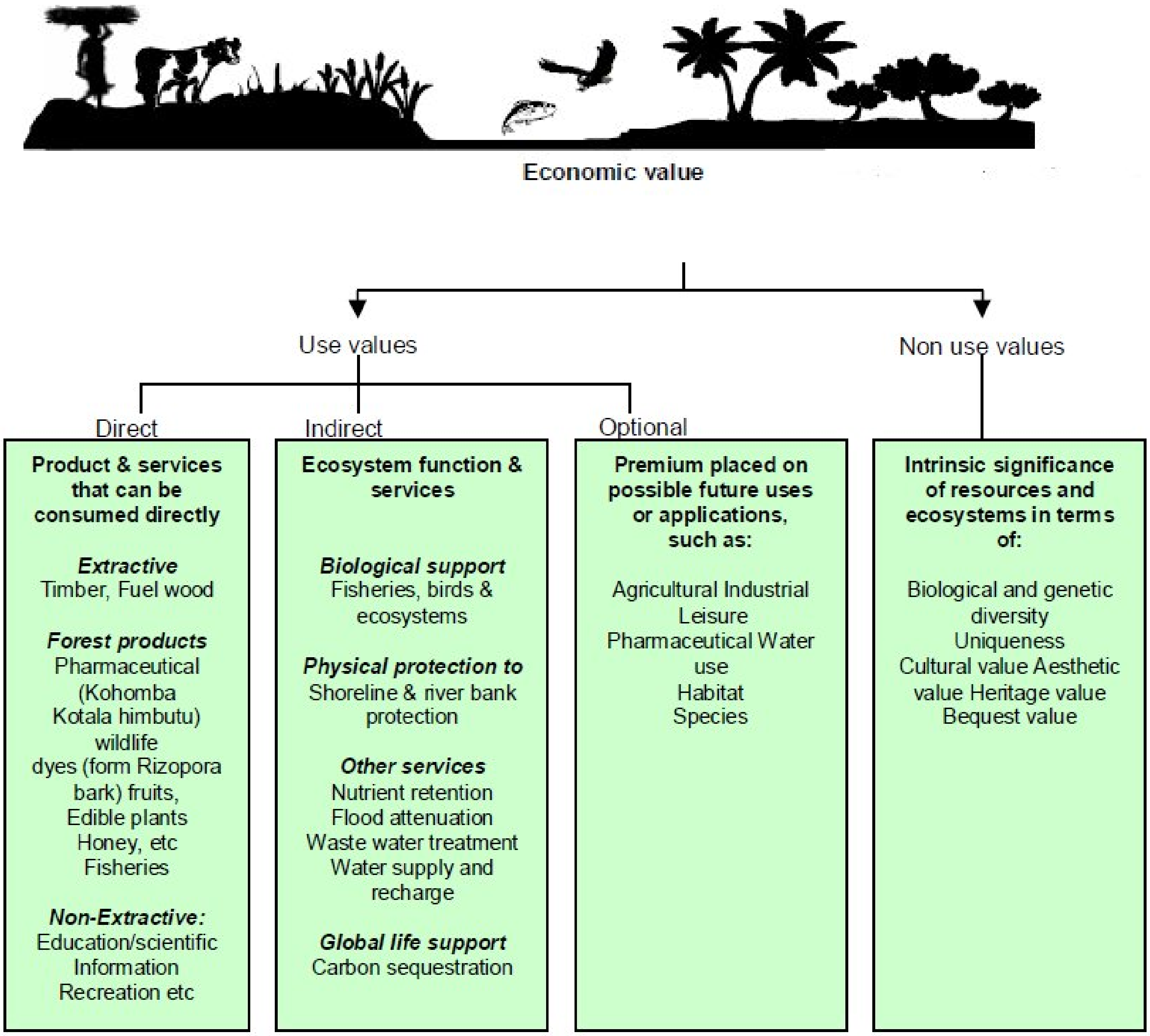


Figure 2.1 Economic value of mangrove forest

2.2 WAVE ATTENUATION BY MANGROVES

Wave length and duration principally differentiate the waves of tsunami and storm waves. Tsunami exhibits longer waves (L > 500 km) with wave period ranging from 2 minutes to 2 hours. On the other hand, storm waves have wave length ranging from 100 - 200 m with 5-20 second wave period.

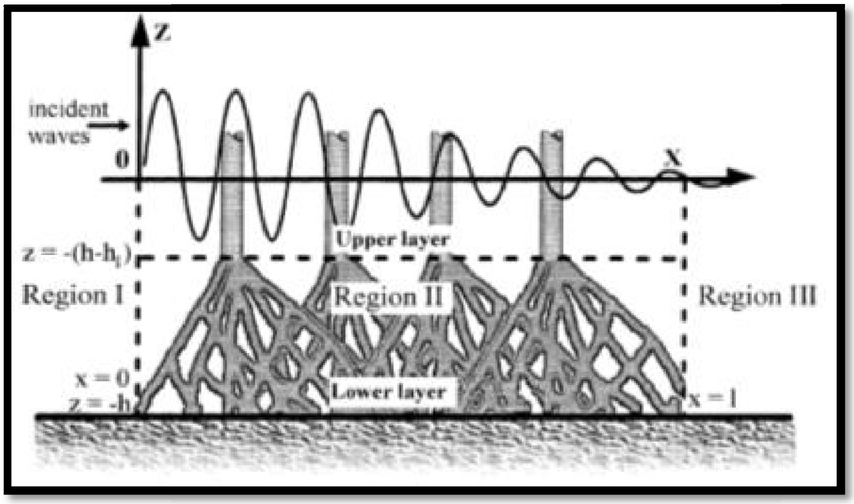


Figure 2.2 Changes of wave height when wave propagates into the forest

There are many studies have been conducted and found the wave height reduction as wave passes through the vegetation forest although they are not directly comparable in terms of parameters.

According to [9], the substantial wave energy loss is because of multiple of wave motion interaction with mangrove structures such as trunk and roots and also due to bottom friction.

Parts of energy waves decrease when these waves propagate through the mangroves forest since they will face resistance from trunks, aerial roots and the whole canopy as well. The root systems of mangroves give significant drag. Thus, this proves that the attenuation of waves contribute to the protection of shoreline. Study by [7] stated that the wave attenuation not only depends on vegetation characteristics, but it is also depends on the hydraulic conditions.

Table 2.2 Wave attenuation in studies of mangroves

Source	Location, measurements, species, wave period	How much mangroves attenuate?	Wave dissipation depends on
[10]	**Location :** River mouth of Kemaman River, Terengganu d = 0.5 km **Species :** *Avicennia* and *Rhizophora* **Measurements:** Experiment by using turbulent	**Initial** L = 10 km H = 1.0 m u = 1.0 m/s Bw = 100 m width **Reduce to :** H = 0.78 m u = 0.73 m/s	Mangrove roots and stems helps in breaking of waves. Species of mangroves and the root density affects the wave height and velocity. The wave height and velocity ratio reduction can be varied but depending on factors; wave height, wave period, wavelength, width and the density of the mangrove forest.
[11]	**Location :** Pekarang Cape, Thailand **Species :** *Rhizophora*	72 % Rhizophora of Bv = 25 – 30 cm survived 19% Rhizophora of Bv=15-20 cm survives Rhizophora with Nv = 0.2 trees/m2 Bv = 15 cm Bw = 400 m T = 30 min D = 3.0 m 30% reduction of inundation depth	Wave attenuation depends on the size of the mangrove trees.

[12]	**Location :** Indonesia **Species :** *Sonneratia*	H = 0.5 m Wave height starts to decrease at Bw = 87 m from mangroves front H = 1.0 m Wave height decreases at Bw = 57 m from mangroves front	The dominant aspects of wave energy dissipation are interaction of wave with mangroves and water depth variation. The energy dissipation due to bottom friction is ignored because it’s smaller value. Large trunk diameters increase the wave damping effect.

Observations has been made by researchers and it can be concluded that mangroves play a good role in attenuate wave energy, height, current and flow, thus they become habitats for marine species, stabilize the coastal area and protect people and properties nearby the area. Many factors can be considered as factors influencing wave reduction rate in mangrove forest.

2.2.1 Species

Species composition affects the capability of mangroves forest to dissipate wave energy. According to [13] the *Rhizophora sp.* attenuates wave at high rate because the roots are widely spread and overlap with root of other trees. *Rhizophora sp.* in Malaysia can be divided into two kinds which are *Rhizophora munocrata sp.* and *Rhizophora apiculata sp.* Both species are dominant species of *Rhizophora sp.* They live along banks of rivers and on the edge of the sea.

<u>Rhizophora apiculata sp.</u>

Rhizophora apiculata sp. lives in the area where the low and high tide are lowest and consist of soft and muddy soil. This species can be found in tropical and subtropical intertidal zones in the region of Indo-West Pacific [14]. The tree can reach as high as 20 m. It has **stilt roots** to adapt the muddy area conditions by providing a wide and broader base to improve stability in the softy mud especially during high tides. Stilt roots also help in aeration since they are exposed for at least most of the day between tides. On the other hand, the adult trees have **prop roots** that grow downwards for additional support which functionally stop tree from falling when hit by waves and strong wind, to comfort anoxic conditions and they have ultra-filters to remove excessive salts in its root. This species has yellow flowers. The leave sheets are thick and the tip is sharp. However, the *Rhizophora apiculata sp.* does not have spots on the underside of the leave and also the leave’s spine and stalk are reddish which make it different from *Rhizophora mucronata sp.*

Rhizophora mucronata sp.

Rhizophora mucronata sp. that lives on the river banks tends to have small to medium height of about 20 to 25 m. Meanwhile, on the fringes of the sea, they can reach up to 10 or 15 m. The trees that are closest to water may have tallest height, and they become shorter further inland. The tree has a big number of aerial stilt roots buttressing the trunk. *Rhizophora mucronata sp.* can adapt in estuaries, tidal creeks and flat coastal areas subject to daily tidal flooding and it tolerates inundation than other mangrove species. It sometimes may grow with *Rhizophora apiculata sp*.

Sonneratia sp.

In Malaya, there are four species which can be found which *Sonneratia alba sp.*, *Sonneratia caseolaris sp.* and *Sonneratia ovate sp*. *Sonneratia sp.* also have pnuematophores characteristic, where their roots are aerial, coil out of substrate and act as obstacles. Trees with complex aerial root structures contributed to higher drag coefficient. When water moves at shallow depths, the attenuation it at highest rate, but lower when the water levels rise.

Avicennia sp.

Avicennia sp. can be found in intertidal zones; estuaries and sometimes standing out to sea. The trees can reach height about 30 m and shorter 10 to 25 m. They have vertical roots or pencil-like roots called pneumatophores projecting from the ground to provide stability in shifting substrates. Their alternative root is anchoring roots that emerge from cable roots and grow downwards, can be very long and emerge some absorbing roots. They are among the most salt tolerant mangroves and subjected to new deposition of sediment. Based on [15], *Avicennia sp.* lives more seaward habitats and exhibit relatively higher waterlogging tolerance, achieving higher survival over a wider tidal range.

Kandelia candel sp.

However, there are some mangroves species that do not have aerial roots, such as *Kandelia candel sp.* Findings of [16] shows that at water depth of 0.7 m, the wave height reduction per meter in a forest dominated by *Kandelia candel sp.* is higher compared to that in mangrove dominated by *Sonneratia sp.*in Vietnam. Further research need to be conducted to investigate which species dissipate wave better at certain condition.

Figure 2.3 (left) *Rhizophora species,* (right): *Kandelia candel species*

2.2.2 Age of tree

The age of the trees, mediate by the shape, size, density of trunks, branches and aerial roots is important in defining the wave attenuation. Age of mangrove tress can be divided into three which are mature, mid-age and young. Study of [1] has identified the specific ages for these groups of mangroves with their own geometry parameters. Below is the typical geometry of a mangrove stated by [1].

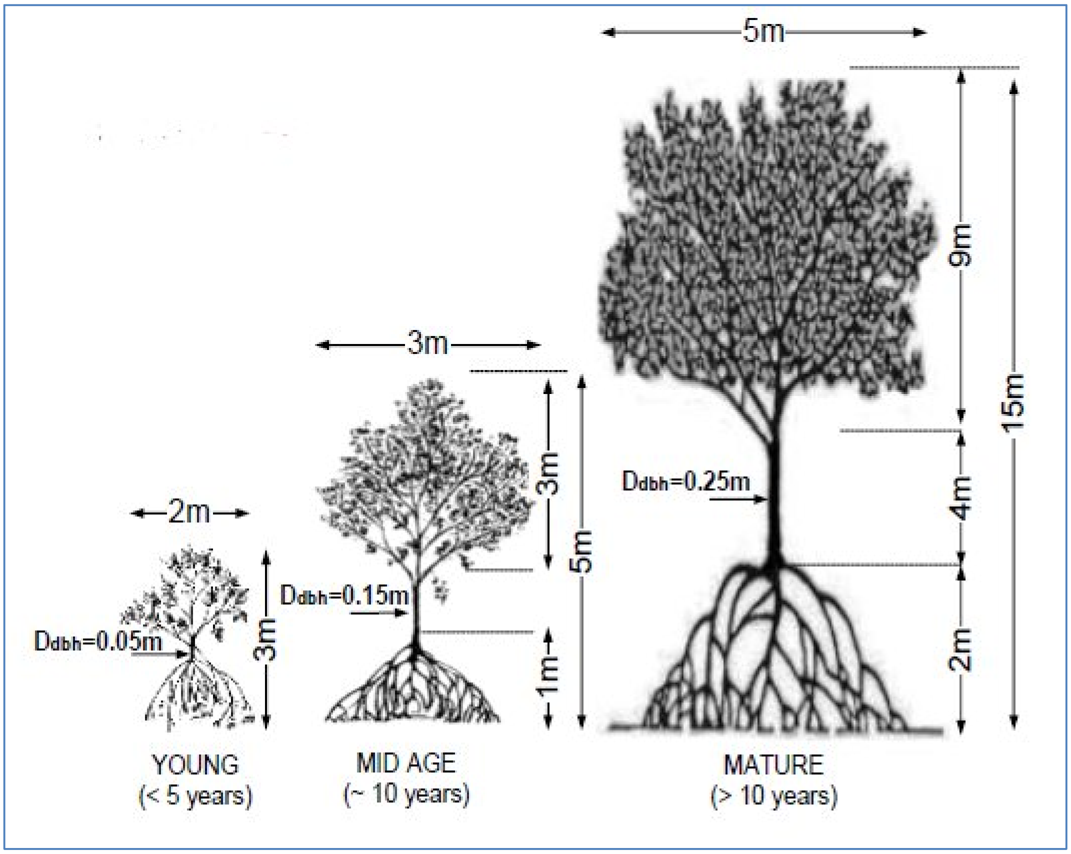


Figure 2.4. Typical geometry of *Rhizophora species* (source:[1])

Table 2.3 Geometry parameters of mangrove tree (source: [1])

Geometry parameters	Mature	Mid-age	Young
Age of tree, t_a (year)	>25	<8	0.8
Total height of tree, h_h (m)	10.34	7	1.38
Height of roots, h_r (m)	1.54	1.2	0.9
Height of trunk, h_t (m)	1.8	1.5	-
Height of canopy, h_c (m)	4.2	4.2	0.48
Diameter of trunk, D_{dbh} (m)	0.2	0.09	0.03
Diameter of roots, D_r (cm)	1.0 - 9.0	1.0 - 3.5	0.02
Diameter of branches, D_{br} (cm)	1.5 - 15	0.5 - 1.5	0.5
Width of roots, w_r (m)	5.6	3	0.98
Width of canopy, w_c (m)	7	3	0.6
Number of branches (-)	24	24	8
Number of leaves/branches (-)	1680	346	134
Average area of leaves, A_1 (m^2)	0.0028	0.0028	0.0028
Estimate LAI (-)	2.9	3.3	1.3

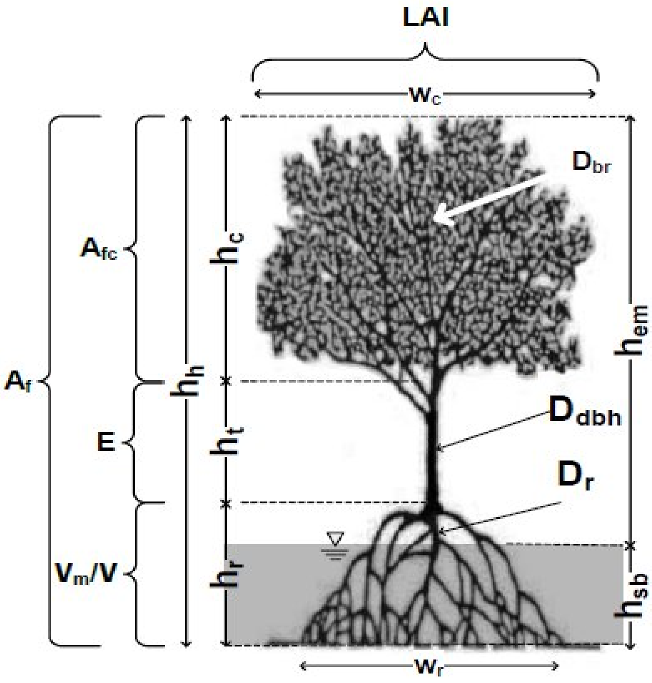


Figure 2.5 Geometry parameters of Rhizophora species (source: [1])

When the mangrove tree is older and bigger, the resistance to wave damage is higher compare. At age 5 to 6 years old, the reduction is large because the roots are better developed that exerted large drag force from incoming wave, meanwhile young mangroves of age 6 months old, the wave dissipation is low because the roots are still young and sparse [13].

