

FRIM Special Publication No. 60

STATUS OF **MANGROVES** IN MALAYSIA

Hamdan Omar





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FOREST RESEARCH INSTITUTE MALAYSIA

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Foreword



The tsunami which hit Malaysia on 26 December 2004 resulted in the government among other things committing itself to enhancing the conservation efforts of mangroves areas. Recognising the destruction caused by the tsunami to life and property caused by the tsunami, it is timely that the government enhance coastal conservation efforts. Hence, the 4th National Biodiversity Council (MBBN) on January 13, 2005 decided that all state governments and Ministry of Natural Resources and Environment (NRE) to take initiative to restore and conserve ecosystems and vegetation of the mangrove forests.

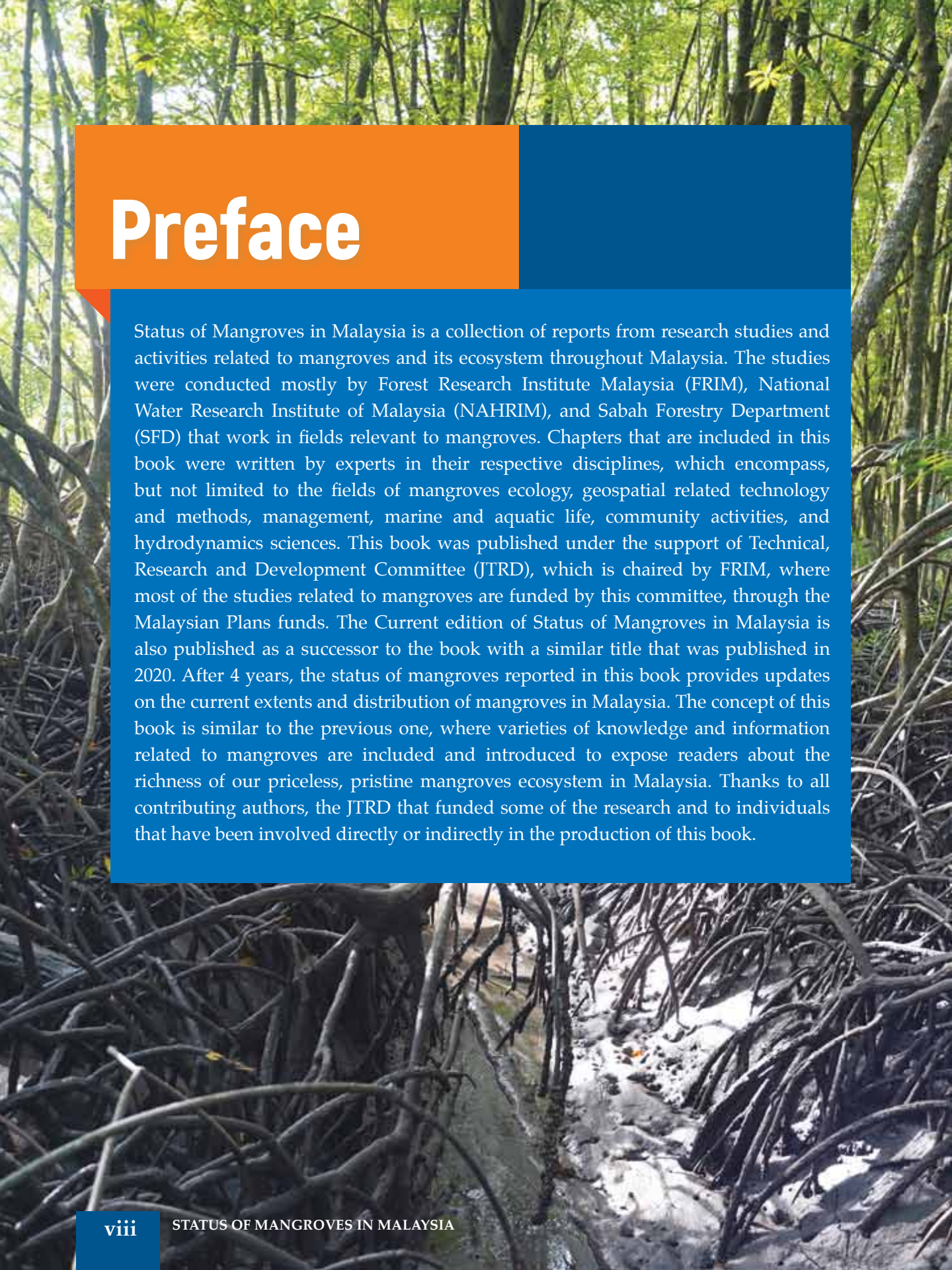
Under the Special Task Force chaired by Secretary General of NRE, now known as Ministry of Natural Resources and Environmental Sustainability (NRES), Director General of Forest Research Institute Malaysia (FRIM) has entrusted to chair of Research and Development Committee (JTRD) to carry out related research and development (R&D) activities. The main objective of JTRD in this regard is to support the implementation of rehabilitation programmes and to strengthen conservation efforts in the mangroves and coastal areas throughout the country .

