EVALUATION OF MANGROVE FOREST FUNCTION IN REDUCING WAVES CURRENTS USING PHYSICAL MODELS

by

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2024

DECLARATION

I declare that this thesis entitled “Evaluation of Mangrove Forest Function in Reducing Waves Currents Using a Physical Models” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Date : 10 June 2024

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Evaluation of Mangrove Forest Function in Reducing Waves Currents Using a Physical Models

ABSTRACT

Mangroves are essential for coastal protection because they attenuate wave forces and lower wave heights, protecting coastlines from erosion and catastrophic weather events. A study was conducted to evaluate the efficiency of mangrove forests in reducing wave currents using physical modelling techniques. The main aim is to measure wave height reduction at different levels of mangrove density and to study the influence of various tree arrangements on wave attenuation. Several controlled tests were carried out in tanks to simulate different wave pressures on mangrove plant densities. Wave height measurements were carried out before and after the wave passage through the mangrove model. The results show a strong relationship between mangrove density and wave height reduction. Furthermore, the configuration of mangroves, such as random vs. in-line arrangement patterns, affected the degree of wave attenuation. Nevertheless, the random arrangement pattern shows more effectiveness than the in-line arrangement in reducing the wave pressure. The results highlight the importance of mangroves' density and geographic distribution in enhancing coastal areas' ability to withstand wave impacts. This research offers valuable insights for coastal management and restoration programs that seek to optimize the protective function of mangrove ecosystems. Therefore, this model can also be applied to educating young people about the importance of mangrove forests for coastal conservation.

Penilaian Fungsi Hutan Bakau dalam Mengurangkan Arus Ombak Menggunakan Model Fizikal

ABSTRAK

Hutan Bakau adalah penting untuk perlindungan pantai kerana ia melemahkan daya ombak dan ketinggian ombak yang lebih rendah, melindungi garis pantai daripada hakisan dan peristiwa cuaca bencana. Kajian telah dijalankan untuk menilai kecekapan hutan bakau dalam mengurangkan arus ombak menggunakan teknik pemodelan fizikal. Matlamat utama adalah untuk mengukur pengurangan ketinggian ombak pada tahap ketumpatan bakau yang berbeza dan untuk mengkaji pengaruh pelbagai susunan pokok terhadap pengecilan ombak. Beberapa ujian terkawal telah dijalankan dalam tangki untuk mensimulasikan tekanan gelombang yang berbeza pada kepadatan tumbuhan bakau. Pengukuran ketinggian ombak telah dijalankan sebelum dan selepas laluan ombak melalui model bakau. Keputusan menunjukkan hubungan yang kuat antara ketumpatan bakau dan pengurangan ketinggian gelombang. Tambahan pula, konfigurasi bakau, seperti corak susunan rawak dan sebaris, mempengaruhi tahap pengecilan gelombang. Namun begitu, corak susunan rawak menunjukkan lebih keberkesanan berbanding susunan dalam talian dalam mengurangkan tekanan gelombang. Hasilnya menyerlahkan kepentingan kepadatan bakau dan taburan geografi dalam meningkatkan keupayaan kawasan pantai untuk menahan kesan ombak. Penyelidikan ini menawarkan pandangan berharga untuk pengurusan pantai dan program pemulihan yang berusaha untuk mengoptimumkan fungsi perlindungan ekosistem bakau. Oleh itu, model ini juga boleh diaplikasikan untuk mendidik golongan muda tentang kepentingan hutan bakau untuk pemuliharaan pantai.

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LIST OF ABBREVIATIONS

m/s	Metre per second
m	Meters
cm	Centimetre
mm	Millimetre

LIST OF SYMBOLS

%	Percentage
x	Multiply

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Mangrove forests is characterized by their unique adaptation to intertidal zones, play a crucial role in coastal ecosystems. These ecosystems provide myriad ecological services, one of which is the attenuation of wave currents. Coastal areas are susceptible to the impact of waves and currents, leading to erosion, sediment transport, and increased vulnerability to storm surges. Understanding the role of mangrove forests in reducing wave currents is essential for coastal management and developing sustainable strategies to mitigate the adverse effects of these natural processes (Venkateswarlu et al., 2023).

Various studies have highlighted the protective functions of mangrove ecosystems, emphasizing their ability to dissipate wave energy and reduce the velocity of tidal currents (Ihinegbu et al., 2023). However, a comprehensive understanding of the specific mechanisms through which mangroves achieve these effects is still evolving. While numerical and theoretical studies have contributed valuable insights, physical models offer a unique opportunity to simulate complex interactions between mangrove vegetation and wave currents under controlled conditions.