This is parallel to finding of [16] where wave attenuation through the youngest decreases when the depth increases because wave attenuation depends on the bottom friction. As the depth increases, youngest mangroves tend to fall, no obstacle presents, thus the bottom friction becomes less important, thus less attenuation of wave occur. This condition is vice versa for older threes where they have leaves and branches that play larger role until wave attenuation increases with depth. Bottom frictions can be described in terms of Manning roughness as a function of the beach landscape types of coastal beds (i.e. sands or mud).

Since the age of mangroves trees increases, the height also will increase until it stops. Figure above shows the amount of energy dissipated increases linearly with vegetation height which can be concluded that the higher the height of vegetation, the higher the amount of energy dissipated. This linear relationship was verified with Dalrymple’s equations.

Dalrymple comes out with derivation of energy dissipation factor which originally based on the Morrison equation. Finding of [17] however estimated the propagation of random breaking and non-breaking waves over the mangrove forests by using Dalrymple’s method. They assumed that the line wave theory is valid, and it expressed the horizontal force per unit volume dependent on the average bulk drag coefficient of vegetations, the horizontal velocity in the vegetation area due to wave motion, the area and the horizontal vegetation density. Dalrymple formulation is the best numerical approximation of wave attenuation in mangrove vegetation and best implemented in modeling software, SWAN [7].

Below is the Dalrymple et al. (1984)’s energy dissipation through a vegetation field equation.

$$\varepsilon_v = \frac{2}{3\pi}\rho C_d b_v N_v \left(\frac{kg}{2\sigma}\right)^3 \frac{sinh^3 k\alpha h + 3\sinh k\alpha h}{3k\ cosh^3 kh} H^3 \qquad (1)$$

where k is the wave number (the wave number is determined by the dispersion relationship for a given water depth and a wave period in the absence of vegetation), σ angular wave frequency, αh is the mean vegetation height, C_d is the drag coefficient, b_v is the stem thickness or diameter and N_v is the vegetation density.

Based on [18], this Dalrymple-based approach is only applicable on regular waves only.

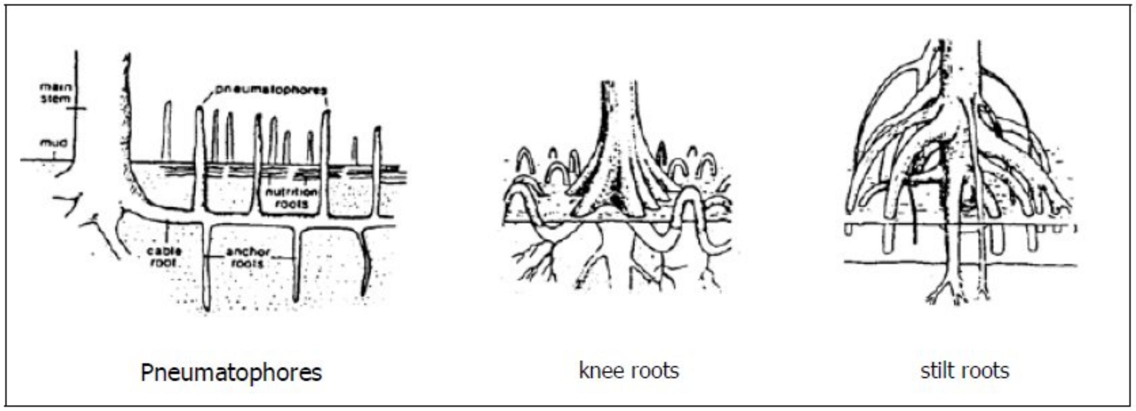


Figure 2.6. Different types of mangrove roots

In the point of engineering views, these roots bring the largest part of drag forces [7].

In this formulation, wave reflection on vegetation is not considered in this formulation. He also stated that the formulation contains the drag coefficient need to be calibrated and it will affect a bulk of physical processes during modeling.

Figure 2.7 and 2.8 below are the graph of wave attenuation of 20 years old and 5 years old respectively. For 20 years old mangrove, the graph pattern for dense, medium and sparse is slightly the same. Meanwhile the attenuation of wave quite differ for 5 years old mangrove trees of dense, medium and sparse.

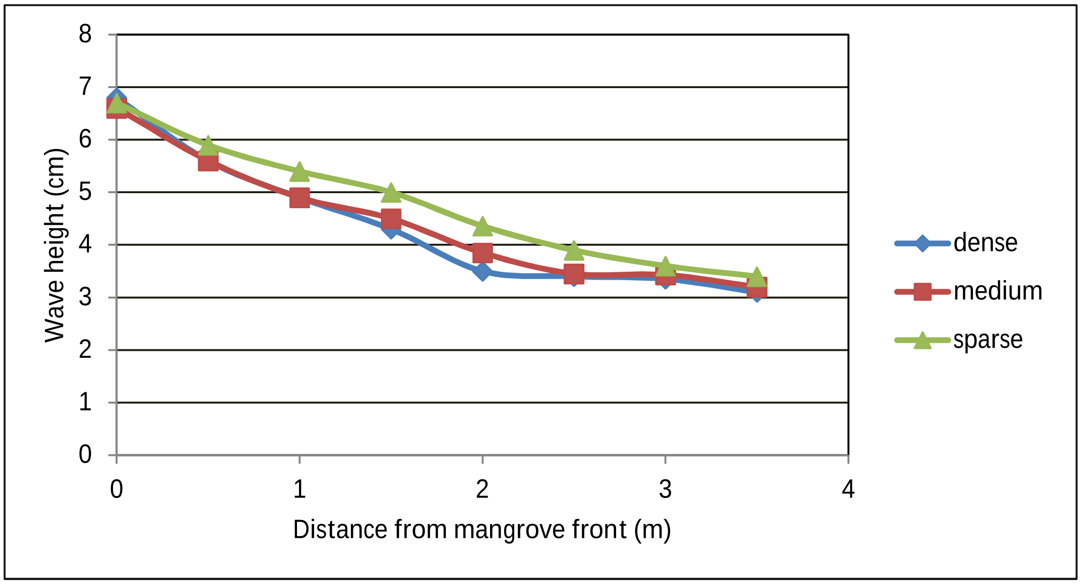


Figure 2.7. Wave attenuation of 20 years old *Rhizophora species*

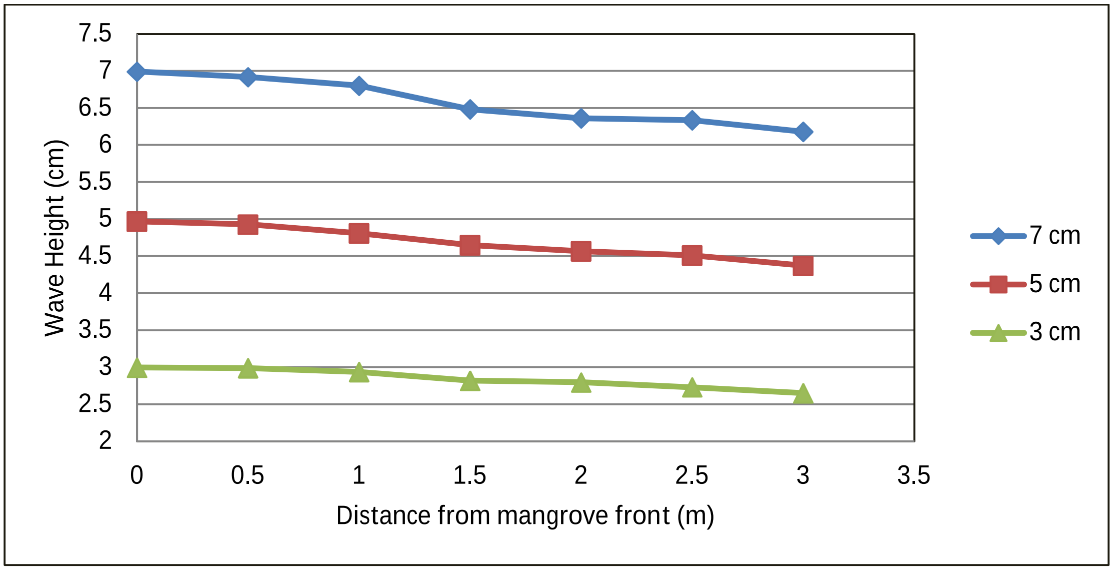


Figure 2.8. Wave attenuation of 5 years old *Rhizophora species*

However, it is still questionable that at what age of tree, the wave is optimally dissipated. Field measurements for mangrove with different ages need to be conducted to verify the assumption made in recent studies. Therefore, analyzing previous data and findings is essential to obtain the empirical relationship.

2.2.3 Band width of mangroves

Based on study of [16], the level of wave attenuation varied from 0.0014/m and 0.011/, where they suggest wave height can be reduced by 50 to 99% across a 500 m width of mangrove forest. However in study of [13] found that a mangrove forest of 80 m width with density 0.11 trees/m^2 to reduce wave height about 80%. Therefore, [19] has come out with a relation to define minimum mangrove band width for coastal protection in Vietnam. He also found that the mean wave height reduce over the first 40 m of forest about 21%, next 40 m is 17% with a total reduction of 35% over the first 80 m of the forest width. In [20], the study proposed that planting of 300 m wide mangrove strips can be a highly feasible and cost-effective substitute to foresting an entire region with mangroves. He also suggested that the optimum width for the mangrove vegetation should be range from 300 to 800 m for maximum protection in terms of wave attenuation. However, beyond 800 m is not suitable since too much protection will cause excessive sedimentation and less water exchange, thus reduce water quality and low nutrients to be absorbed by the mangrove trees. Longer waves have slightly sharper attenuation rates than shorter waves though the rates become almost the same beyond a forest width of around 1000 m.

Table 2.4 Classification of mangrove forest for prevention of sea wave (source: [19])

Levels	Index of mangrove structure, V	Required band width (m)	Name of levels
I	< 0.005	> 240	Very weak prevention
II	0.005 - 0.010	120 - 240	Weak prevention
III	0.010 - 0.015	80 - 120	Moderate prevention
IV	0.015 - 0.028	40 - 80	Strong prevention
V	> 0.028	< 40	Very strong prevention

*the maximum wave height is assumed to be 300 cm.

Based on [19], the effect of mangrove forest band width on wave height can be as followed;

$$W_h = a \times e^{b \times B_w} \tag{2}$$

where W_h = the wave height behind the forest (cm)
B_w = forest band width (m)
a = $0.9899 \times I_{wh} + 0.3526$
b = $0.048 - 0.0016 \times H - 0.00178 \ln(N) - 0.0077 \ln(CC)$
I_{wh} = initial sea wave height (cm)
H = average tree height (m)
N = tree density (tree ha^{-1})
CC = canopy closure (%)

2.2.4. Forest density

According to [21], the density of forest is a major factor in order to know the forest status and indicate the coastal management. In [1] his study stated that there are at least three definitions to determine the forest canopy which are canopy volume, canopy closure and the frontal area. These are quite often used as parameters compared to trunk and roots.

Forest canopy cover or canopy cover and crown cover can be defined as the proportion of the forest floor covered by vertical projection of the tree crown. Forest density brings significant reduction of wave propagation through the forest.

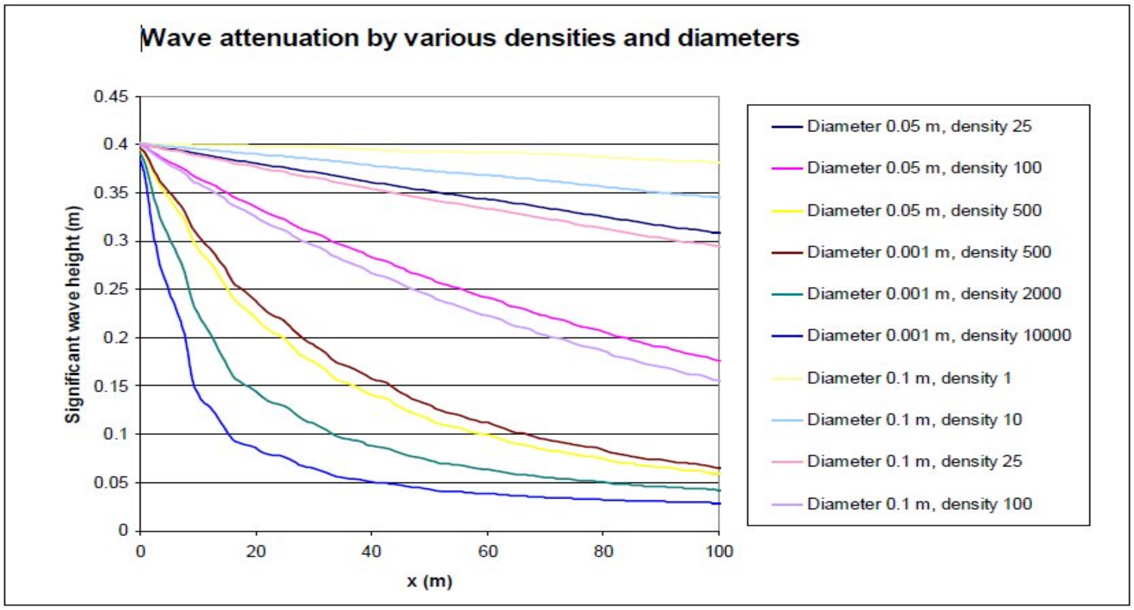


Figure 2.9. The wave attenuation by various densities and diameters (Source: [7])

Based on [7] larger attenuation happens when wave propagates through high density of forest. It seems that the density is dominant than that of the diameter of tree. This is due to the dissipation of energy of the vegetation parameters are multiplied with each other based on Rayleigh distribution in (3) below.

$$S_{veg} = (\varepsilon_v) = \frac{1}{2\sqrt{\pi}}\rho\widetilde{C_D}b_v N_v(\frac{gk}{2\sigma})^3 . \frac{sinh^3 k\alpha h+3\sinh k\alpha h}{3k\ cosh^3 kh} {H_{rms}}^3 \tag{3}$$

Meanwhile, finding of [13] stated that dense mangroves dissipate more wave than less dense mangroves. This has been supported by mathematical and field data of some researchers mentioned above. Therefore, this research is conducted to identify the empirical relationship and find the optimal vegetation density so that optimum wave can be dissipated.

CHAPTER 3

RESEARCH METHODOLOGY

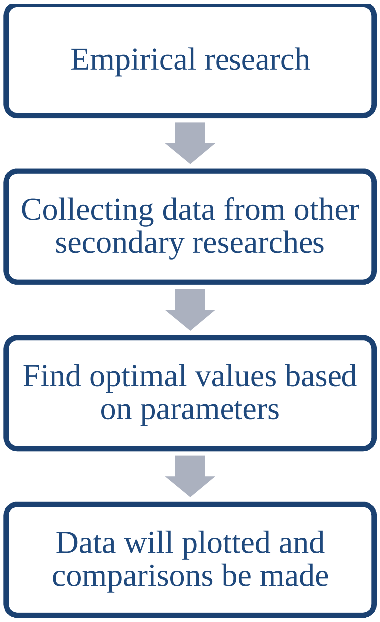
3.1 FYP 1 SUMMARIZATION

These are the list of Final Year Project (FYP) I activities during last semester.

> FYP titles and supervisor selection were conducted in the first two weeks of the semester whereby students got to choose their own supervisor and FYP titles or propose new title. Discussions of proposed project topic were conducted to achieve both interest and agreement between supervisor and student. Next, preliminary researches were conducted on existing studies based on journals, articles, books, conference papers, newspapers and etc. General discussion on introduction, background of study, and scope of study were done between student and supervisor. Extended proposal on the selected topic were sent and presented, whereby the continuation of the proposed project topic was decided. More research studies on were conducted on data collection; mainly on mangroves characteristics and wave interaction. Next was proposal defense whereby student needed to defense their project and specified reasons behind their chosen topic. Project work continued by doing analysis. Lastly, students needed to send the interim report of their progress for FYP I.