The JTRD to date has organised seven seminars as platforms to present research findings not only from FRIM but also other agencies, institutions and universities related to forestry R&D. The committee has also produced various types of technical and semi-technical information, guidelines and publications including more than 30 books for reference purposes among relevant stakeholders.

We always encourage and support exchange of knowledge through seminars, publications and other ways of communication. Therefore, publication of this book is welcomed by the JTRD to further enhance our knowledge on scientific information related to mangroves. I believe that the readers will find this book enlightening and useful especially in generating for greater understanding of mangroves in Malaysia. It is also our hope that recommendations provided by authors of the various chapters can be adopted for management purposes of the mangroves which are priceless resources of our country.

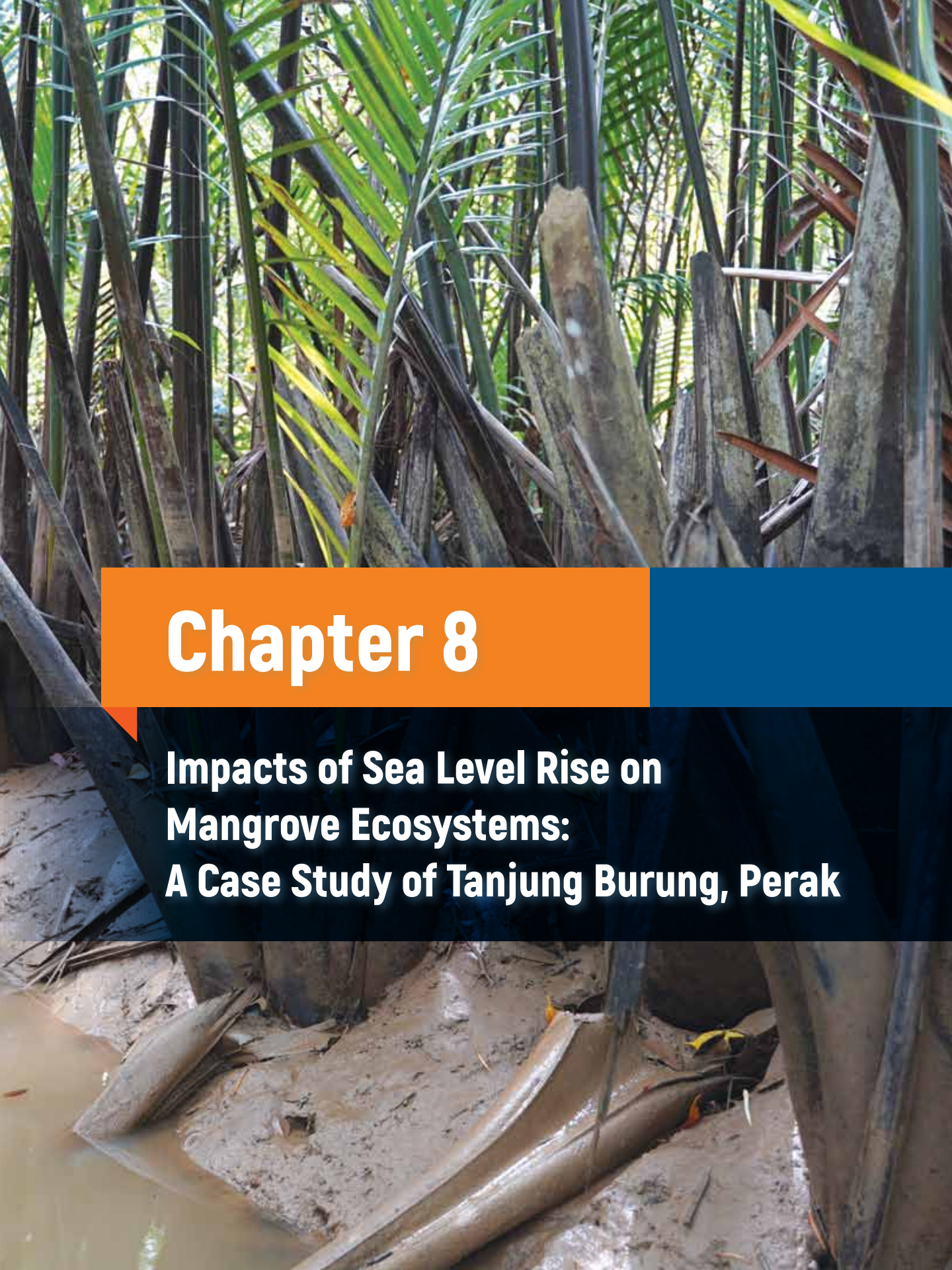
DATO' DR. ISMAIL HJ. PARLAN

Director General, Forest Research Institute Malaysia (FRIM)
Chairman of Research and Development Committee (JTRD)

The background of the entire page is a photograph of a mangrove forest. The top half shows the dense green canopy of the trees, while the bottom half shows the intricate, dark, and tangled root systems of the mangroves growing out of the ground. The lighting is bright, suggesting a sunny day.