The background of this study is grounded in the need for a more detailed and empirical examination of the wave-reducing function of mangrove forests. Physical models allow for the manipulation of critical variables, such as mangrove density, species composition, and canopy structure, providing a controlled environment to quantify the impact of these factors on wave dynamics. By bridging the gap between theoretical understanding and practical application, this research aims to contribute to the growing knowledge of mangrove ecology and its implications for coastal resilience (Devi et al., 2021).

Furthermore, with the increasing threats to mangrove ecosystems globally, including habitat loss, pollution, and climate change, a more profound comprehension of their role in reducing wave currents becomes imperative (Bindiya et al., 2023). This study seeks to contextualize mangrove functions within the broader scope of coastal management, emphasizing the potential of these ecosystems as natural solutions for mitigating the impacts of wave energy and promoting sustainable coastal development.

1.2 PROBLEM STATEMENT

The vital role of mangrove forests in attenuating waves and currents remains a subject of considerable interest due to their potential contribution to coastal protection. Despite numerous studies highlighting the importance of mangroves, there is a need for a comprehensive evaluation of their function in reducing wave currents using physical models. The quantitative effects of mangrove vegetation characteristics are still poorly understood. The existing literature provides valuable insights, but a gap exists in understanding the specific mechanisms through which mangrove forests influence wave dynamics. This research addresses this gap by employing physical models to simulate and analyse the intricate interactions between mangrove vegetation density and different percentage of wave currents. Through a systematic investigation, the study seeks to quantify the effectiveness of mangrove forests in reducing wave heights and currents, providing essential information for coastal management and sustainable mitigation strategies.

1.3 OBJECTIVE

This study aimed:

i. To quantify the wave height reduction with various mangrove densities

ii. To study the influence of tree arrangements on wave reduction through physical model settings

1.4 SCOPE OF STUDY

The physical model was built with several different situations of mangrove ecosystem. Different parameter in tree density and wave energy was set to record the impact of intensity of waves coming into the sea before hitting the coastline using physical model. Test was done in a tank and control environment.

1.5 SIGNIFICANT OF STUDY

Mangrove habitats are acknowledged for their ecological significance, especially in coastal regions, where they serve as innate obstacles against wave energy and aid in stabilizing shorelines. Nevertheless, a thorough and measurable evaluation of their efficacy in diminishing wave currents must be done. The study aims to get practical insights to inform future attempts to rehabilitate and preserve mangroves. The research seeks to enhance our understanding of how various characteristics affect the ability of mangroves to act as wave barriers. This knowledge is valuable in developing specific conservation strategies and improving the outcomes of restoration projects, ultimately supporting sustainable coastal management practices. The study is significance as its capacity to enhance comprehension of mangrove forests' function in reducing wave currents, employing physical models as a reliable investigative instrument as said in Ismail et al. (2022).

The importance of this study is to emphasis the use of physical models to obtain accurate and empirical information about the influence of mangrove forests on wave dynamics. The results have practical consequences for the management of coastal areas, providing valuable information on the ideal qualities of mangroves. This knowledge may be used to develop effective conservation strategies and guide future restoration projects. Given the growing risks posed by climate change and human actions to coastal areas, it is crucial to comprehend the measurable advantages of mangrove forests in mitigating wave currents. This knowledge is essential for advocating sustainable coastal resilience and developing evidence-based policies to protect and restore these crucial ecosystems.

CHAPTER 2

LITERATURE REVIEW

2.1 Importance of Mangrove Forests

Awang et al., (1999) highlighted the importance of mangroves as a valuable natural asset in coastal areas. Although mangroves may have slowed growth and faced competition from faster-growing mesophotic tropical vegetation in non-saline places (Jan de Voz, 2004), it is widely recognized as one of the most productive ecosystems on Earth. The high growth rate found in this ecosystem makes it suitable for use as a coastal protection measure. Better efficiency leads to rapid growth of mangroves, resulting in better coastal protection in a relatively short period. Figure 1 shows the state of wave currents when there are mangrove forests and when there are none.

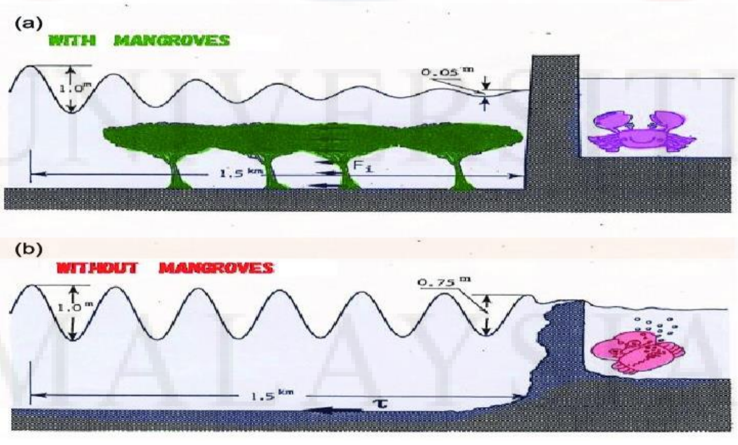


Figure 2.1 shows wave current with and without passing mangroves forests (Jan de Voz, 2004)