3.2 DATA COLLECTION

Empirical research is conducted by collecting available data from primary or secondary research. The reason for this empirical research need to be done is to find the optimal value and to obtain empirical relationships of different parameters. The parameters that will be studies are species of trees, ages of tree, band width of mangrove forest, density of trees and canopy closure, initial wave height, height of wave dissipated, and percentage of wave dissipation. These data will then be plotted and comparison will be made between the previous data. Other geometric parameters will be taken considerable into analysis and compare the wave dissipation percentage. Then, they will be analyzed using Microsoft Excel to obtain an empirical relationship.



A total of two mangrove forest plots were set in two different locations along the coastal of Perak. About 2-5 transects were set to measure the height of waves at different cross-shore distances (i.e. 0 m, 3 m, 6 m, 10 m and 12 m) from the fringe of mangrove forest to the center of the mangrove forest.

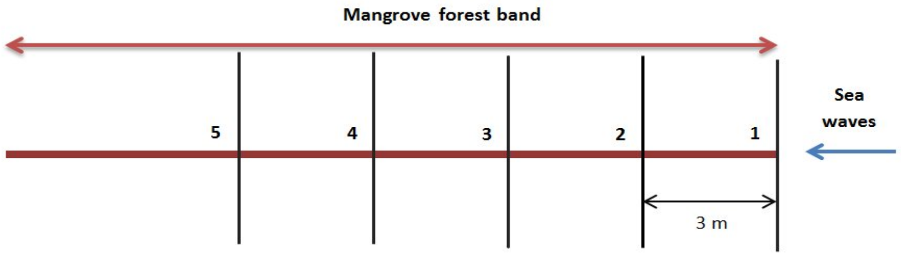


Figure 3.1. Measurement of wave height on a cross-shore transect

The wave height was measured by people standing at five cross-shore distances. Species of trees, diameter at breast height (DBH), heights of tree, tree density and canopy closure are among the mangrove forest structures that need to be measured. The attenuation of wave was analyzed with respect to distance, initial wave height and the structure of mangrove forest.

Based on [22], the measurement of DBH is done by measuring the DBH at breast level where it is approximately 1.3 m above the ground by using measuring tape. Since there is no diameter tape, normal measuring tape is used to measure the circumference of the trunk. Next, calculation has been done to calculate the diameter of trunk of the tree.

The vegetation density is calculated by calculating number of trees per 100 m^2.

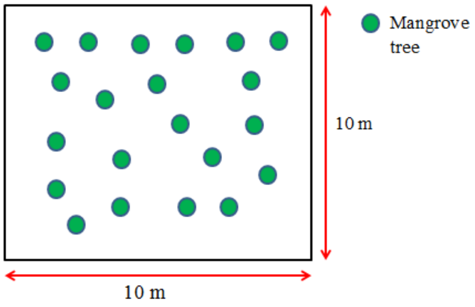


Figure 3.2. Vegetation density measurement

The height of tree can be measured if the height is less than 2 m. For the trees have height of more than 2 m, the measurement has been done by estimating them using comparison with a measureable object nearby a trunk; a 1 m measuring staff has been used in this case to measure the height and looking from a distance of how many times the object fits the tree. Another measurement of height of tree also is done by using goniometry where the tree's height is equal to the distance to tree with eye's height.

Figure 3.3. Measurement on tree height

Canopy closure can be defined as the proportion of sky hemisphere obscured by vegetation when view from a single point [23]. For this measurement, a camera is as the instrument in forest canopy measurement. Camera is kept in vertical position whereby it is set into binary image so that the canopy is in black and the sky is in white. The percentage of black and white pixels in the binary image is calculated. Based on [24], tree height does not affect the canopy cover as the vertical projection of the crown alone is assessed.

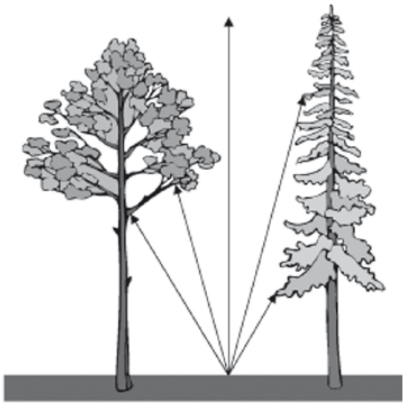


Figure 3.4 Canopy closure measurement

3.3 SITE VISIT

In order to fulfill the aim of this project, physical measurement will be done during site visit. Site visit need to be conducted to verify the empirical relationship, to obtain accurate result and also make observation on the condition at mangrove swamp. For this study, Kuala Sepetang, Kuala Gula, Pantai Lekir in the state of Perak; Teluk Bahang, Balik Pulau in the state of Pulau Pinang and Kuala Muda, Kedah have been chosen for as site visit for the sake of this research.

For this visit, the people who directly and indirectly involved are:

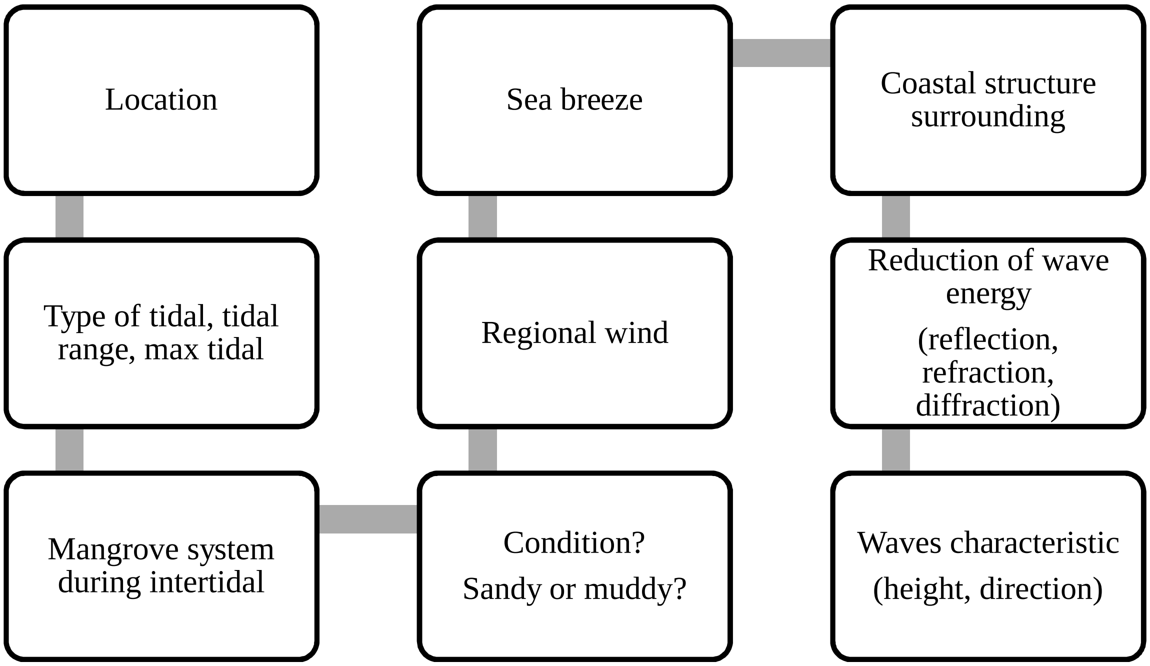
1. AP Ahmad Mustafa bin Hashim
2. Tuan Nurul Shakira Bt Tuan Mohd Shukri
3. Meor Asniwan bin Meor Ghazali
4. Mohd Idris bin Mokhtar
5. Nor Khalida Binti Abd Kadir
6. Nor Azimah Binti Abd Kadir
7. Abrar Abdul Majid
8. Aaron Keith Phillips
9. Ali Akram

The coastlines of these places are well protected by different species of mangroves. These mangrove forest reserves have been proven to act as a natural barrier against tsunamis and wind waves, and also waves coming from movement of boats.

During this site visit, vegetation characteristics and wave data has been measured and collected. For this study, these are the conditions of mangrove forests that have been investigated.

- Types of mangroves
- Age of mangroves
- Stem diameter of trees
- Vegetation density
- Mean vegetation height
- Replanted or natural mangroves trees

Below is the measurement and survey has been conducted to investigate the characteristic of mangrove forest, and the surrounding.



The site visit to Kuala Sepetang Mangrove Park and Kuala Muda was ruined due to inaccessibility to the site of mangroves, meanwhile in Teluk Bahang and Balik Pulau, the mangrove areas are too far away from the main road.

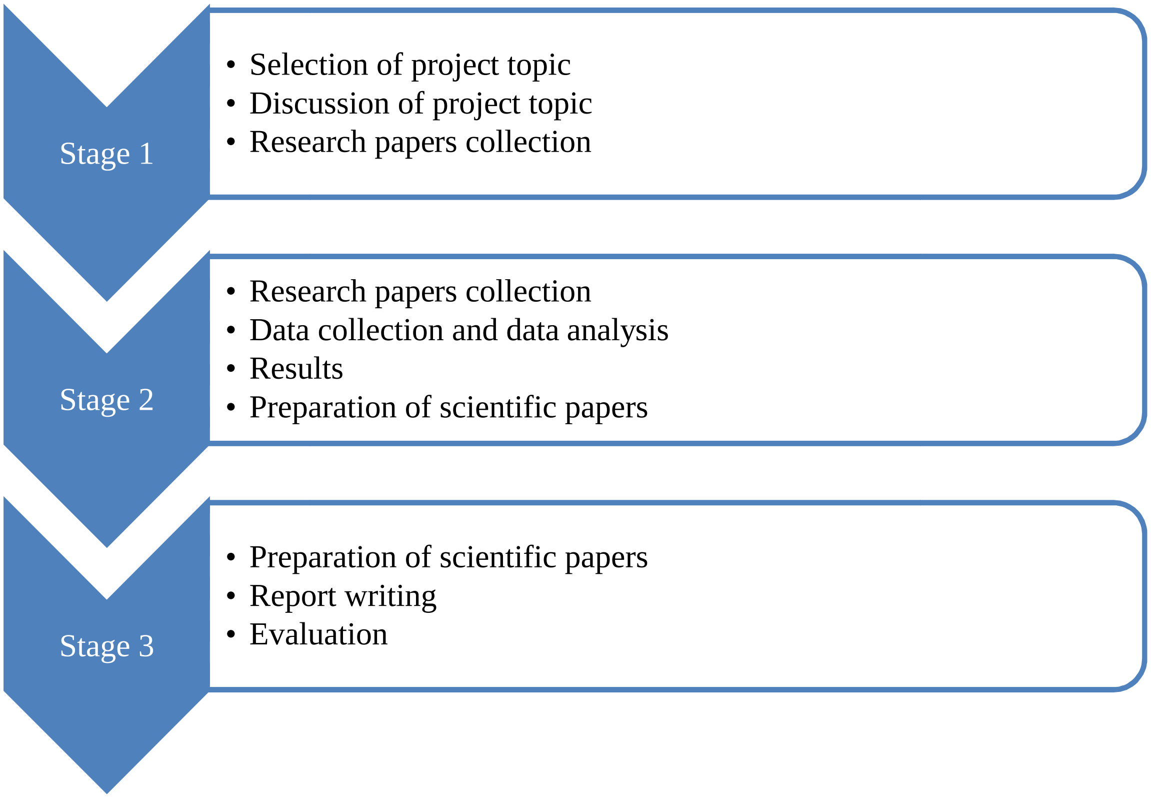
In Kuala Sepetang Mangrove Park, the mangroves there do not react with incoming wave from sea since it is located far away from the sea. Since this study need to measure the tidal wave from sea and coast, this reserved forest is not suitable for this study. However, there is preserved area where the trees are in good conditions and suitable for other types of research. Although no wave data obtained from Kuala Sepetang, some information about mangroves can be learnt such as the types of trees, age, forest density and others.

The chosen site locations for the field assessment are Kuala Gula and Pantai Lekir since they can be assessed and suitable for measurement since they are exposed to open sea.

3.4 TOOLS REQUIRED

For critical and intensify analysis, Microsoft Excel was used to plot graphs from obtained data of previous research. From there also, an equation can be developed, and the equation can be used to know the empirical relationship. During site visit, measuring tapes, camera and staffs are required to make physical measurement.

3.5 PROJECT KEY MILESTONES



Stage 1

- Selection of project topic
- Discussion of project topic
- Research papers collection

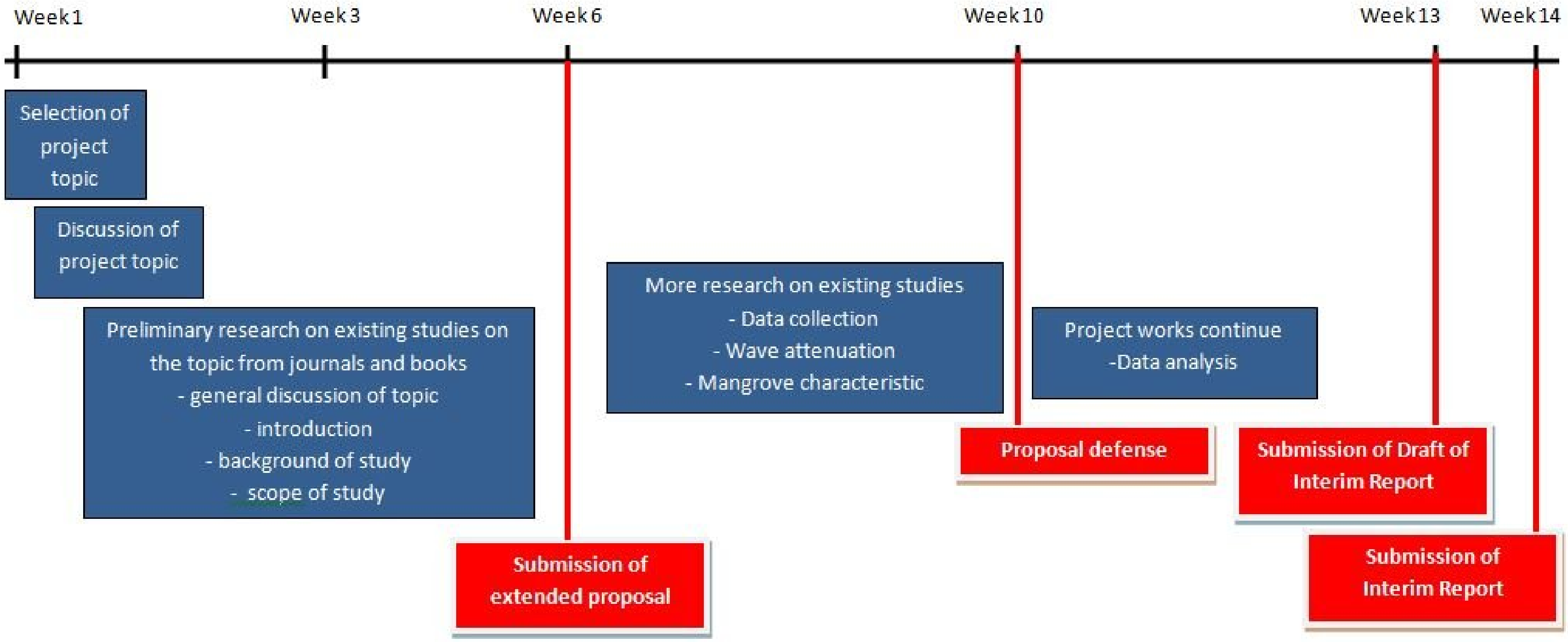
Stage 2

- Research papers collection
- Data collection and data analysis
- Results
- Preparation of scientific papers