Preface

Status of Mangroves in Malaysia is a collection of reports from research studies and activities related to mangroves and its ecosystem throughout Malaysia. The studies were conducted mostly by Forest Research Institute Malaysia (FRIM), National Water Research Institute of Malaysia (NAHRIM), and Sabah Forestry Department (SFD) that work in fields relevant to mangroves. Chapters that are included in this book were written by experts in their respective disciplines, which encompass, but not limited to the fields of mangroves ecology, geospatial related technology and methods, management, marine and aquatic life, community activities, and hydrodynamics sciences. This book was published under the support of Technical, Research and Development Committee (JTRD), which is chaired by FRIM, where most of the studies related to mangroves are funded by this committee, through the Malaysian Plans funds. The Current edition of Status of Mangroves in Malaysia is also published as a successor to the book with a similar title that was published in 2020. After 4 years, the status of mangroves reported in this book provides updates on the current extents and distribution of mangroves in Malaysia. The concept of this book is similar to the previous one, where varieties of knowledge and information related to mangroves are included and introduced to expose readers about the richness of our priceless, pristine mangroves ecosystem in Malaysia. Thanks to all contributing authors, the JTRD that funded some of the research and to individuals that have been involved directly or indirectly in the production of this book.

A photograph of a mangrove forest with numerous tall, slender trees and dense green foliage. The ground is muddy and wet, with some fallen branches and debris visible in the foreground.

Chapter 8

Impacts of Sea Level Rise on Mangrove Ecosystems: A Case Study of Tanjung Burung, Perak

Impacts of Sea Level Rise on Mangrove Ecosystems: A Case Study of Tanjung Burung, Perak

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Abstract

Mangrove ecosystems found in the inter-tidal zones of tropical and subtropical coastlines, provide critical ecological services, including shoreline stabilisation, carbon sequestration, and habitat for diverse flora and fauna. With the accelerating pace of global sea level rise attributed to climate change, understanding the intricate interactions between rising sea levels and mangrove ecosystems is paramount for effective coastal management and conservation.

Changes in water depth, salinity, and hydrodynamics induced by rising sea levels have profound effects on mangrove vegetation, thus influencing growth patterns, species distribution, and overall ecosystem structure. The intricate balance between sediment accretion and inundation plays a crucial role in determining the resilience of mangrove habitats to sea level rise.

This chapter explored alterations in current speed and wave dynamics within mangrove areas, shedding light on how these changes influence sediment transport, nutrient cycling, and the ecological niches supporting mangrove-dependent species. Researchers also documented that areas that experience above 0.3 m/s of current speed will affect the growth and survival of the mangrove trees [1, 2]. The potential for mangroves to adapt to rising sea levels through migration, vertical accretion, and genetic adaptation is discussed alongside the challenges posed by anthropogenic activities, land-use changes, and altered sediment supply.

In conclusion, recognising the vulnerability and resilience of these ecosystems is essential for developing adaptive strategies that integrate ecological, social, and economic considerations in the face of ongoing climate change.

1. Introduction

The landscape most vulnerable to climate change is the intricate inter-tidal zone where land and sea converge. Among the resilient ecosystems nestled in this transitional realm, mangrove forests emerge as critical players in a dynamic dance with the rising tides.

Mangroves grow in the tidally influenced areas and play an essential role in the ecosystem. Their unique root system serves as a natural breeding ground for many species of invertebrates and vertebrates, acts as a natural buffer against the threat of high, storm-generated waves [3], winds, surges and typhoons and tsunamis [4]. Their ability to attenuate and absorb wave energy helps to stabilise the beach against coastal erosion [5]. It also plays a unique role in ecology and biology. As sentinels of the shoreline, mangroves provide an array of ecosystem services, from shoreline stabilisation and habitat provision to carbon sequestration. However, their very existence is now imperilled by the escalating phenomenon of sea level rise.

Sea level rise (SLR), driven by global climate change, presents an imminent threat to coastal ecosystems worldwide. The melting of polar ice caps and glaciers, coupled with the thermal expansion of seawater, results in a relentless encroachment of the sea onto land. This encroachment disrupts the delicate equilibrium that mangroves have maintained for centuries, challenging their adaptive mechanisms and resilience.

The SLR will cause changes in the intensity and frequency of extreme events (from combined effects of high spring tides, heavy rainfall, storm surges, high surface waves, and river flooding) [6]. These extreme events may cause temporary or permanent inundations due to increased sea and flood levels. An increase in wave heights and current velocities will intensify coastal erosion and sedimentation rates, damage to coastal structures, and loss of property and marine habitats. Similarly, saltwater intrusions will deteriorate water quality; hinder agriculture and aquaculture activities. These impacts are potentially significant, bringing discomfort to the local communities [7].

This dynamic interplay between SLR and mangrove ecosystems shall be explored. The rising seas not only jeopardise the physical existence of mangroves but also reverberate through the intricate web of ecological relationships they sustain.