2.2 Impacts of Mangrove on Surrounding Ecosystems

In addition to their ability to facilitate sedimentation and reduce wave energy, mangrove forests substantially influence adjacent ecosystems, and this interaction reciprocally affects their survival and ecological functionality. Mangroves prevent sediment from dispersing widely into the open sea by trapping it within their swamps. In turn, it promotes clear water conditions conducive to the habitation of organisms like coral reefs. The clarity of the water is also instrumental in enhancing the efficiency of the photosynthesis process for seagrasses, particularly in comparison to environments with high turbidity. Furthermore, mangroves contribute essential nutrients to seagrass beds, with studies by Buillon et al. (2004) estimating that 21-71% of the sedimentary organic matter pool in various seagrass beds originates from mangrove forests.

2.3 The Functions of Mangroves in Reducing Wave Energy

Hadi et al. (2003) in his study showed that mangroves are crucial for marine habitats, shoreline stabilization and protection of living beings and belongings involved in coastal life. It is based on the property of mangroves to reduce wave current speed because velocities within a matter are rarely over 0.1m/s while these generally exceed 1 m/s outside.

Mangrove forests contribute to soil stabilization along coastal areas by reducing wave current velocity, preventing coastal erosion, and distributing runoff water. Unlike traditional engineering solutions like breakwaters and seawalls, mangroves do not disrupt natural coastal processes, avoiding erosion, damage to marine ecosystems, and water pollution. Furthermore, the cost of planting and maintaining mangrove trees is significantly lower than implementing engineering solutions.

The mangroves' most outstanding feature of coastal erosion is that they helped during the December 26, 2004 tsunami disaster. The fact that the two low-relief islands of Andaman and Nicobar Islands, as well as Tamil Nadu in India, are characterized by numerous mangrove coastal forests is crucial because, despite their violent tsunami waves, there have only few deaths and less property damage compared to other areas (Osti et al., 2008). It highlights the role of mangrove forests in protecting against large waves, regardless if they are tsunami or rainstorm-like events, with effectiveness depending on variables such as density and width over time. The visual explanation is as Figure 2.2.

Wave energy dissipation efficiency depends on mangrove tree maturity. Compared to young trees, sufficiently tall mangrove trees may not reduce wave energy and the rates can reach up to 20% per every hundred meters (Jan de Voz, 2014). However, even young mangroves that are only five years old can be very good wave suppressors if closely clumped and tall enough (Othman, 1991).

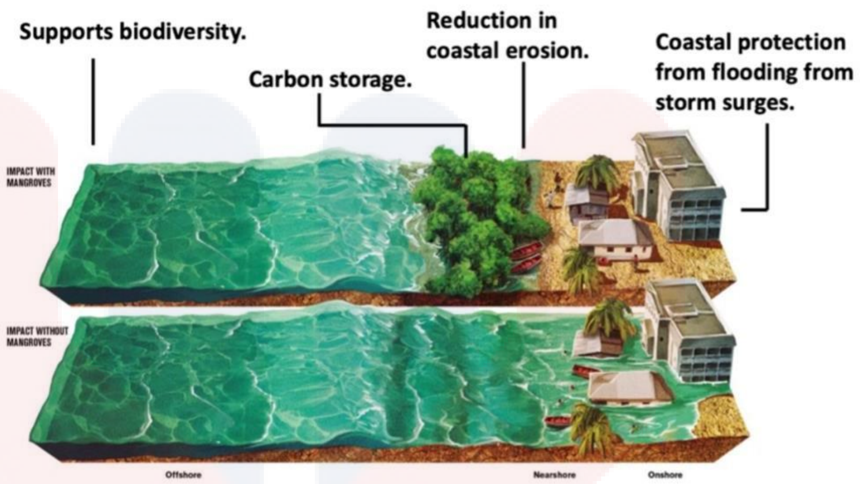


Figure 2.2 Function of mangrove forest on coastal protection explain in visual (Osti et al., 2008)

The depth of seawater influences the impact of mangroves on wave attenuation. Exposed roots exert a more significant drag force in shallow water, while pneumatophores effectively dissipate small waves in combination with low water levels (Jan de Voz, 2004). Roots are less influential in deeper water, and the canopy becomes more crucial, particularly during storms with high water levels (Burger, 2005).

Research indicates that there is less attenuation for longer-period waves, such as swells, rather than the short-period types of locally generated wind waves, which experience a large amount of energy dissipated during interactions with vegetation (Brinkman 1999: Burger.2005). Even more, longer waves do not show as much velocity variation compared to smaller waves, thus resulting in higher energy dissipation for shorter wavelengths. More enormous wave amplitudes also increase the wave energy absorbed due to more pronounced interaction with vegetation in greater influence depth (Burger, 2005).