Stage 3

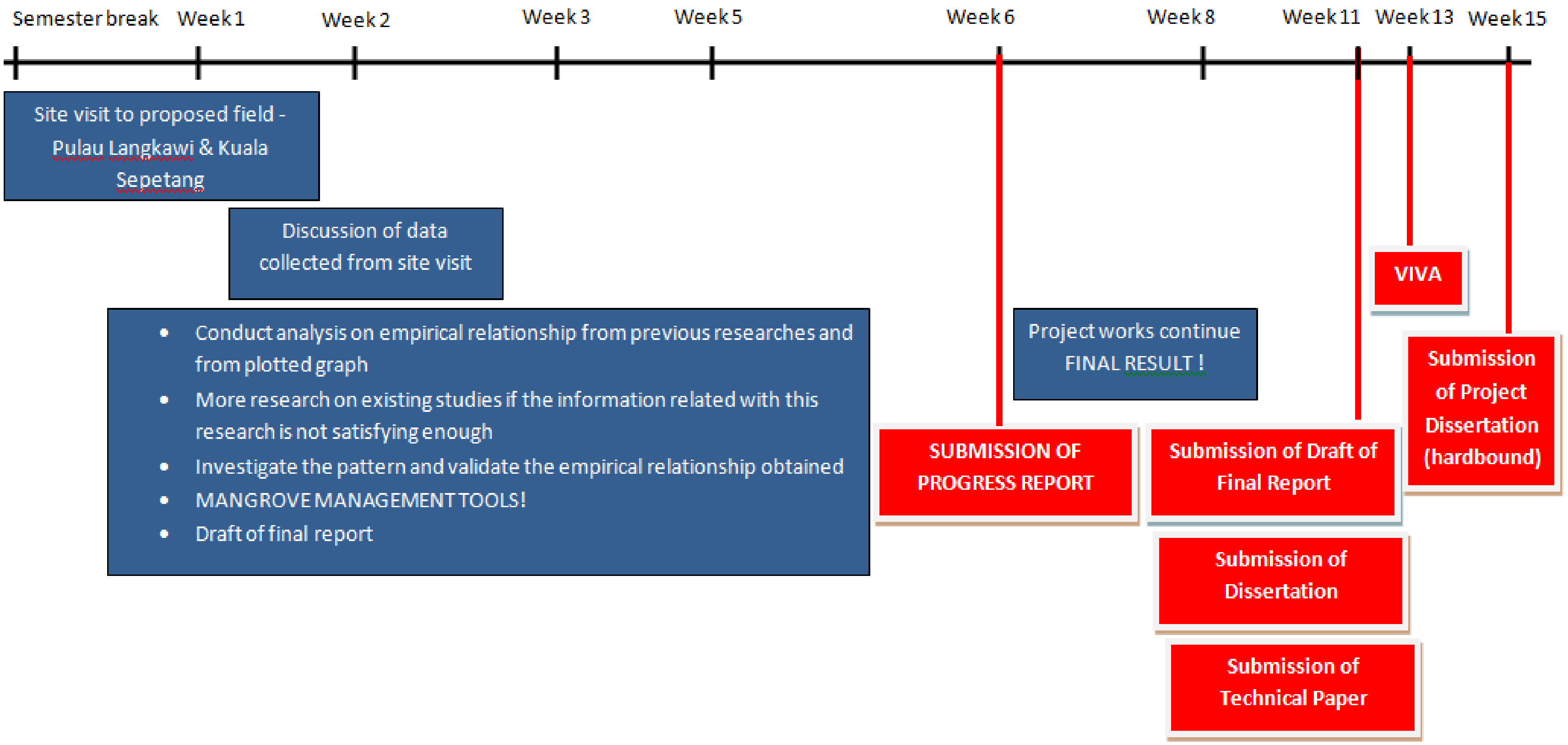
- Preparation of scientific papers
- Report writing
- Evaluation

3.5.1 PROJECT MILESTONE FOR FINAL YEAR PROJECT I



🟥 Submission of paperwork and presentation 🟦 Project activities

3.5.2 PROJECT MILESTONE FOR FINAL YEAR PROJECT II



Site visit to proposed field - Pulau Langkawi & Kuala Sepetang

Discussion of data collected from site visit

- Conduct analysis on empirical relationship from previous researches and from plotted graph
- More research on existing studies if the information related with this research is not satisfying enough
- Investigate the pattern and validate the empirical relationship obtained
- MANGROVE MANAGEMENT TOOLS!
- Draft of final report

Project works continue FINAL RESULT !

SUBMISSION OF PROGRESS REPORT

Submission of Draft of Final Report

Submission of Dissertation

Submission of Technical Paper

Submission of Project Dissertation (hardbound)

🟥 Submission of paperwork and presentation 🟦 Project activities

3.6 GANTT CHART

3.6.1 GANTT CHART FOR FINAL YEAR PROJECT I

NO	DETAILS\WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	Selection of project topic	■	■												
2.	Preliminary research work			■	■	■	■								
3.	Submission of extended proposal						🟥								
4.	Proposal defense							■	■	🟥					
5.	Project Work Continues								■	■	■	■	■	■	
6.	Submission of Interim Draft Report													🟥	
7.	Submission of Interim Report														🟥

■ **Project activities** 🟥 **Submission of paperwork and presentation**

3.6.2 GANTT CHART FOR FINAL YEAR PROJECT II

NO	DETAILS\WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	Project Work Continues	🟦	🟦	🟦	🟦	🟦	🟦	🟦							
2.	Submission of progress report						🟥								
3.	Project Work Continues + Final Result							🟦	🟦	🟥					
4.	Submission of Draft Final Report											🟥			
5.	Submission of Dissertation (soft bound)												🟥		
6.	Submission of Technical Paper												🟥		
7.	VIVA													🟥	
8.	Submission of Project Dissertation (hard bound)														🟥

🟦 **Project activities** 🟥 **Submission of paperwork and presentation**

CHAPTER 4

RESULT AND DISCUSSION

4.1 WAVE ATTENUATION IN KUALA GULA

A. Field Measurement

Result shown below is obtained from the field measurement that has been conducted in natural mangrove forest of Kuala Gula, Bagan Serai. Table below shows the measured wave height over some distances of vegetation (0 m, 3 m, 6 m, 9 m, and 12 m).

Table 4.1 Measured Wave height over distance of mangrove forest in Kuala Gula

Forest band width, B_w (m)	Measured Wave Height (cm)
0	11.2
3	4.9
6	1.1
9	1.8
12	1.5

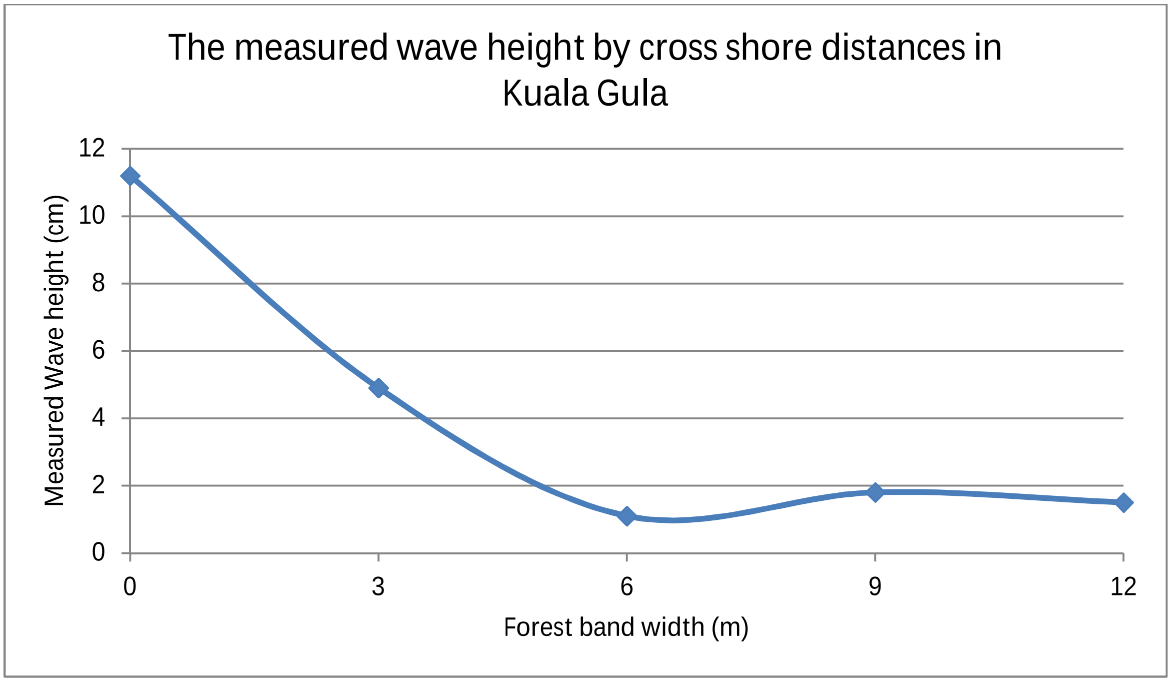


Figure 4.1 The measured wave height by cross shore distances in Kuala Gula

Based on the graph above, the wave attenuates over 6 m distance through the forest. However, there is slightly addition of 0.7 cm to the wave height as it reaches 9 m distance. The reason behind this result is that the angle of wave attack was not constant at 90° for all the runs at the particular measurement site and time.

Figure 4.2 Wave attack of different angle in Kuala Gula

After the distance = 9 m, the wave attenuates about 0.3 cm from 1.8 cm into 1.5 cm.

$$Percentage\ wave\ attenuation = \frac{Initial\ Wave\ Height - Final\ Wave\ Height}{Intial\ Wave\ Height} \times 100\% \qquad (4)$$

The percentage of reduction through 12 m of forest band width is about 86 %.

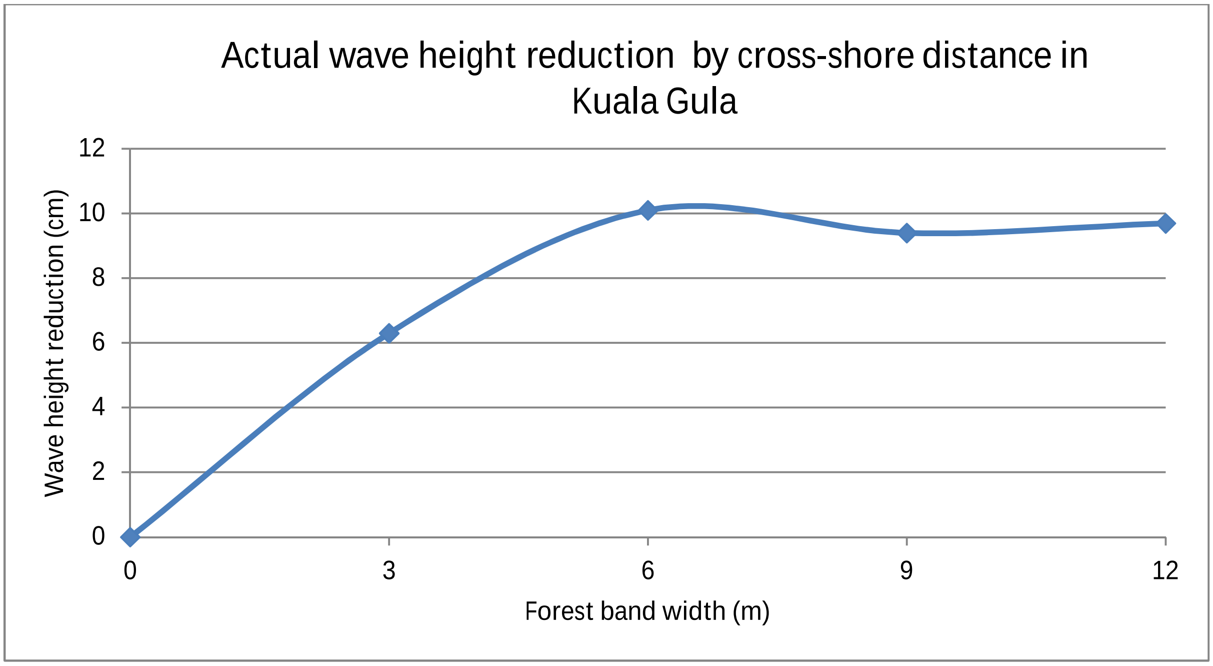


Figure 4.3 Actual wave height reduction by cross-shore distance in Kuala Gula

From the **Figure 4.3** above, wave reduction keeps increasing up until 6 m width of forest, and it remains constant after the distance = 6 m.

Although there is slightly addition to wave height at the middle it can be concluded that wave height can be attenuated by some distance of forest.

B. Theoretical measurement

Table 6 showed below is the theoretical measurement of wave height based on Bao's equation in (5).

$$W_h = \left(0.9899\, I_{wh} + 0.3526\right) \times e^{[(0.048\, -0.0016H - 0.00178\ln(N) - 0.0077\ln(CC))(B_w)]} \tag{5}$$

For the calculation of the wave attenuation by mangroves, many important parameters have been collected and measured. In the measurement, mangrove forest band width remains as a manipulative factor for the whole calculation. The initial wave height, I_{wh} =

11.2 cm, the height of tree, H = 5.4 m, the vegetation density, N = 1800 tree/ hectare and the canopy closure, CC = 90 % are kept constant throughout the calculation.

Table 4.2 Theoretical wave height through distance of mangrove forest in Kuala Gula

Forest band width, B_w (m)	**Theoretical wave height (cm)**
0	11.74
3	10.58
6	9.54
9	8.60
12	7.75

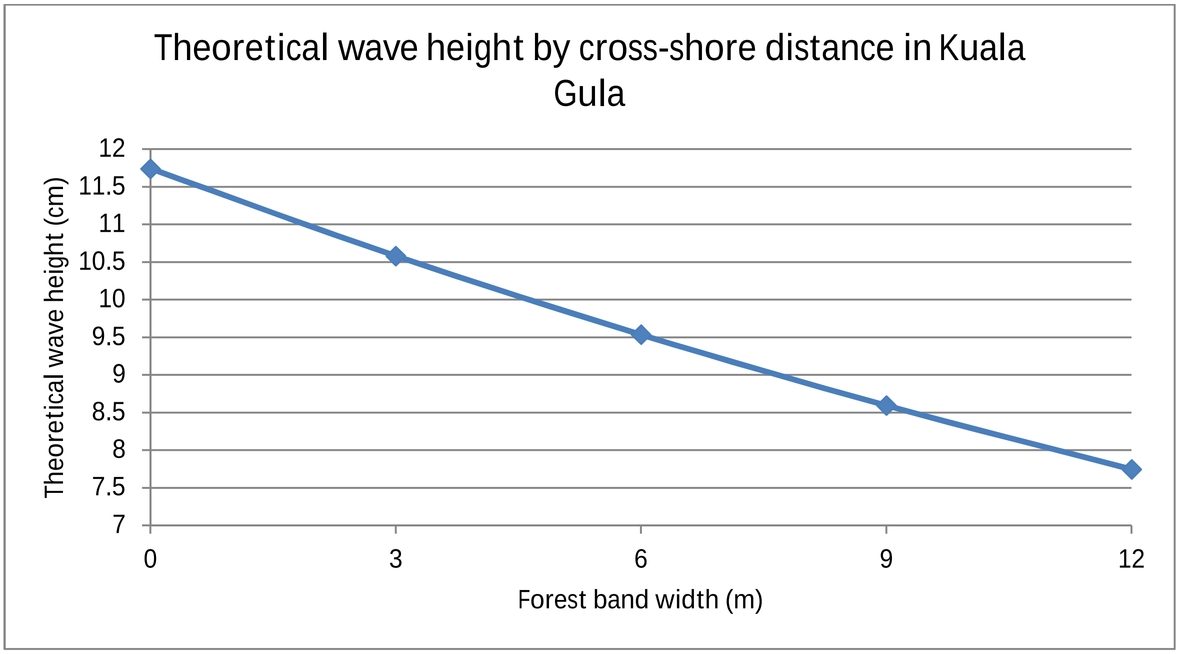


Figure 4.4 Theoretical wave height by cross-shore distance in Kuala Gula

From the theoretical result above, it can be seen that the wave height reduces linearly as the waves got through some distance of the mangrove forest. This finding is in parallel with results of wave attenuation by distance of mangrove forest by [7, 13, 16, and 19].

The percentage of attenuation as waves go through 12 m distance of mangrove forest is 34%.