In this chapter, from the mangrove realms and rising tides, the vulnerabilities of mangrove ecosystems to sea level rise, and the adaptive strategies they deploy to navigate this change will be discussed. It becomes clear that understanding the intricate dance between mangroves and rising seas is not just an ecological imperative but a crucial step towards securing the resilience of our coastal environments in the face of an uncertain future.

1.1 Objectives of the Study

The primary objective of this study was to identify and analyse the impact of rising sea levels on the hydrodynamics of the study area. The analysis and evaluation were based on the output results from the simulation of existing and projected sea level rise conditions.

Investigating mangrove growth in the context of rising sea levels involves a multidisciplinary approach that considers ecological, hydrological, and geological factors. The methodology used in this study are as follows:

2.1 Site Selection

- a. Study sites representative of different mangrove ecosystems were identified by considering variations in species composition, tidal regimes, and geomorphology.
- b. Sites with historical data on sea level rise was chosen based on where current rates of sea level rise were well-documented.

2.2 Data Collection:

- a. Sea Level Data:
 - i. Historical sea level data was acquired from reliable sources such as tide gauge records or satellite altimetry.
- b. Mangrove Growth and Health:
 - i. Field surveys were conducted to assess mangrove species composition, tree density, and canopy cover.
 - ii. Individual tree height, diameter at breast height (DBH) were measured, and leaf samples were collected for physiological analyses.
 - iii. Remote sensing tools (satellite or drone imagery) were used to assess changes in mangrove cover over time.
- c. Sediment Accretion:
 - i. Sedimentation monitoring stations were established by using sediment traps or sediment cores to measure the rate of sediment accretion around mangrove roots.
 - ii. Sediment composition and texture was analysed to understand how sediment dynamics influence mangrove growth.

2.3 Hydrological and Ecological Parameters:

- a. Hydrological surveys were conducted to measure tidal inundation patterns, salinity levels, and water quality.
- b. Nutrient availability in the soil was evaluated through soil sampling and analysis.
- c. Factors which can influence mangrove growth such as temperature, precipitation, and freshwater inflow was monitor.

2.4 Growth Modelling:

- a. Models to simulate mangrove growth was developed under different sea level rise scenarios.
- b. Various data on sea level, sedimentation, and ecological parameters were integrated into growth models to predict the potential impacts of sea level rise on mangrove ecosystems.

2.5 Historical Analysis:

- a. Historical aerial photographs, satellite imagery, and ecological surveys were analysed to assess changes in mangrove extent over time.
- b. Correlation between historical sea level rise rates with observed changes in mangrove growth and distribution was established.

2.6 Community Engagement:

- a. Engagement with local communities and stakeholders were organised to gather traditional ecological knowledge about mangrove growth and changes in sea level.
- b. Community perceptions and experiences were incorporated into the research to enhance the study's contextual understanding.

2.7 Statistical Analysis:

- a. Statistical methods were applied to identify correlations between sea level rise and mangrove growth parameters.
- b. The variability in mangrove growth patterns concerning different environmental factors were analysed.

2.8 Synthesis and Reporting:

- a. The collected data, model outputs, and community feedback were synthesised to conclude the influence of rising sea levels on mangrove growth.
- b. Comprehensive reports and visualisations were prepared to communicate findings to the scientific community, policymakers, and local stakeholders.

A comprehensive understanding of how mangrove ecosystems respond to rising sea levels can be gained by employing this multidisciplinary methodology, thus providing valuable insights for conservation and management strategies in the face of climate change.

3. Study Area

Global variations in coastal geomorphology, tidal regimes, and climate conditions result in diverse impacts of SLR on mangroves. The total mangrove forest in Malaysia is 629,038 hectares whereby 18% are located in Peninsular Malaysia, 22% at Sarawak and 60% in Sabah [8]. Case studies from Tanjung Burung, Perak provide valuable insights into the nuanced responses of mangrove ecosystems to rising seas. Compartment 113 Tanjung Burung Forest Reserve is located in the Kinta/Manjung area. Tanjung Burung (long:100.619171°, lat: 4.479632°) is under the Perak Forestry Department's jurisdiction. National Water Research Institute of Malaysia (NAHRIM), through Jawatankuasa Teknikal Mengenai Penyelidikan dan Pembangunan (JTRD), has been appointed to conduct an extensive study in this area due to the severe loss of mangrove forests. Therefore, a site visit was conducted on 19th November 2020 followed by data collection in January 2022 along the stretch of Tanjung Panchor to Tanjung Remis. Figure 1 is a picture of the study area. Field observations showed that the frontier of the mangrove line in this area is under severe threat.



Figure 1. The study area conditions.

4. Data Collection

One of the most crucial inputs in the hydrodynamic model is the bathymetry of the coastal area of interest. The tidal observations near the study area are also essential as these dictate tides' action and potential contribution to the current systems within the study area. NAHRIM had conducted field data collection from 11 February 2022 until 5 March 2022 (a total of three weeks) covering both the tidal cycle; Spring and Neap Tide events and all the methods were in line with the DID's guidelines [9]. All the locations, planning and methods for the deployment of equipment and relevant surveys at the site were proposed by NAHRIM.