In cases of water level increase, wave energy may last longer in the forest due to reduced drag force. However, this does not necessarily mean less wave attenuation; it may be higher with increased mangrove density, even in deeper water (Massel et al., 1999).

Understanding these dynamics is crucial for accurately assessing the protective role of mangroves in coastal areas, especially during high water levels, such as during severe storms. Figure 2.3 shows the advantages of mangrove forests that can be used as ecosystem services.

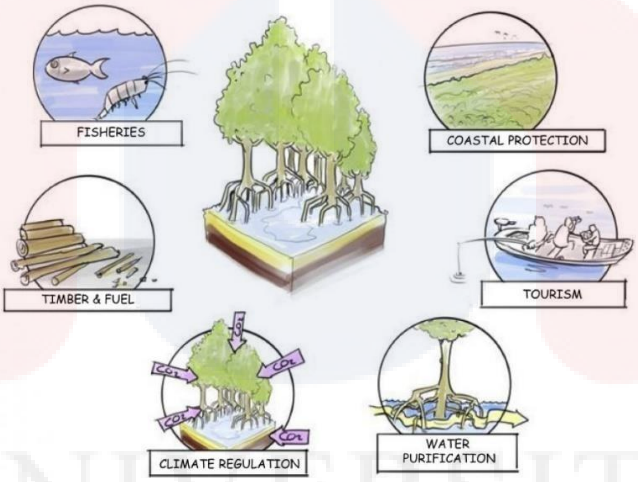


Figure 2.3: Ecosystem Services of mangroves forests (Jan de Voz, 2004)

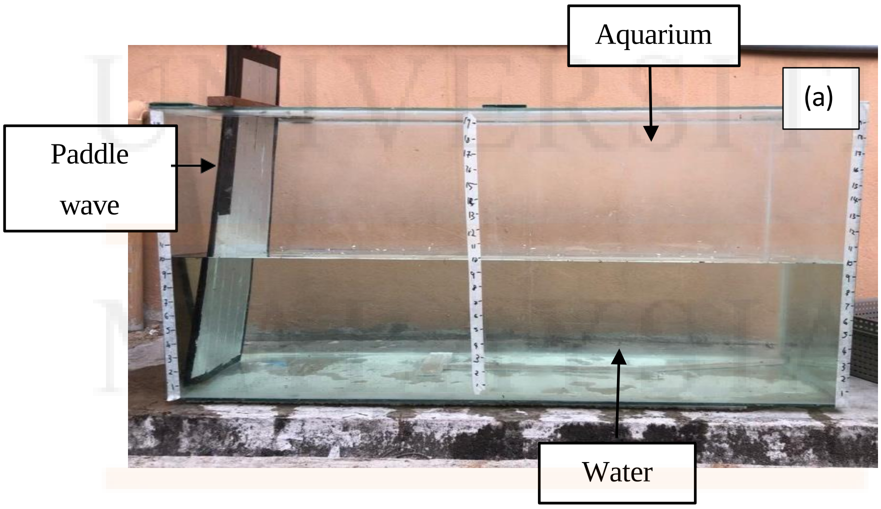
CHAPTER 3

MATERIALS AND METHOD

3.1 Physical Model Development

The physical model for this study was set and established using tree miniatures, sand and soil and the trees are arranged in random and in-line with three different densities of sparse, median, and dense. Tree miniatures was used to imitate mangrove trees in real condition and soil was used as the base.

The size of the aquarium for model setting is 1.22 meters long, 0.43 meters wide and 0.52 meters height. Flood currents and waves is prepared using wave gauge paddles following Hashim & Catherine (2013). Figure 3.1 show the actual and sketched physical model used in this study.



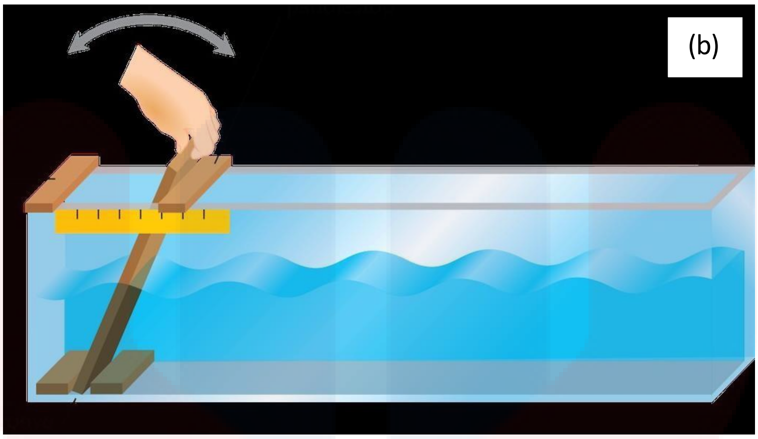


Figure 3.1: (a) Real physical model (b) sketch of physical model use in this study