Table 4.3 Theoretical and measured wave height by distance through mangrove forest

Forest band width, B_w (m)	Wave height (cm)	
	Measured	Theoretical
0	11.2	11.74
3	4.9	10.58
6	1.1	9.54
9	1.8	8.60
12	1.5	7.75

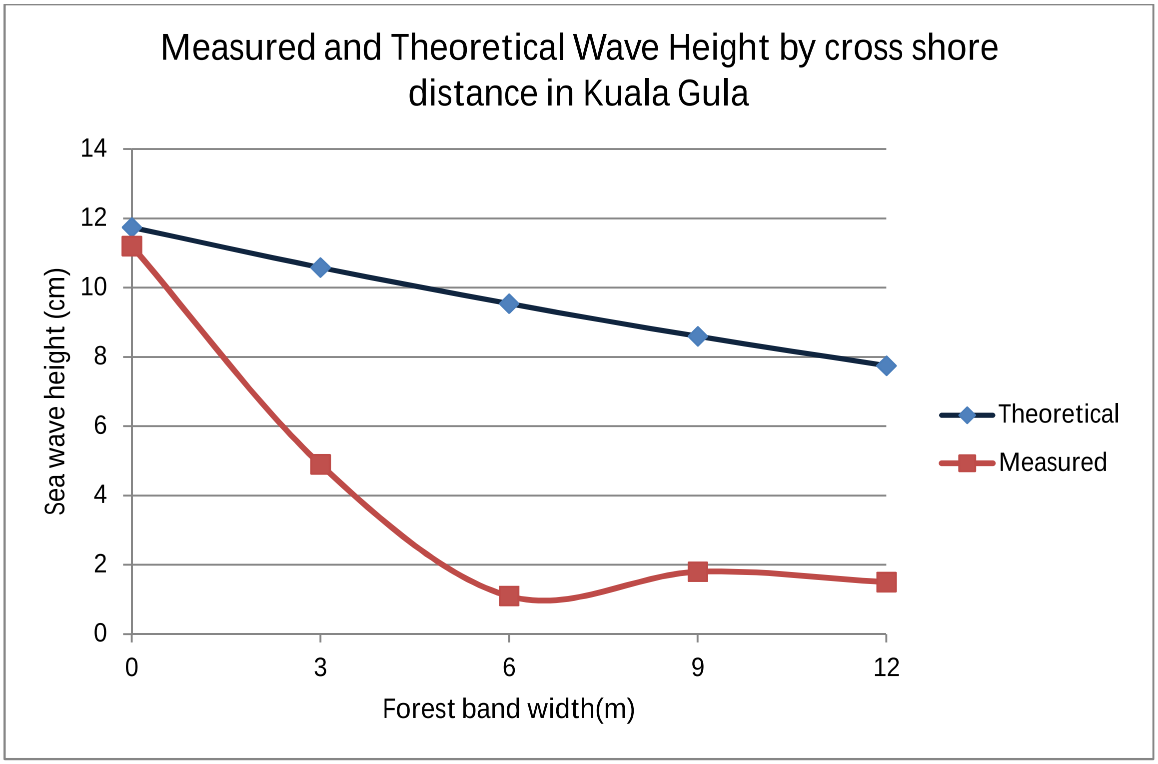


Figure 4.5 Measured and Theoretical Wave Height by cross shore distance in Kuala Gula

Based on the **Figure 4.5**, the difference between measured and theoretical wave height can be seen. The difference is quite high.

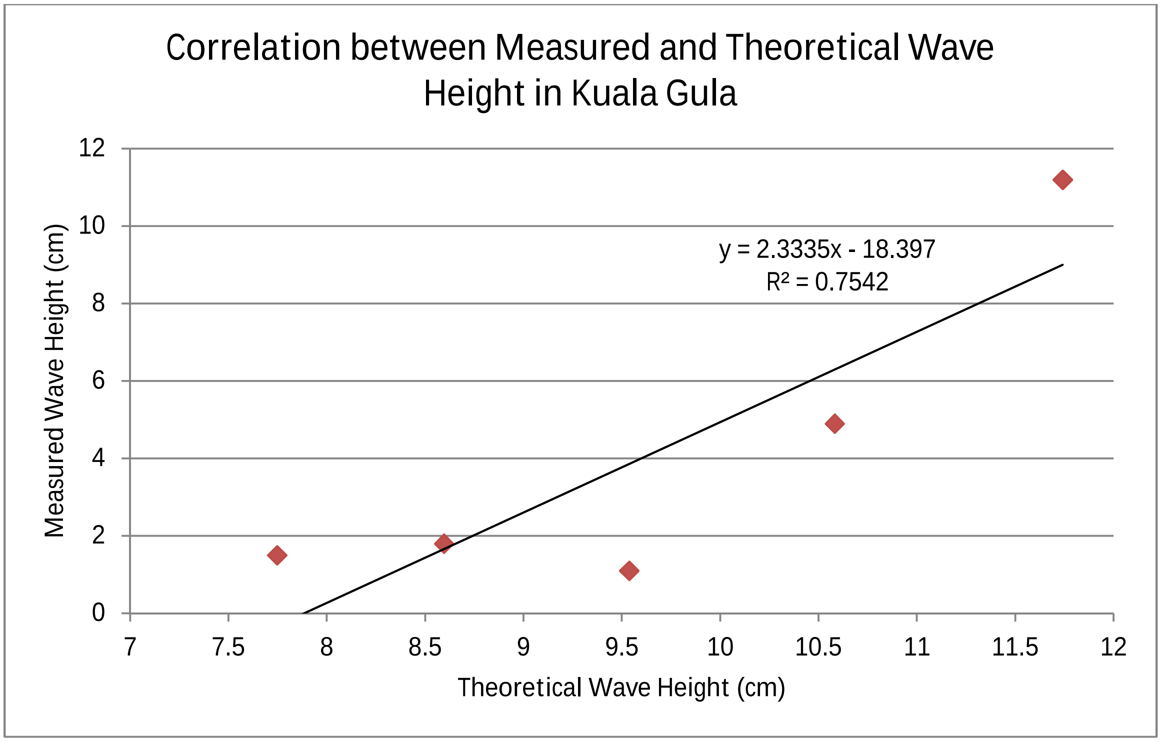


Figure 4.6. Correlation between Measured and Theoretical Wave Height in Kuala Gula

Regression analysis has been done in Excel 2010 to validate the accuracy between theoretical values are compared with the actual data.

Based on R^2 = 0.7542 obtained, it can be said that 75% of the variation in measured wave height can be predicted by the variation in theoretical wave height. Another 25% of the variation would be due to other factors that are not accounted for by the measured wave height such as the vegetation density, canopy closure, height of tree and others.

The different of percentage wave attenuation through 12 m distance through a mangrove forest by measured and theoretical data which is 86% and 36%, respectively can be seen. There are few reasons in the major difference between both measured and theoretical data.

Although the equation (5) is applicable in calculating prediction of wave attenuation, it does not mention few geometry parameters in his calculation such as the height of roots, density of roots of mangroves, width of roots. In this context, the importance of roots can be highlighted as they are also the main factors in wave attenuation. The roots give large drag coefficient to act as resistance to wave attenuation. Based on [16], above the prop roots, the trunks of *Rhizophora sp*. present less of obstacles to wave reactions; therefore they allow the waves to pass more easily. The attenuation of waves is high at shallows depths, however it reduces as the depth of water becomes deeper and the waves are less affected by the prop roots. In equation (5), it only emphasized on the trunk of the mangrove trees only.

C. Wave attenuation at extreme condition

Extreme condition should be considered in studying the wave attenuation of by the mangrove forest. For extreme condition, the wave height can reach about 3.5 m with wind about 40-50 km/hour, where it is dangerous for properties and people in coastal area of Kuala Gula.

Prediction on wave height attenuation can be done by derivation of Bao's equation in (5) whereby the width of the mangrove forest can be known.

$$B_w = \frac{\ln\left(H_{safe}\right) - \ln\,(0.9899H_o + 0.3526)}{0.048 - (0.0016\,TH) - (0.00178 \times \ln(N)) - (\ln(CC))} \tag{6}$$

where B_w is the required mangrove band width (m), H_{safe} is the safe wave height for wave behind the mangrove (cm), TH is average rate of tree height (m), N is the vegetation density (trees/hectare) and CC is the canopy closure (%).

Based on collected data on maximum wave heights in Kuala Gula, the ranges of maximum wave height are from 1.0 m to 3.5 m. Therefore, 3.5 m wave height is used. The safe weight height is assumed about 30 cm based on fisherman in this area. The height of tree, the vegetation density and the canopy closure are kept constant which are 5.4 m, 1800 trees/hectare and 90%, respectively.

Based on equation (6), the required band width of mangrove forest to dissipate 3.5 m waves is 0.5 m or 50 cm. This finding is opposite with equation (5).

Equation (5) shows that to achieve the safe wave height, H_{safe} = 30 cm, the required band width is should be about 70 m where it is opposite with the value obtained by equation (6) which is 0.5 m.

Based on [16], equation (5) and (6) above is applicable for data of small waves where wave heights less than 70 cm, therefore this equation can be used for the wave condition in Kuala Gula. Therefore, the equation is not applicable for extreme wave condition.

Table 4.4 Predicted forest band width in Kuala Gula

Forest Band Width, B_w (m)	**Wave height (cm)**
0	355.96
3	320.82
6	289.14
9	260.60
12	234.87
15	211.68
18	190.78
21	171.94
24	154.97
27	139.67
30	125.88
33	113.45
36	102.25
39	92.15
42	83.06
45	74.86
48	67.47
51	60.81
54	54.81
57	49.40
60	44.52
63	40.12
66	36.16
69	32.59

When the distance through the forest reaches about 70 m, the wave height is approximately 30 cm, where it is the safe condition for wave height. The percentage of attenuation at Bw = 70 m is about 90%.

D. Wave attenuation based on different height of mangrove trees

Table 9 below is the wave attenuation based on different heights of *Rhizophora apiculata sp.* after going through some distance into the forest. For the calculation of the wave attenuation by mangroves, many important parameters have been collected and measured. The main contributing factor is the height of the tree. Mixed height of vegetation can be observed in Kuala Gula. Equation (5) is used in this data analysis.

The initial wave height (at distance = 0 m) is constant throughout the calculation with value I_{wh} = 11.2 cm. Vegetation density, N is calculated by calculating number of trees per 100 m^2 whereby approximately 18 trees of various height in 100 m^2.

Table 4.5 Wave attenuation based on different heights of tree in Kuala Gula

Point	**Distance through the forest (m)**	**Average tree height (m)**			
		1.5	**3.0**	**4.8**	**5.4**
1	**0**	11.81451034	11.78618951	11.75793657	11.74101733
2	**3**	10.63482411	10.60933113	10.58389927	10.56866942
3	**6**	9.572930284	9.549982799	9.527090322	9.513381185
4	**9**	8.617067221	8.596411057	8.575804408	8.563464137
5	**12**	7.756647681	7.738054048	7.719504986	7.708396899

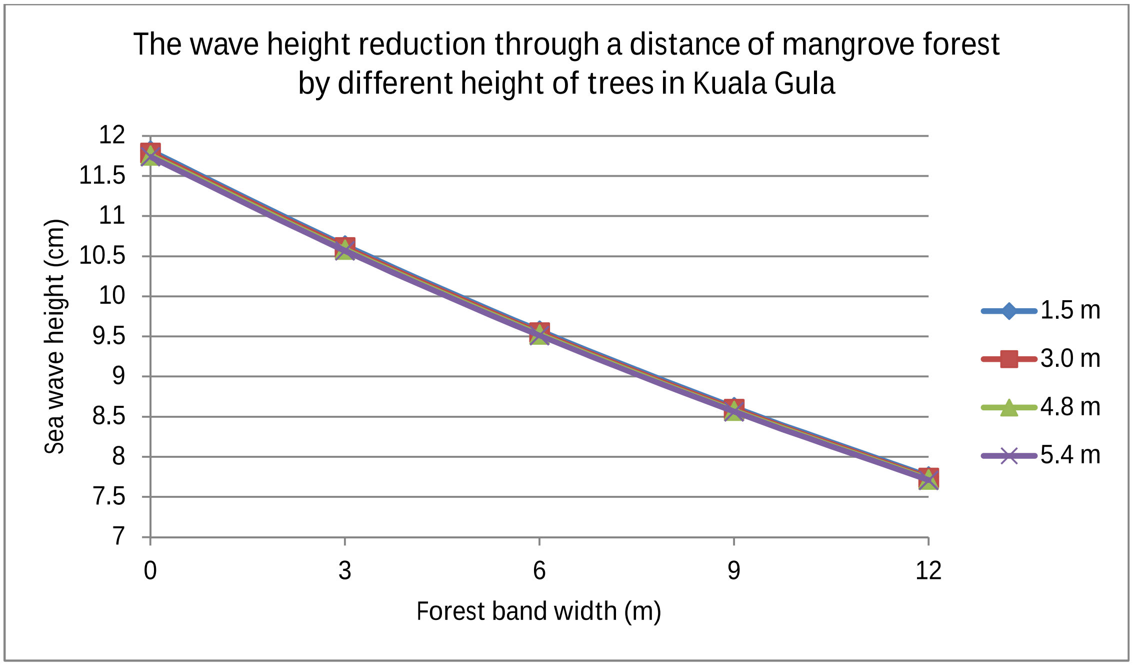


Figure 4.7 The wave height reduction through a distance of mangrove forest by different height of trees in Kuala Gula

From the **Figure 4.7**, it can be seen that the attenuation of waves by Bao's equation of different height of trees are almost the same. This theoretical result shows that although the height varies (1.5 m, 3.0 m, 4.8 m and 5.4 m), the obtained result shows that the plots are very close to each other. The result shows that the less significant wave attenuation by different height of tree (height of tree indicating the age of tree). This result is opposite to the finding of [13] where the resistance to wave attacks is higher when the mangrove tree is older, as they got bigger due to developed structure of mangrove plans.

Based on regression analysis and solver in Excel 2010, modified theoretical data has been obtained to fit the actual condition of Kuala Gula.

$$W_h = \boldsymbol{r_1}\left[\left(0.9899\, I_{wh} + 0.3526\right) \times e^{\left[\left(0.048 - 0.0016H - 0.00178\ln(N) - 0.0077\ln(CC)\right)(B_w)\right](\boldsymbol{r_2})} \tag{7}$$

The value of **r₁** and **r₂**, are the coefficients that may represent the geometry of mangrove roots. However, further studies need to be conducted to validate this finding. The value for **r₁** and **r₂** obtained based in Kuala Gula are 6.63 and 4.47 respectively. This analysis has been done with various height of mangroves tree of *Rhizophora species* (1.5 m, 3.0 m, 4.8 m and 5.4 m).

$$W_h = \boldsymbol{6.63}\left[\left(0.9899\, I_{wh} + 0.3526\right) \times e^{\left[\left(0.048 - 0.0016H - 0.00178\ln(N) - 0.0077\ln(CC)\right)(B_w)\right](\boldsymbol{4.47})} \tag{8}$$

Below is the Table 4.6 that represents the measured and modified theoretical data.

Table 4.6 Measured and modified theoretical data in Kuala Gula

Forest band width, Bw (m)	**Wave height, Wh (cm)**	
	Measured	**Modified theoretical**
0	11.2	12.95250237
3	4.9	7.885434629
6	1.1	4.800622886
9	1.8	2.922601122
12	1.5	1.779268549