The following data were acquired for the hydrodynamic model:

- a. Current speed and directions, wave height and wave directions were measured using an Acoustic Wave and Current Profiler (AWAC) in two locations..
- b. Tidal elevation were measured using tide gauges and AWACs in two locations for each equipment.

- c. Hydrographic/ bathymetric survey for bathymetry and coastlines topography survey.
- d. River discharge measurement at Sg. Panchor and Sg. Beruas.
- e. Grab sampling analysis within the project area for the sedimentation model.
- f. Total Suspended Sediment (TSS) concentrations within surrounding coastlines.
- g. Beach profiling including core sample analysis along the shorelines.
- h. Purchased wind and wave data by UKMO.
- i. Generated tidal constituents from Royal Malaysian Navy (RMN) and Department of Survey and Mapping Malaysia (JUPEM).

All the data acquired in the previous paragraph were incorporated either as input for numerical model or as calibration purposes. Observed currents and tides were needed in the simulation of coastal hydrodynamic modelling for model calibration.

It is vital to establish the baseline conditions so that once the impacts are quantified, it is possible to evaluate the relative hydrodynamic changes to the surrounding shoreline. The location of the data collection coverage area is depicted in **Figure 2**.

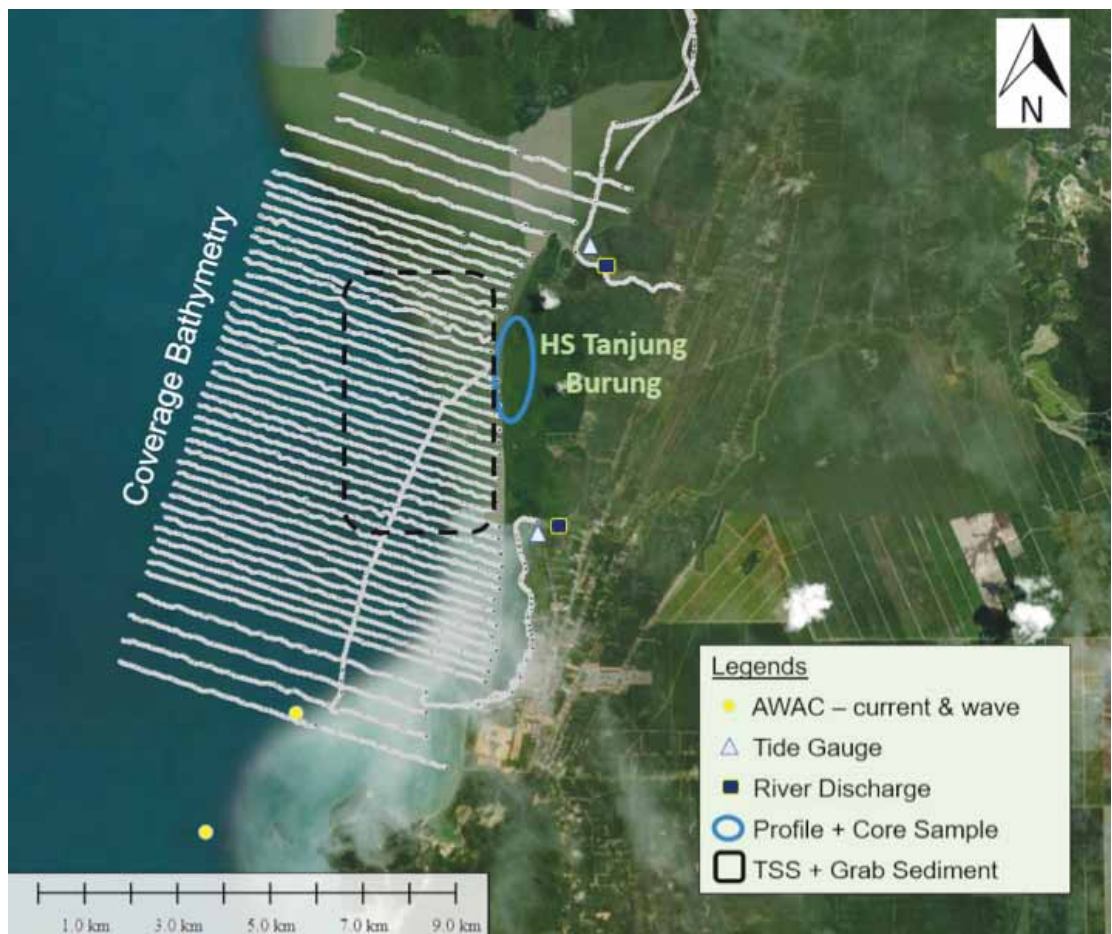


Figure 2. Summary of Data Collection Coverage Area at HS Tanjung Burung.