3.2 Method

This study utilizes aquarium-like box as the experimental setting, where a model is carefully constructed of approximately 1.22m x 0.43m x 0.53m. The model employs sand as its base, and mangrove tree miniature were created from tree branches and rattan-like branches. The tree miniatures were arranged in a container filled with soil in dimension of 30 cm long and 30 cm wide. The containers have three types of tree densities: sparse, median, and dense. Each density is arranged differently, which is in-line and random arrangement. The choice of holes in the model for inserting trees is random, and the average diameter of the tree miniatures is 0.05 mm. A scheming led to the decision of incorporate 47 trees in the model that simulates a high-density mangrove forest, 32 trees for medium-density and 15 trees for low-density is following the suggestion by Hadi et al. (2003) as shown in Figure 3.2.

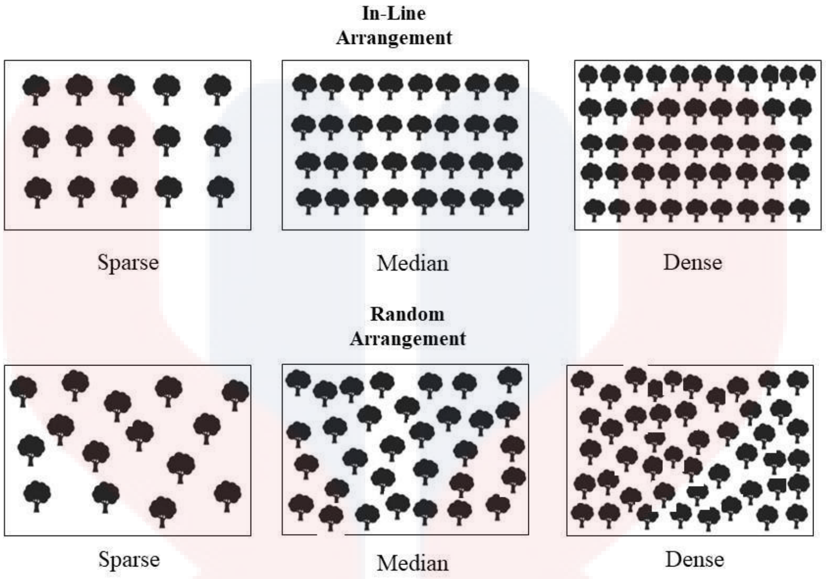


Figure 3.2: Arrangement of the tree miniatures for in-line and random with different tree densities

Subsequently, wave height and attenuation testing was conducted using a paddle. The paddler was rowed to create a wave height according to inches, where low currents create a move of paddle at 2 inches, 5 inches for medium currents and 7 inches for high currents. The simulation was done at different settings as show in Figure 3.3.

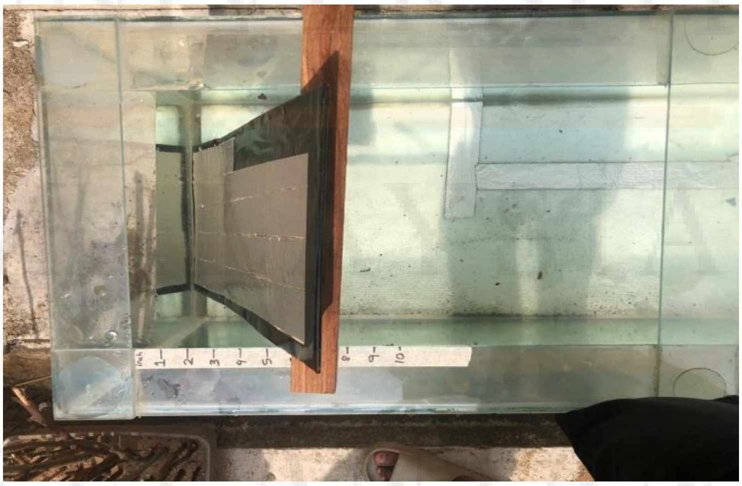


Figure 3.3: Gauge paddle use to generate wave height (above view)

The wave height were examined with and without using any mangrove density. Throughout the tests, wave height before and after passing the mangrove trees miniatures were recorded. Parameters that were tested in this study are shown in Table 3.1.