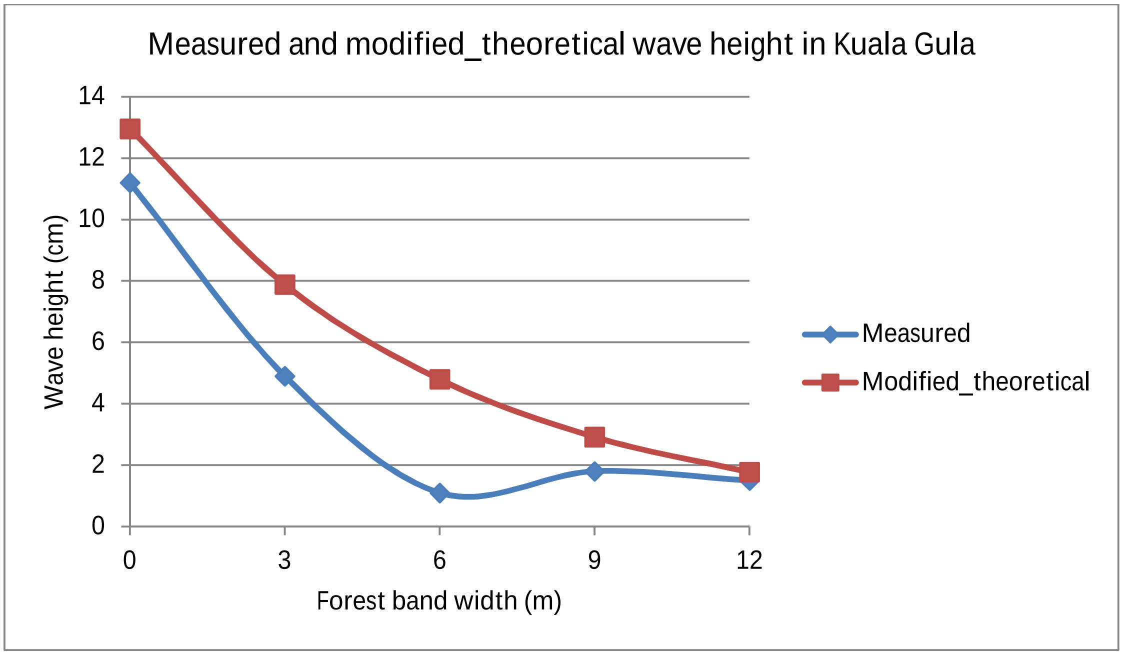


Figure 4.8 Measured and modified theoretical wave height in Kuala Gula

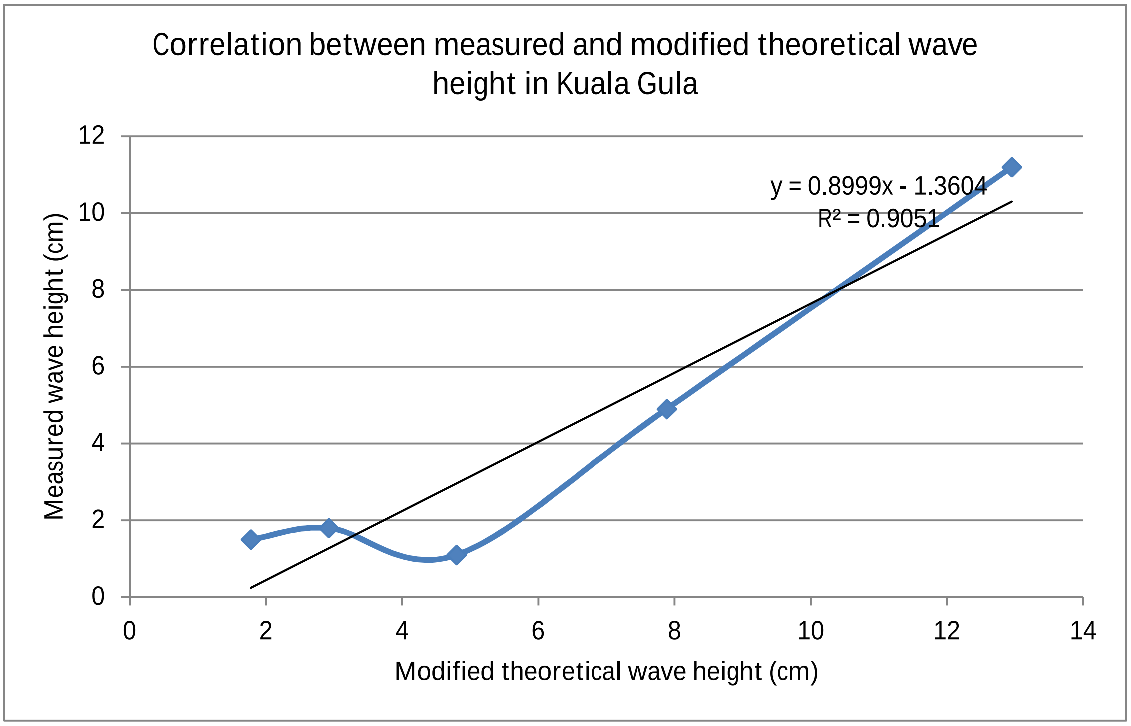


Figure 4.9 Correlation between measured and modified theoretical wave height in Kuala Gula

The R^2 obtained from the regression analysis is 0.9051 (R^2>0.90) that shows high correlation between the measured and modified theoretical wave height in Kuala Gula.

E. Wave energy dissipated based on Dalrymple and Rayleigh distribution in Kuala Gula

The analysis on the wave energy dissipation has been done using equation (1) and (3).

a) At depth of water = 0.42 m

Table 4.7 Wave energy dissipated based on Dalrymple and Rayleigh distribution at d = 0.42 m

Height of tree (m)	Wave energy dissipated, Ev (N/ms)	
	Dalrymple	Rayleigh
1.5	3.36	974.92
3.0	4.34×10^{5}	1.42×10^{9}
4.8	2.34×10^{13}	3.03×10^{16}
5.4	4.92×10^{15}	3.54×10^{16}

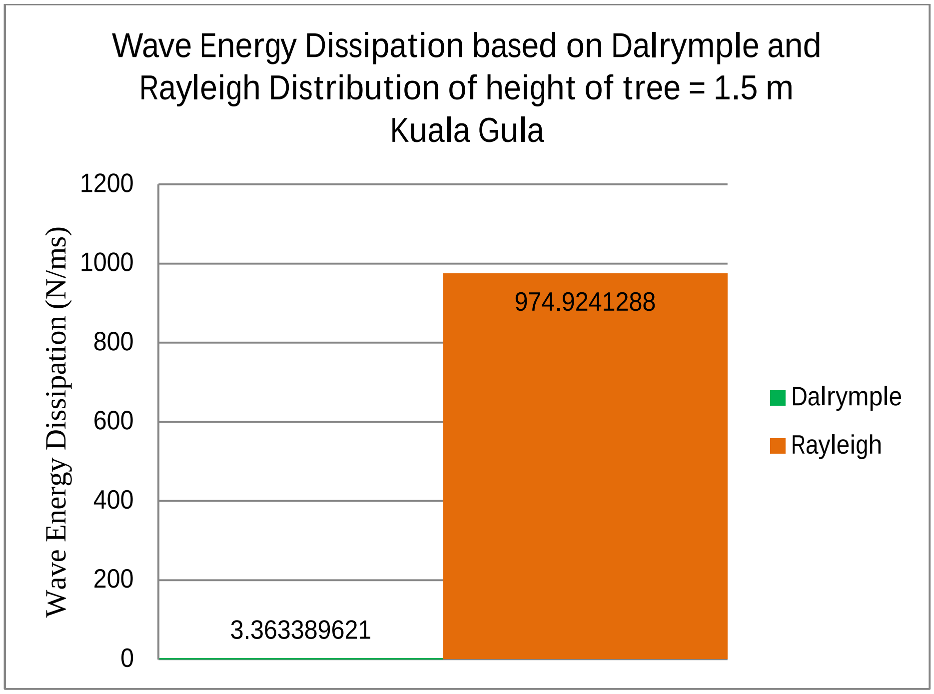


Figure 4.10 Wave Energy Dissipation based on Dalrymple and Rayleigh Distribution of height of tree = 1.5 m in Kuala Gula at depth = 0.42 m

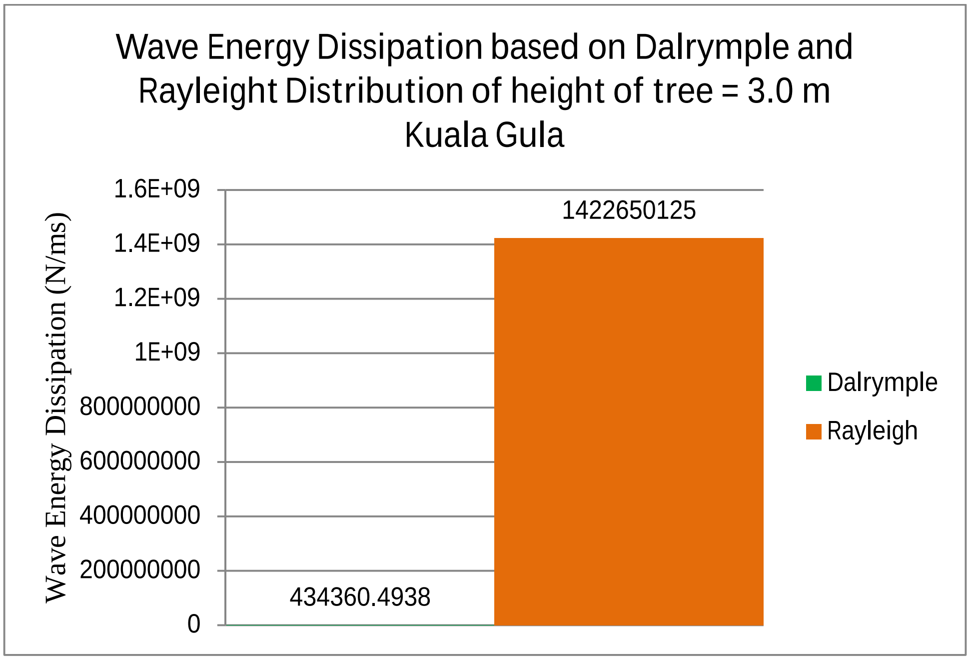


Figure 4.11 Wave Energy Dissipation based on Dalrymple and Rayleigh Distribution of height of tree = 3.5 m in Kuala Gula at depth = 0.42 m

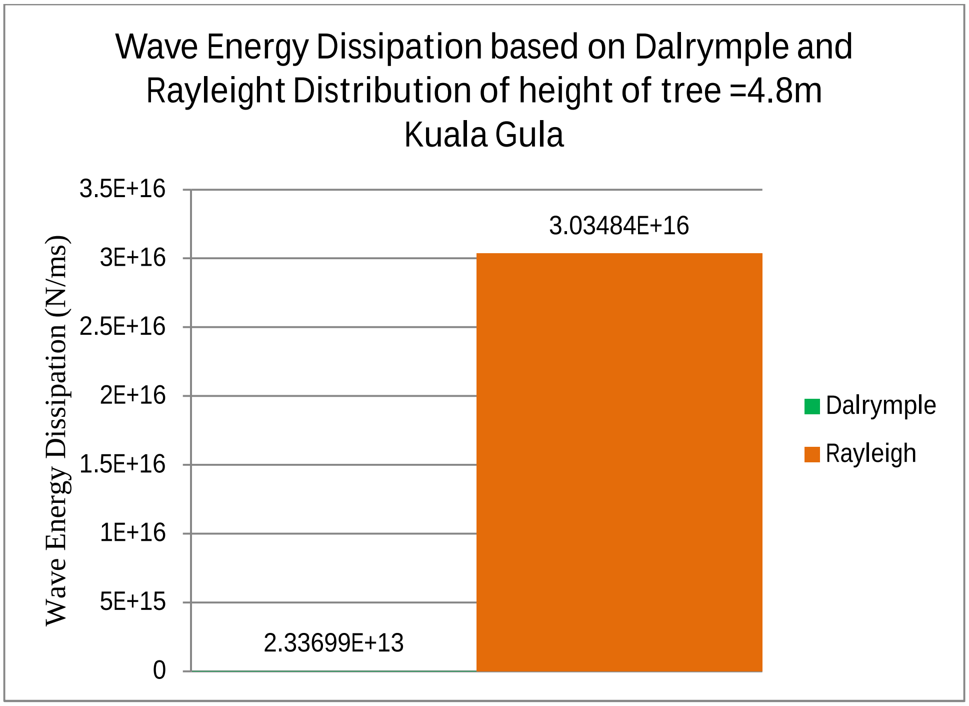


Figure 4.12 Wave Energy Dissipation based on Dalrymple and Rayleigh Distribution of height of tree =4.8 m in Kuala Gula at depth = 0.42 m

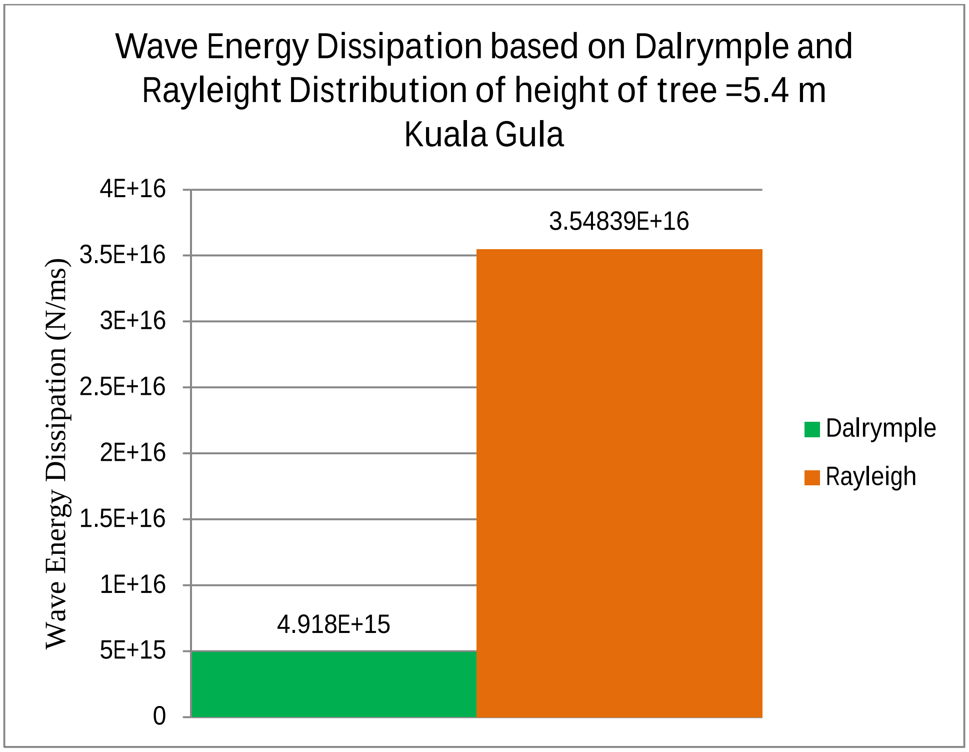


Figure 4.13 Wave Energy Dissipation based on Dalrymple and Rayleigh Distribution of height of tree = 5.4 m in Kuala Gula at depth = 0.42 m

b) At depth of water = 0.15 m

Table 4.8 Wave energy dissipate based on Dalrymple and Rayleigh distribution with d=0.15 m

Height of tree (m)	Wave energy dissipated, Ev (N/ms)	
	Dalrymple	**Rayleigh**
1.5	1.86×10^{4}	3.39×10^{4}
3	1.40×10^{13}	2.84×10^{14}
4.8	5.44×10^{23}	1.11×10^{24}
5.4	1.81×10^{23}	2.88×10^{27}

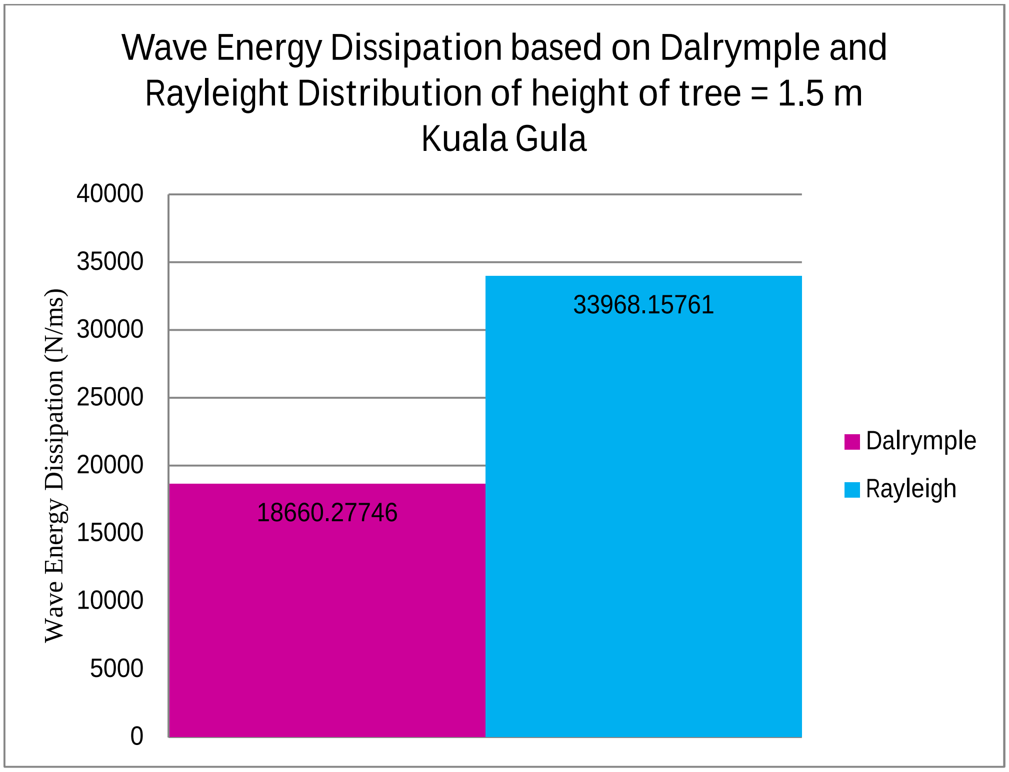


Figure 4.14. Wave Energy Dissipation based on Dalrymple and Rayleigh Distribution of height of tree = 1.5 m in Kuala Gula at depth = 0.15 m