5. Hydrodynamic Model

MIKE 21 Flow Model FM is a versatile mesh-based modelling solution. The model was developed by Danish Hydraulic Institute (DHI) to solve complex interaction of oceanographic, coastal, and estuary environments through numerical modelling. The Hydrodynamic (HD) Model was used in this study. The hydrodynamic module simulates the water level variations and flows in response to various forcing functions in coastal areas. The development of numerical modelling in this study are as follows:

- a. Hydrodynamic Model (MIKE 21 HD) – Base Model
- b. Spectral Wave Model (MIKE 21 SW)
- c. Hydrodynamic Model (MIKE 21 HD) – SLR Model (2040, 2060, 2080 & 2100)

The MIKE 21 HD was used to study the changes in currents and water levels due to projected sea level rise. It is the basic module of the entire MIKE 21 systems that provide water levels and flow patterns within the study area. Bathymetry information including bed resistance coefficients, wind and wave field data are essential input for the HD model.

The following methodology was adopted to evaluate the potential impact:

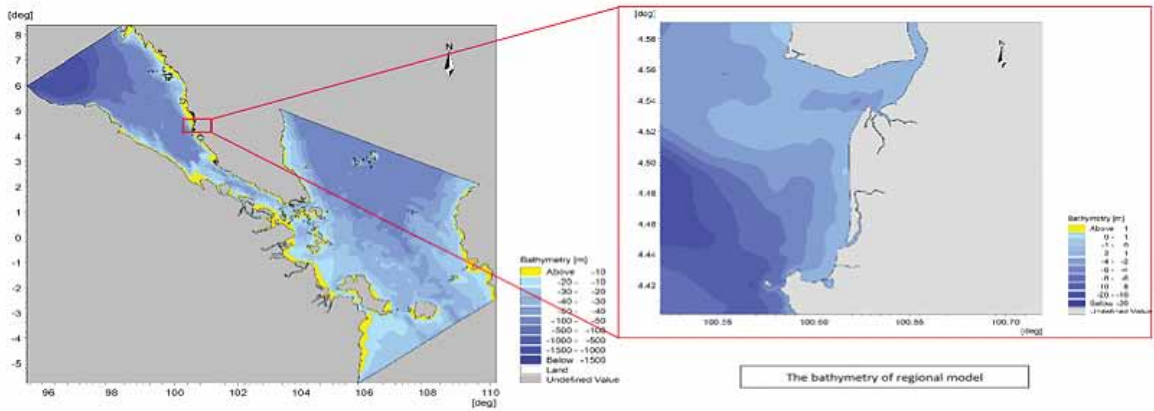
- a. A regional model was established that describes regional coastal currents and water levels for the Strait of Malacca and Andaman Sea to provide boundary conditions to a refined local model.
- b. Detailed local model in the study was established.
- c. Hydraulic model was calibrated and verified.
- d. Design scenarios for currents and flows were determined and simulated.
- e. Baseline model and projection model was simulated to evaluate the potential impact on currents and water levels.
- f. The simulation of model were analysed and presented.

Impact assessment on the baseline and with the projected SLR scenario were determined based on three scenarios for 2040, 2060, 2080 and 2100.

5.1 Detailed Hydrodynamic Model Development

The model setup requires transforming actual world events and data into a format that could be understood. All data collected were resolved on the spatial grid selected, including the time step required. Simulations for the hydrodynamic model were carried out to simulate SLR conditions according to Sea Level Rise Projections for Malaysia [10] in the year 2040, 2060, 2080 and 2100 with 0.16, 0.29, 0.46 and 0.67 m increment respectively. The hydrodynamic models were simulated for the various years of interest by increasing the tidal boundary conditions corresponding to the projection of sea level rise.

The bathymetry data for the model set-up was incorporated based on a C-MAP digital chart and surveyed data. The bathymetry data were transformed into a MIKE 21 readable format. The grid resolution of the model varied as the flexible mesh was used to compute, which ranged from 1km² to 20m²; with finer resolution of about 20m² at the chosen Tanjung Burung coastline, as depicted in **Figure 3**.



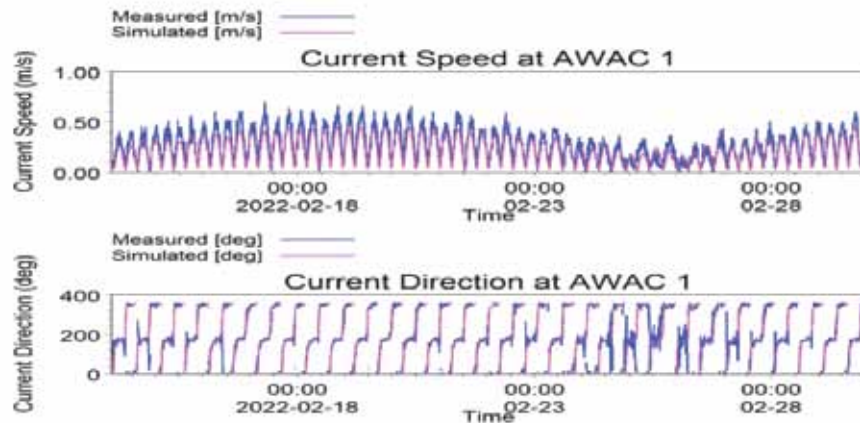


Figure 5. Calibration of Current Speed and Direction at AWAC 1.