Table 3.1: Parameters that was tested in physical mangrove model

Settings	Tree density and arrangement	Tides category	Observation
With mangrove	Mangrove density: • Sparse • Median • Dense Mangrove arrangement: • In-line • Random	Tides/Currents: • Low • Medium • High	Record the impact of different situation before and after passing through different tree density/arrangements
Without mangrove	-		

Impact of tides produced from paddle movements with different situation were observed and recorded. The flow of the study is shown in Figure 3.4 and the interpretation of the findings is discussed in the Chapter 4 of this study. Simulation video could be access from (https://acesse.one/BjnyF) after QR code below:

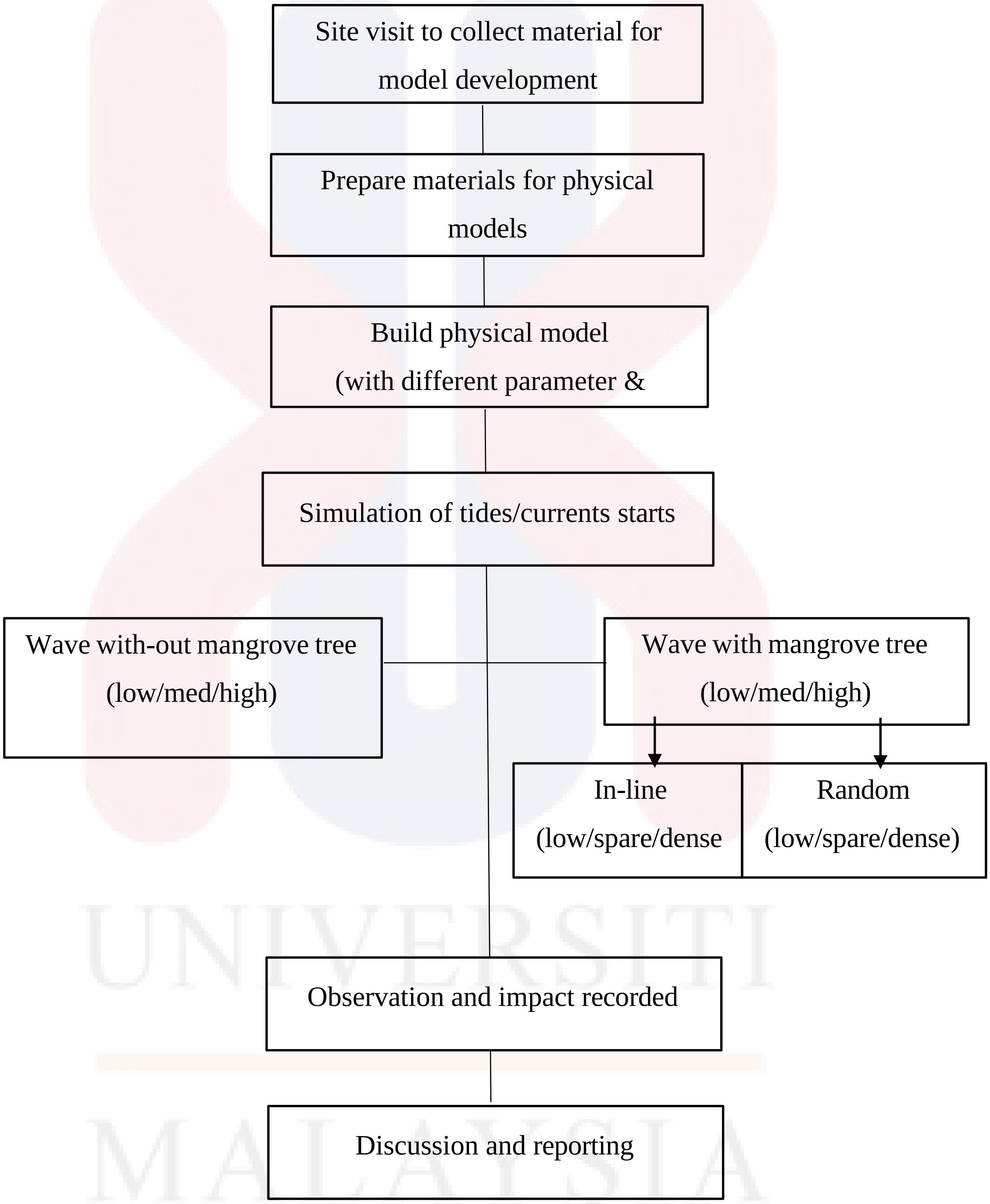


Figure 3.4: The flow of the study

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Wave Height Reduction with Various Mangrove Densities

Table 4.1 shows the wave height of with and without using any mangrove density. It also compares the efficiency of in-line and random tree arrangements on sparse mangrove setup with 15 trees for sparse density, 32 trees for median density and 47 trees for dense density.