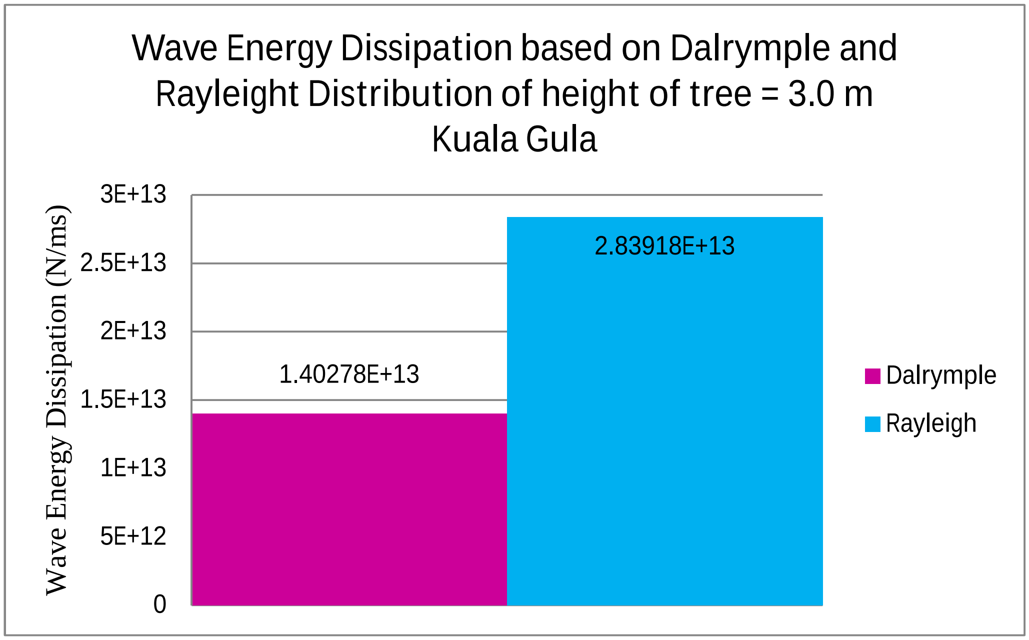


Figure 4.15 Wave Energy Dissipation based on Dalrymple and Rayleigh Distribution of height of tree = 3.0 m in Kuala Gula at depth = 0.15 m

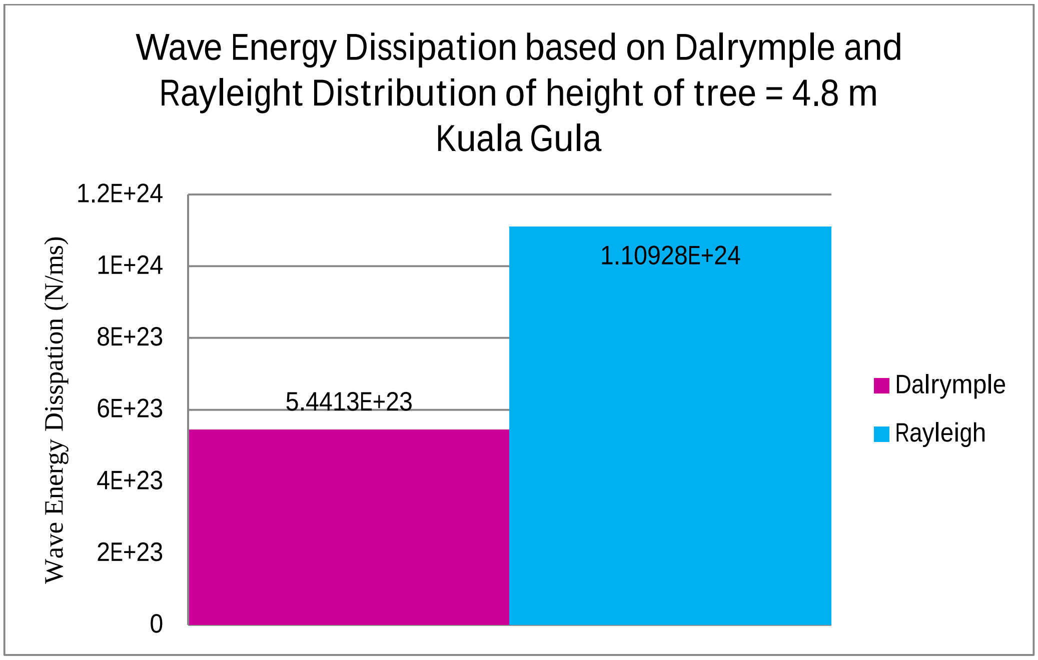


Figure 4.16 Wave Energy Dissipation based on Dalrymple and Rayleigh Distribution of height of tree = 4.8 m in Kuala Gula at depth = 0.42 m

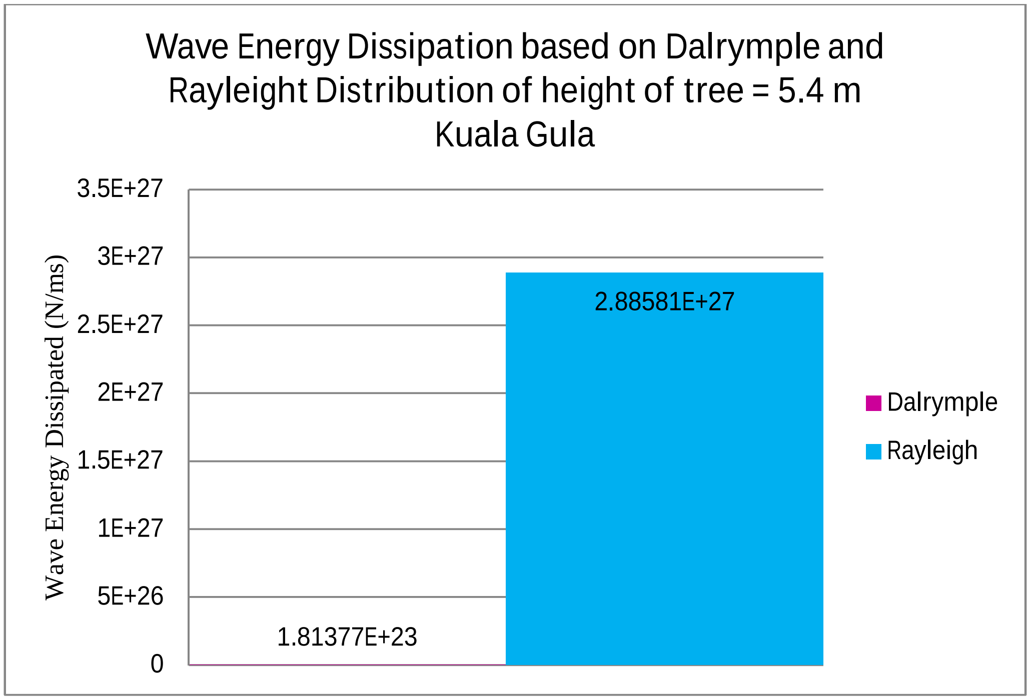


Figure 4.17 Wave Energy Dissipation based on Dalrymple and Rayleigh Distribution of height of tree = 5.4 m in Kuala Gula at depth = 0.42 m

Table 4.9 Comparison between wave energy dissipated by Dalrymple and Rayleigh distributions

Height of tree (m)	Wave energy dissipated, E_v (N/ms)			
	d = 0.42 m		d = 0.15 m	
	Dalrymple	Rayleigh	Dalrymple	Rayleigh
1.5	3.36	974.92	18660.28	33968.16
3.0	4.34×10^{5}	1.42×10^{9}	1.41×10^{13}	2.84×10^{13}
4.8	2.33×10^{13}	3.03×10^{16}	5.44×10^{23}	1.11×10^{24}
5.4	4.92×10^{15}	3.54×10^{16}	1.81×10^{23}	2.89×10^{27}

From the graph above, it can be seen that the wave energy dissipated by Rayleigh distribution is much higher compared to the wave energy dissipated by Dalrymple distribution. The difference between the wave energy dissipated by both Rayleigh and Dalrymple is very high. This can be explained by study of [18]. Rayleigh distribution focus more on the root mean square wave height, H_{rms} in the calculation meanwhile Dalrymple distribution only use the significant wave height, H_s at a particular period only. The value of H_{rms} can be very big compared to the value of H_s. In their study also, it was mentioned that the Rayleigh distribution of wave heights is applicable in narrow-banded field wave or the when wave spectral width parameter approaches zero which follows the wave energy spectrum. Rayleigh distribution is more suitable for deep-water conditions. Morever, the Dalrymple distribution is only valid for regular waves where the waves during site measurement in Kuala Gula and Pantai Lekir behave.

4.2 WAVE ATTENUATION IN PANTAI LEKIR

A. Field Measurement

Result shown below is obtained from the field measurement that has been conducted in natural mangrove forest of Pantai Lekir. Table below shows the measured wave height over some distances of vegetation (0 m, 3 m, 6 m, 9 m, and 12 m).

Table 4.10 Measured Wave height over distance of mangrove forest in Pantai Lekir

Forest band width, B_w (m)	Measured Wave height (cm)
0	25.1
3	18.5
6	14.5
9	12.7
12	8.2

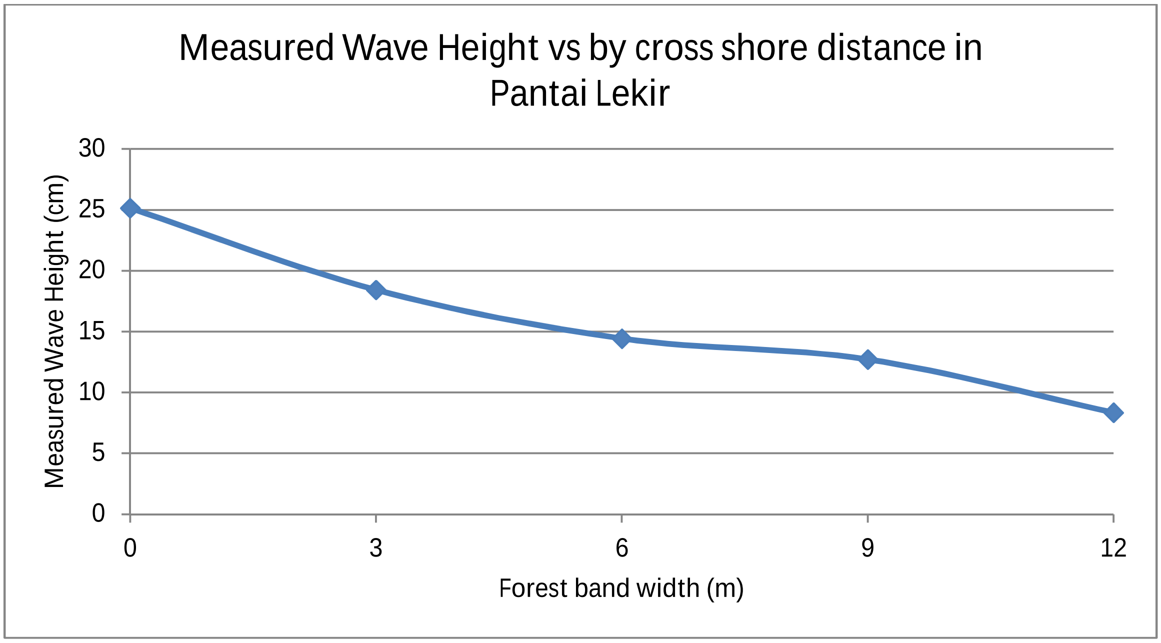


Figure 4.18 Measured Wave Height vs by cross shore distance in Pantai Lekir

Based on the Figure 33 above, the attenuation of waves happens as the waves go deeper through 12 m distance of mangrove forest with *Avicennia marina sp.* where it can be seen that the wave heights reduce.

The percentage of wave dissipation as the waves go through up until 12 m of mangrove forest is 67%.

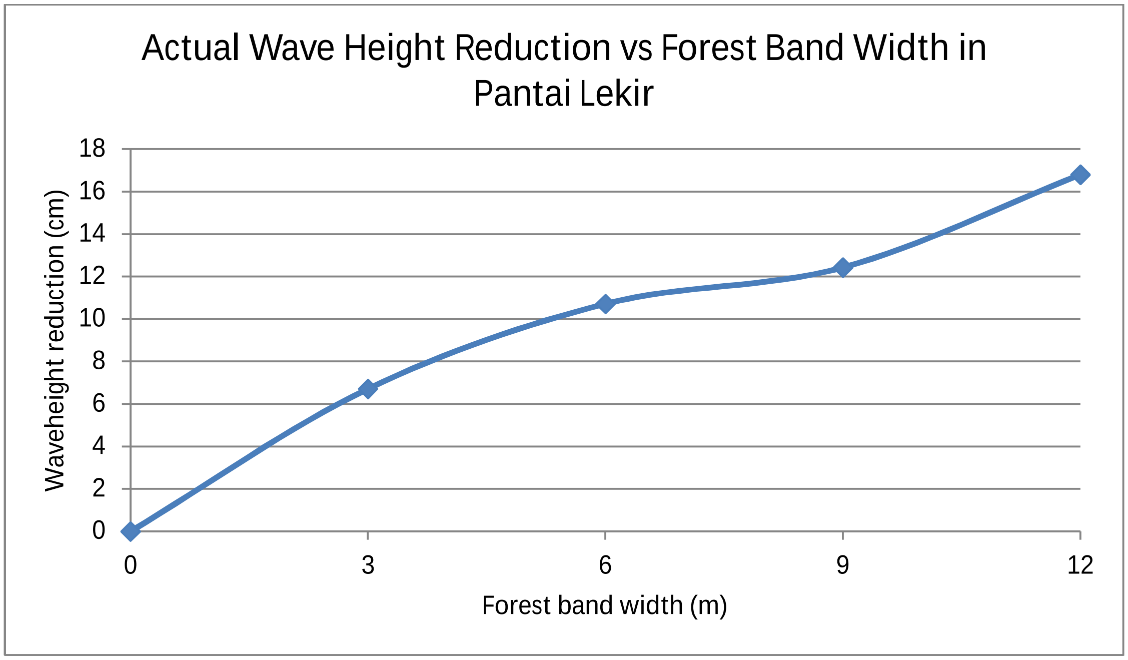


Figure 4.19 Actual Wave Height Reduction vs Forest Band Width in Pantai Lekir

The **Figure 4.19** above shows the wave height reduction and the pattern of the wave attenuation.

B. <u>Theoretical measurement</u>

Table showed below is the theoretical measurement of wave height based on Bao's equation; in equation (5).

For the calculation of the wave attenuation by mangroves, many important parameters have been collected and measured. In the measurement, mangrove forest band width remains as a manipulative factor for the whole calculation. The initial wave height, I_{wh} = 25.1 cm, the average height of tree, H = 3.2 m, the vegetation density, N = 900 tree/ hectare and the canopy closure, CC = 75 % are kept constant throughout the calculation.

Table 4.11 Theoretical wave height through distance of mangrove forest in Pantai Lekir

Forest band width, B_w (m)	Theoretical wave height, W_h (cm)
0	26.03
3	23.56
6	21.32
9	19.30
12	17.47

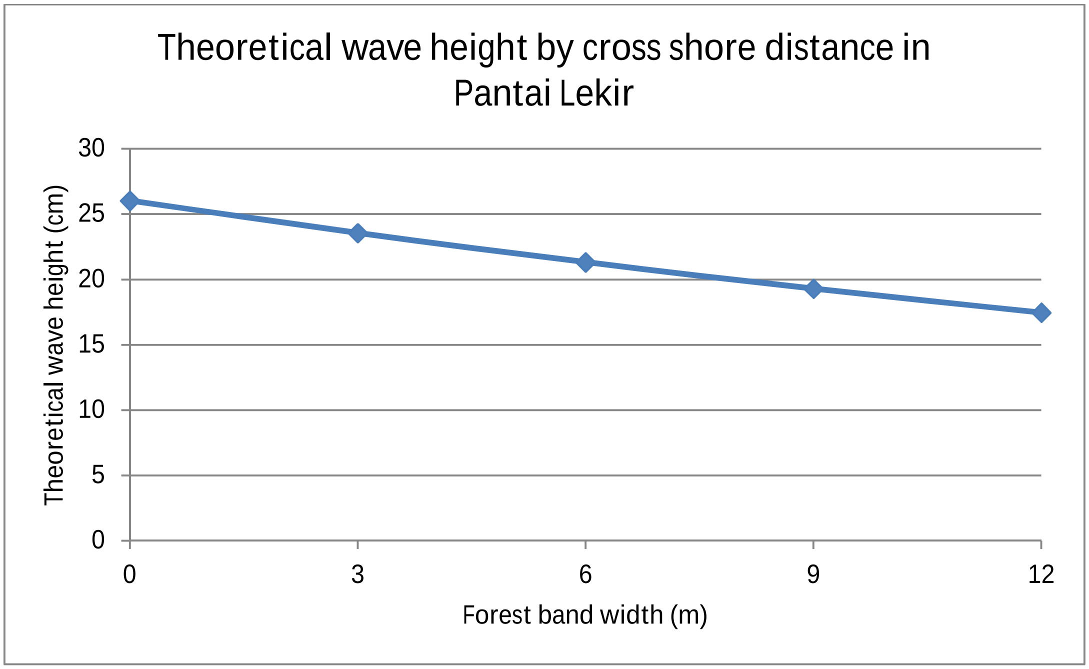


Figure 4.19 Theoretical wave height by cross shore distance in Pantai Lekir

From the theoretical result above, it can be seen that the wave height reduces linearly as the waves got through some distance of the mangrove forest. This finding is in parallel with results of wave attenuation by distance of mangrove forest by [7, 13, 16, and 19].