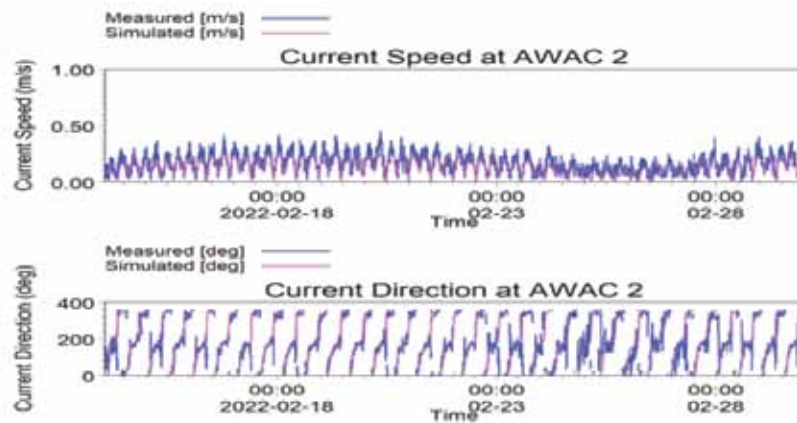


Figure 6. Calibration of Current Speed and Direction at AWAC 2.

In order to assess the deviation between predicted/measured and simulated data, RMSE WAS used to measure the fitness between values predicted by a model and measured values. The extracted water levels from the model simulation compared well with the measured tides with RMSE values within an acceptable deviation of 10% specified in the DID guidelines [9, 11]. The percentage of RMSE results for water level stations TG1 and TG2 and the current speed and direction of AWAC 1 and 2 are listed in **Table 1**.

Table 1. RMSE of Water Level, Current Speed and Direction for Local Grid Model.

Point	RMSE (%)		RMSE Current Direction (Degree)
	Water Level &	Current Speed (%)	
TG Bagan Panchor	10.3		-
Tide Gauge Beruas	10.6		-
AWAC 1	8.6		8.8
AWAC 2	5.9		11.4

6. Results and Discussion

The mean and maximum statistical analysis results of water levels are presented in **Figures 7 to 11**. The surface elevation at the model baseline condition showed that the mean water level for the baseline condition is between 0.2 and 0.4 m. Meanwhile, the maximum water level is between 1.0 and 1.2 m.

The surface elevation for sea level in 2040 is projected to rise to a value of 0.2 m compared with the baseline model in which the maximum water level falls between 1.2 and 1.4 m, while the mean water level is projected to be similar to the baseline, which is between 0.2 - 0.4 m.

The surface elevation for rising sea levels in 2060 is expected to show a maximum water level similar to 2040 model. Despite showing an equivalent maximum water level, the model shows an increasing flooding area in 2060 mainly in the northern part of Sg Panchor. The mean surface elevation shows an increment where the water level is between 0.2 – 0.6 m.

The maximum surface elevation for rising sea level in 2080 is projected to increase to between 1.4 – 1.6 m while mean surface elevation is projected to be between 0.4 to 0.6 m. In 2100, it is projected maximum surface elevation to be between 1.6 and 1.8 m while it is between 0.6 and 0.8 m for mean surface elevation.

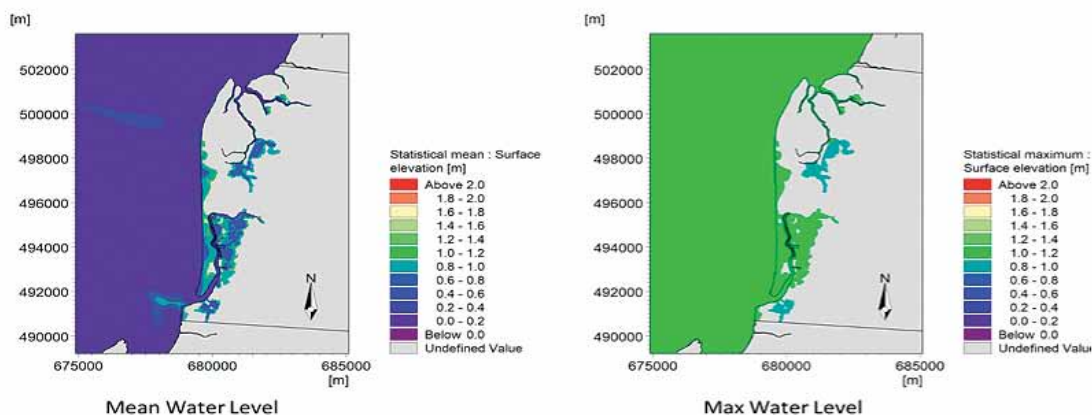


Figure 7. Statistical Mean and Maximum Water Level during Existing Condition.