Table 4.1: Result for In-Line and Random Arrangements

(cm)	In-line Tree Arrangement			Random Tree Arrangement			Without Mangroves
Wave Condition	Sparse	Median	Dense	Sparse	Median	Dense	
Low	15.2	14.0	12.7	14.0	12.7	12.7	15.2
Medium	17.8	15.2	12.7	17.8	13.2	12.7	17.8
High	20.3	17.8	12.7	20.3	15.2	12.7	20.3

Significant variations in wave heights at different tidal phases exist in a sparse mangrove setup consisting of 15 trees, depending on whether the trees are arranged in-line or randomly. During low tide, the in-line arrangement generated waves of 15.2 cm in height, surpassing the 14 cm observed for the random configuration. This suggests that the in-line structure was less successful in reducing wave height. Both layouts exhibited a wave height of 17.8 cm during medium tide, indicating comparable efficacy in reducing wave height. Both setups consistently measured a wave height of 20.3 cm during high tide, indicating reliable functioning. The average wave height for the in-line design was 17.8 cm, slightly more significant than the 17.4 cm for the random pattern. This suggests that the random layout has a tiny edge in reducing wave height. The flexible structure of mangroves, which absorbs and scatters wave energy, is essential in reducing the intensity of waves (Shu, 2023).

Among median density mangrove layouts consisting of 32 trees, the random layout demonstrated more efficacy in reducing wave height during low tide, measuring 12.7 cm compared to the 14 cm recorded by the in-line design. Both layouts exhibited a wave height of 15.2 cm during medium tide, suggesting comparable performance. During high tide, the random layout outperformed the in-line design with a wave height of 15.2 cm, compared to 17.8 cm. The average wave height for the in-line layout was 15.7 cm, whereas the random arrangement had a lower average of 14.4 cm. This suggests that the random construction is more effective at reducing wave height under various tidal situations. The effectiveness of median-density mangroves in disrupting wave movement is attributable to their improved root network.

Within thick mangrove environments consisting of 47 trees, both in-line and random arrangements, they exhibited identical wave heights of 12.7 cm during low tide, indicating comparable levels of wave energy dissipation. During medium tide, the random pattern proved more efficient, measuring a wave height of 12.7 cm, whilst the in-line design recorded a height of 14 cm. Both setups exhibited identical wave heights of 12.7 cm during high tide. The average wave height for the in-line design was 13.1 cm, slightly more significant than the random pattern of 12.7 cm. This suggests that the random layout consistently performed well. Mangrove trees, with their dense foliage, exert substantial resistance and friction, decreasing wave velocity and energy dissipation, ultimately leading to a noticeable drop in wave height (Masaya Yoshikai, 2022). In some studies, dense and young mangrove trees can be very good wave suppressors if closely clumped and tall enough (Othman, 1991).

In the absence of mangroves, wave height measurements exhibited notably greater values, measuring 15.2 cm during low tide, 17.8 cm during medium tide, and 20.3 cm during high tide. The mean wave height in the absence of mangroves was 17.8 cm. The results emphasise the significance of mangroves in safeguarding coastal regions by consistently decreasing wave heights under different tidal situations. This highlights their efficacy in reducing wave energy and shielding coastal areas from negative impacts (Bijsterveldt, 2023).

4.2 Influence of Tree Arrangements on Wave Reduction

Figure 4.1 depicts the impact of tree configurations on wave attenuation, specifically comparing linear and random layouts across various mangrove densities (sparse, median, and dense) and tidal circumstances (low, medium, and high tides). The data reveals clear patterns in the decrease of wave height based on the placement and density of trees.