The percentage of attenuation as waves go through 12 m distance of mangrove forest is 33 %.

Table 4.12 Measured and Theoretical wave height through distance of mangrove forest in Pantai Lekir

Forest band width, B_w (m)	Wave height (cm)	
	Measured	Theoretical
0	25.1	26.03
3	18.5	23.56
6	14.5	21.32
9	12.7	19.30
12	8.2	17.47

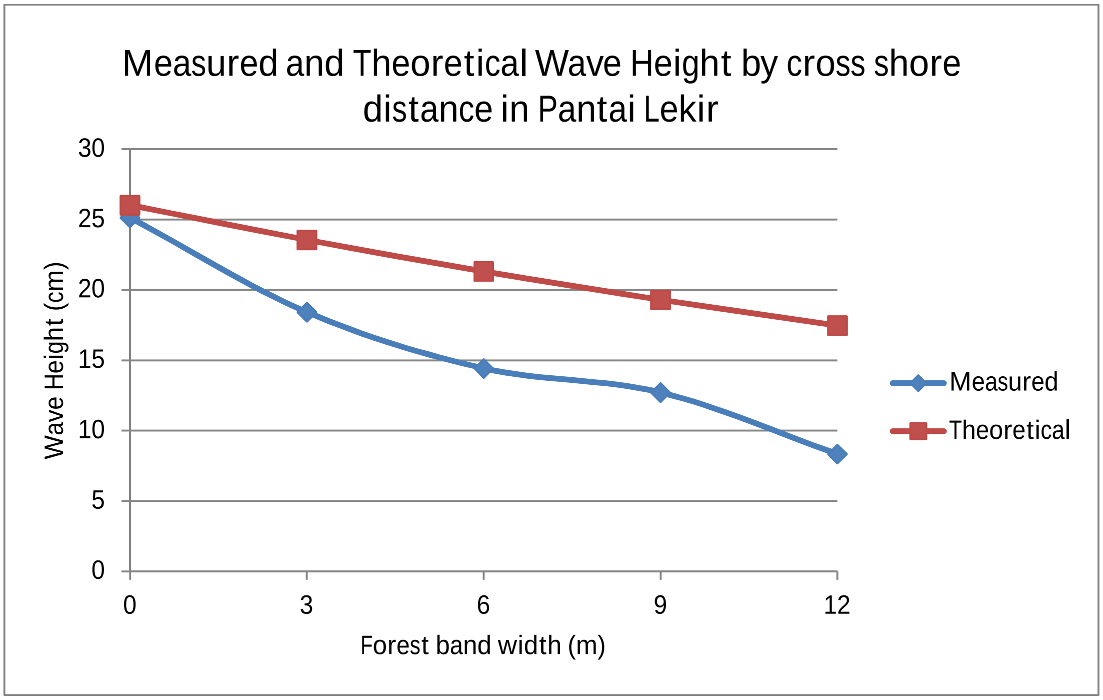


Figure 4.20 Measured and Theoretical Wave Height by cross shore distance in Pantai Lekir

The measured and theoretical wave heights by the cross shore distance in Pantai Lekir are of the same pattern and the difference between them is not high.

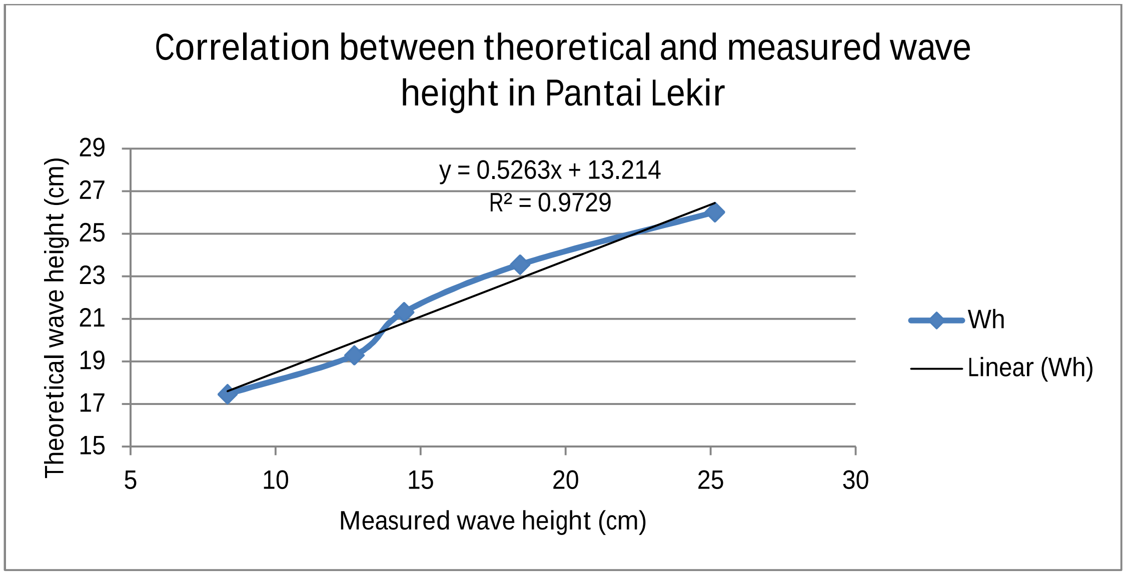


Figure 4.21 Correlation between theoretical and measured wave height in Pantai Lekir

Regression analysis has been done in Excel 2010 to validate the accuracy between theoretical values are compared with the actual data. It shows a high correlation between the measured and theoretical wave height whereby R^2 = 0.97 (R^2 > 0.95). However, there is still significance different of percentage wave attenuation through 12 m distance through a mangrove forest by measured and theoretical data which is 67% and 33%, respectively can be seen. This can be explained by Bao's equation. In his equation, few geometry parameters are not mentioned in his calculation such as the height of roots, density of roots of mangroves, width of roots. With the same condition as *Rhizophora apiculata sp.* in Kuala Gula, the importance of root is not highlighted in part of the calculation. In this context, the importance of roots can be highlighted as they are also the main factors in wave attenuation. The roots give large drag coefficient to act as resistance to wave attenuation. Based on [16], the pneumatophores and aerial roots of *Avicennia sp.* which project out of the ground can reach about 20 to 30 cm in height which can helps in wave attenuation. In Bao's equation, he emphasized on the trunk of the mangrove trees only. Based on [25], *Avicennia sp.* reduces wave height and currents by the root system, and together with its trunk. Greater wave energy will be dissipated when the mangrove trees are close to each other.

C. Wave attenuation at extreme condition

Extreme condition should be considered in studying the wave attenuation of by the mangrove forest. During extreme condition, the wave height can reach about 3.5 m with wind about 40-50 km/hour same as extreme condition in Kuala Gula, where it is dangerous for properties and people in coastal area of Pantai Lekir.

Prediction on wave height attenuation can be done by derivation in (6) of Bao's equation whereby the width of the mangrove forest can be known. Based on collected data on maximum wave heights in Pantai Lekir, the ranges of maximum wave height are from 1.0 m to 3.5 m. Therefore, 3.5 m wave height is used. The safe weight height is assumed about 30 cm based on fisherman in this area. The height of tree, the vegetation density and the canopy closure are kept constant which are 3.2 m, 900 trees/hectare and 75%, respectively.

Based on equation (6), the required band width of mangrove forest to dissipate 3.5 m waves is 0.5 m or 50 cm, where this value also is the same as in value for Kuala Gula. This finding is opposite with equation (5). Equation (5) shows that to achieve the safe wave height, H_{safe} = 30 cm, the required band width is should be about 70 m where it is opposite with the value obtained by equation (6) which is 0.5 m.

Based on [16], equation (5) and (6) above is applicable for data of small waves where wave heights less than 70 cm, therefore this equation can be used for the wave condition in Pantai Lekir as well. However, the equation is not applicable for extreme wave condition; Southwest Monsoon season.

Table 4.13 Predicted forest band width in Pantai Lekir

Forest band width, B_w (m)	Wave height (cm)
0	357.66
10	256.50
20	183.95
30	131.92
40	94.61
50	67.85
60	48.66
70	34.89
80	25.02

When the distance through the forest reaches about 80 m, the wave height is approximately 30 cm, where it is the safe condition for wave height. The percentage of attenuation at Bw = 80 m is about 90%. This result is closely related to the study by [25] whereby a 50-metre-wide belt of *Avicennia* is sufficient to reduce waves of 1 m to a height less than 30 cm in his observations in Sungai Besar, Selangor since these two places are closely located which is about 70 km.

From the result obtained, it can be seen that the wave attenuation occur.

Hence, this study has proved that;

1. Wave will attenuate after passing the mangroves forests.
2. Band width of forest is important to reduce wave energy.
3. Rayleigh distribution can be used in narrow-banded field wave or deep water instead of shallow water.
4. *Avicennia species* and *Rhizophora species* attenuates almost the same percentage of waves for Kuala Gula and Pantai Lekir despite they are having different height of tree which indicates different age.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Based on few previous studies, it is has been proven that mangrove forests are effective to dissipate wave attenuation compared to the area without mangrove forest. The wave impact on shoreline also is minimal in mangrove areas. However, further studies need to be conducted to obtain the optimal requirement of mangrove forest to dissipate wave energy.

Regression analysis has been used to estimate the forest band width to reduce attenuation about 90% to achieve safe wave height behind the forest which is 30 cm. The field measurement and studies have found that about 100 m of mangrove forest can reduced the wave attenuation by using Bao's equation although the structure of mangrove roots is not considered in the calculation.

This approach relies on extrapolating the data of wave beyond the measured wave height and this study has only been on tested in Malaysian mangrove and it is useful for the use of non-experts level.

Thus, more studies needs to be conducted so that in future, a developed mangrove management tools can be used to analyze wave dissipation by mangrove and this will ease for future studies and for future planning and management of mangrove re-plantation to ensure sustainability of the coastal area and the mangrove forest.

5.2 RECOMMENDATION

Based on the research, recommendations for future study can be done:

1. Make collaboration with FRIM/ Sahabat Bakau as they are specialize in mangrove research

2. Make variation of parameters to produce accurate results.

3. Site observation must be done first before doing site measurement to avoid inconveniences

4. More field and laboratory assessments are conducted to validate the empirical research.

REFERENCES

[1] S. Husrin. “Attenuation of Solitary Waves and Wave Trains by Coastal Forests,” doctoral dissertation, Faculty of Architecture, Civil Engineering and Environmental Sciences, University of Braunschweig – Institute of Technology, Braunschweig, Germany, 2013.

[2] M.F.I. Abdullah. “Roles of Mangrove in Coastal Protection,” degree dissertation, Department of Civil Engineering, Universiti Teknologi PETRONAS, Tronoh, Malaysia. 2010.

[3] Z. Hu, T. Suzuki, T. Zitman, W. Uittewaal, M. Stive. “Laboratory study on wave dissipation by vegetation in combined current–wave flow,” *Coastal Engineering, 88*, pp. 131-142. 2014

[4] The World Conservation Union (IUCN). (2006, October). Conservation Benefits of Mangroves. [Online]. Retrieved October 26, 2014 from http://cmsdata.iucn.org/downloads/sri_lanka_conservation_benefits_of_mangroves_1.pdf

[5] World Wildlife Fund. (2005, October). Mangroves Shielded Communities Against Tsunami. [Online]. Retrieved June 14, 2014 from www.sciencedaily.com/releases/2005/10/051028141252.htm

[6] C. Giri, E. Ochieng, L.L Tieszen, Z. Zhu, A. Singh, T. Loveland, J. Masek, N. Duke N (2011). Global distribution of mangroves forests of the world using earth observation satellite data. In Supplement to: Giri et al. (2011). Cambridge (UK): UNEP World Conservation Monitoring Centre. URL: data.unep-wcmc.org/datasets/21

[7] B. Burger. “Wave Attenuation in Mangrove Forests Numerical modeling of wave attenuation by implementation of a physical description of vegetation in SWAN,” Delft University of Technology, Delft, Netherlands, 2005.

[8] K. Kathiresan, N. Rajendran, “Coastal mangrove forests mitigated tsunami,” *Estuarine, Coastal and Shelf Science, 65*(3), pp. 601-606. 2005

[9] A Mitra. *Sensitivity of Mangrove Ecosystem to Changing Climate*. New Delhi: India, 2013.

[10] N.A. Aziz. O. Inayatullah. M.Z.M. Jusoh, “The mechanism of mangrove tree in wave energy propagation,” *Advanced Materials Research Vols. 614-615*, pp. 568-572. 2013

[11] H. Yanagisawa, S. Koshimura, K. Goto, T. Miyagi, F. Imamura, A. Ruangrassamee, C. Tanavud, “The reduction effects of mangrove forest on a tsunami based on field surveys at Pakarang Cape, Thailand and numerical analysis,” *Estuarine, Coastal and Shelf Science 81*, pp. 27–37. 2009

[12] Muliddin, S. R. Pudjaprasetya, S. Hadi, H. Latief. “Wave Energy Reduction in *Sonneratia* sp. Mangrove Forest,” *Applied Mathematical Sciences, Vol. 8, No. 96*, pp. 4749 – 4762, 2014.

[13] A. M. Hashim, S.M.P Catherine. “Effectiveness of mangrove forests in surface wave attenuation: A review,” *Research Journal of Applied Sciences, Engineering and Technology, 5(18),* pp. 4483-4488. 2013

[14] X. Lin, F. Peng, J. Huang, T. Zhang, S. Shi, T. Tang, “Isolation and characterization of RARE-1, a Ty1/copia-like retrotransposon domesticated in the genome of rhizophora apiculata,” *Biochemical Systematics and Ecology, 50,* 248-257. doi:10.1016/j.bse.2013.03.039. 2013

[15] W. Lu, L. Chen, W. Wang, N.F. Tam, G. Lin, “Effects of sea level rise on mangrove Avicennia population growth, colonization and establishment: Evidence from a field survey and greenhouse manipulation experiment,” *Acta Oecologica* 49, pp. 83-91. 2013.

[16] A.L. McIvor, I. Moller, T. Spenser, M. Spalding. (2012), “Reduction of Wind and Swell Waves by Mangroves,” *Natural Coastal Protection Series: Report 1. Cambridge Coastal Research Unit Working Paper 40. Published by the Nature Conservancy and Wetlands International. 27 pages. ISSN 2050-7941*. 2012.

[17] F. J. Mendez, I.J Losada, “An empirical model to estimate the propagation of random breaking and nonbreaking waves over vegetation fields.” Coastal Eng., 51(2), 103–118. 2004.

[18] Q. Chen, H. Zhao, “Theoretical Models for Wave Energy Dissipation Caused by Vegetation,” *J. Eng. Mech*..138, pp. 221-229. 2012

[19] T. Bao. “Effect of mangrove forest structures on wave attenuation in coastal Vietnam,” *Oceanologia*, 53(3), 807-818. doi:10.5697/oc.53-3.807. 2011.

[20] S. Narayan, T. Suzuki, M.J.F Stive, H.J Verhagen, W.N.J Ursem, R. Ranasinghe, *“On the effectiveness of mangroves in attenuating cyclone-induced waves”*. Proceedings of the Coastal Engineering Conference. 2010.

[21] Z. Azizi, A. Najafi, H. Sohrabi. “Forest Canopy Density Estimationg, Using Satellite Images,”. *The International Archieves of the Photogrammetry Remote Sensing and Spatial Information Science. Vol XXXVII. Part B8*. Beijing. 2008.

[22] Agriculture, Fisheries and Conservation Department Conservation Branch, “Measurement of Diameter at Breast Height (DBH),” *Nature Conservation Practice Note No. 02*, pp. 1-6. 2006.

[23] L. Korhonen, K.T. Korhonen, M. Rautiainen and P. Stenberg, “Estimation of Forest Canopy Cover: a Comparison of Field Measurement Techniques,” *Silva Fennica* 40(4), pp. 577–588. 2006.

[24] S.B. Jennings, N.D. Brown, D. Shied. “Assessing forest canopy and understory illumination: canopy closure, canopy cover and other measures,” *Forestry, Vol. 72(1). 1999*

[25] G. Prasetya. (n.d). The role of coastal forests and trees in protecting against coastal erosion. [Online]. Available: http://www.fao.org/docrep/010/ag127e/ag127e09.htm