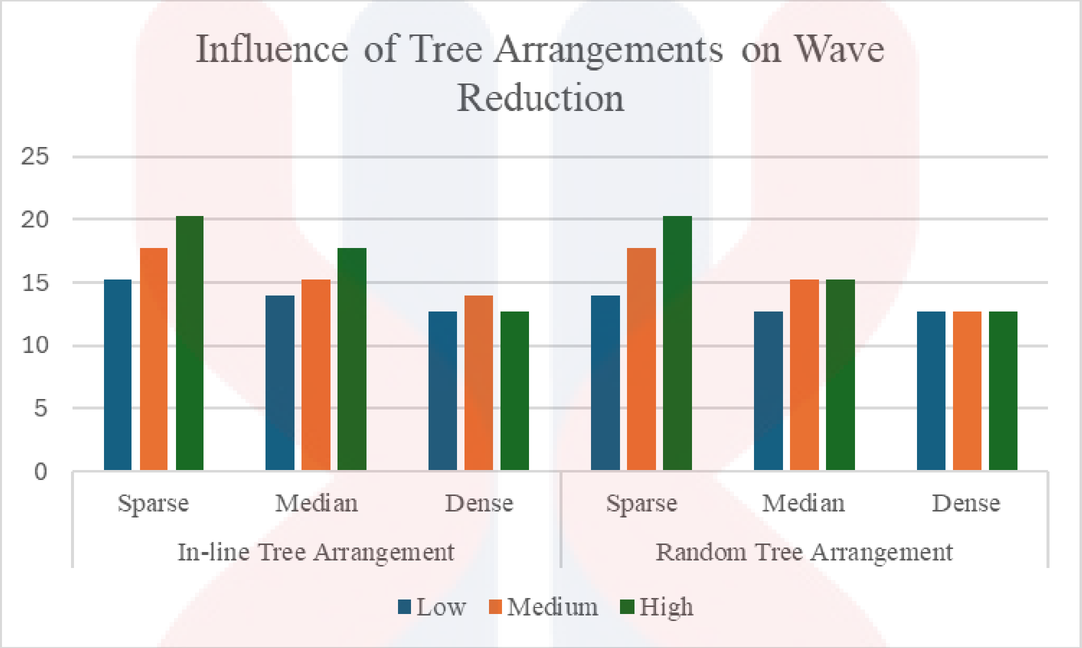


Figure 4.1: Influence of Tree Arrangements on Wave Reduction

The wave heights recorded for a sparse density trees were 15.2 cm at low tide, 17.8 cm at medium tide, and 20.3 cm at high tide. Conversely, the haphazard configuration led to wave heights of 14 cm during low tide, 17.8 cm during medium tide, and 20.3 cm during high tide. These findings indicate that the random structure is more efficient in decreasing wave height during low tide than the in-line arrangement. Nevertheless, both layouts exhibit comparable performance during medium and high tides, suggesting that the arrangement has minimal impact on reducing wave height under more intense tidal circumstances when the density is low.

In the median density configuration of 32 trees, the wave heights were measured to be 14 cm at low tide, 15.2 cm during medium tide, and 17.8 cm during high tide in the in-line arrangement. The random configuration exhibited superior performance when subjected to wave heights of 12.7 cm during low tide, 15.2 cm during medium tide, and 15.2 cm during high tide. The random layout consistently exhibits a significant decrease in wave height, especially during low and high tides, compared to the in-line configuration. This suggests that the random setup's complex root network and tree structure improve wave attenuation by more effectively interrupting the passage of waves.

In-line and random configurations of 47 trees had a wave height of 12.7 cm at low tide, indicating equivalent wave energy dissipation for dense density. However, discrepancies were seen during medium tide, with the in-line arrangement measuring 14 cm compared to 12.7 cm for the random layout. This suggests that the random configuration performed better. During high tide, both setups once again measured 12.7 cm. The random structure consistently results in lower wave heights at all tidal conditions, indicating that the random configuration offers better wave reduction at higher densities due to increased friction and drag forces from the dense mangrove network.

In summary, the findings suggest that random tree configurations is more successful in decreasing wave heights under various densities and tidal circumstances. The density of trees exhibits some variation, with random arrangements being more effective when low tide, while medium and dense densities consistently demonstrate the superiority of the random layout. The random arrangement of mangroves enhances the interruption of wave flow and energy dissipation mechanisms, making it a more compelling layout for coastal protection and wave energy reduction.

CHAPTER 5

CONCLUSION AND RECOMMEDATIONS

5.1 Conclusion

The study investigated the impact of different configurations of trees (in-line and random) on the lowering of wave height. This was done by considering various densities of mangroves (sparse, median, and dense) and different tidal settings (low, medium, and high tides). Outcomes from this study clearly showed that higher mangrove density results in lower wave heights across all wave conditions (low, medium, high) for both in-line and random tree arrangements.

Random configurations were more effective in reducing wave height during low tide for sparse-density mangroves trees. However, both layouts performed similarly at medium and high tides. This indicates that the design has a more pronounced effect at lower densities. The median trees revealed that random configurations consistently resulted in a better wave height reduction, especially during low and high tides. This can be attributed to the improved root network and tree structure, which effectively disrupts the passage of waves. Very dense vegetation for inline and random design did not show a difference in wave reduction. Random arrangement proved more effective only during the medium tide, suggesting its advantage in areas with higher tree density. In the other hand, the test without mangroves had shown that wave heights increased dramatically, highlighting the crucial role of mangroves in safeguarding the coast by continually lowering wave heights and limiting the negative impact of wave energy on coastal areas.

The study suggest that for coastal protection and wave energy reduction, random arrangement of mangroves trees would enhances the interruption of wave flow and energy dissipation mechanisms, demonstrating their excellence in protecting coastal areas. This finding is crucial and offers valuable insights for coastal management and restoration programmes that seek to optimise the protective functions of mangrove ecosystems. Hence, the model also could be applied in educating the youngster on the importance of mangrove for shorelines conservation.

5.2 Recommendations

To enhance the research, several suggestions are as follows:

- Uses a machine to create waves in the physical model to get a more accurate and efficient view.
- To optimise wave attenuation, it is recommended that future coastal restoration initiatives prioritise the random arrangement of mangrove trees rather than in-line layouts.
- Coastal planners and environmental engineers should employ physical models, as this paper exemplifies, to customise mangrove restoration initiatives according to precise coastal circumstances.

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