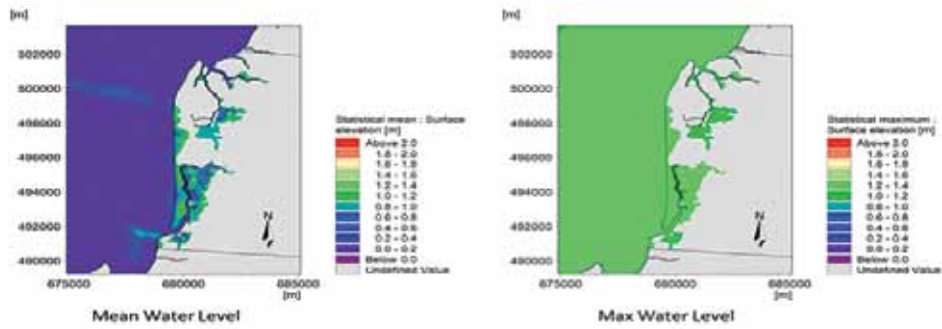


Figure 8. Statistical Mean and Maximum Water Level during SLR 2040.

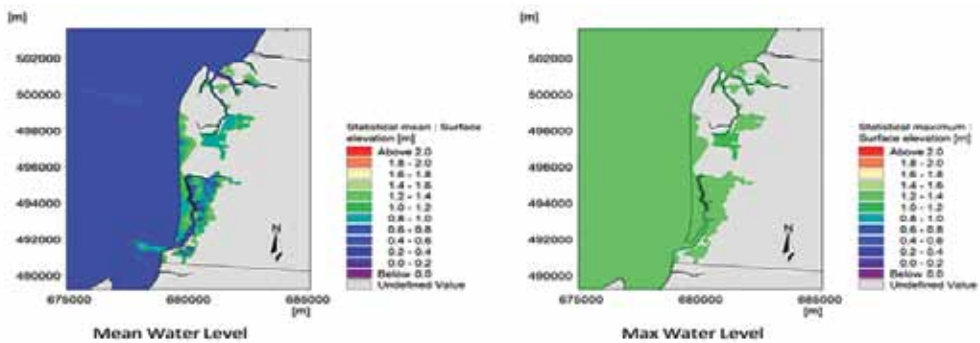


Figure 9. Statistical Mean and Maximum Water Level during SLR 2060.

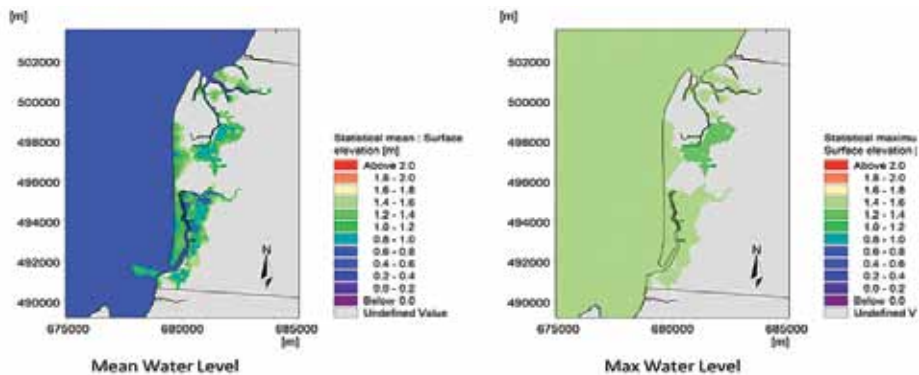


Figure 10. Statistical Mean and Maximum Water Level during SLR 2080.

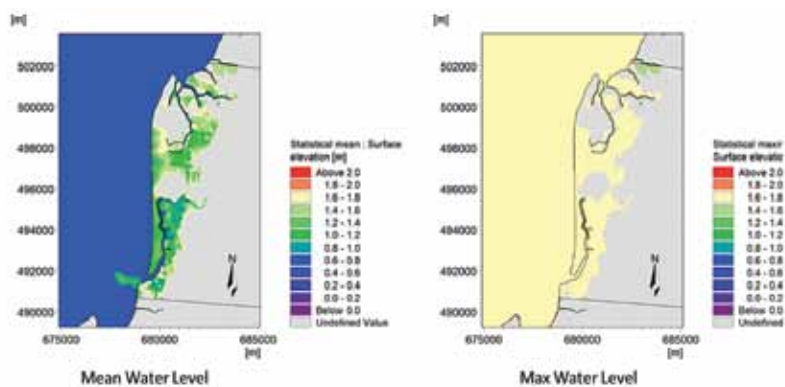


Figure 11. Statistical Mean and Maximum Water Level during SLR 2100.

The difference in mean surface elevation from baseline to the projected year 2100 ranges from 0.2 m to 0.4 m. At the same time, the maximum surface elevation difference is 0.2 m to 0.6 m. The results are presented in **Figure 12**.

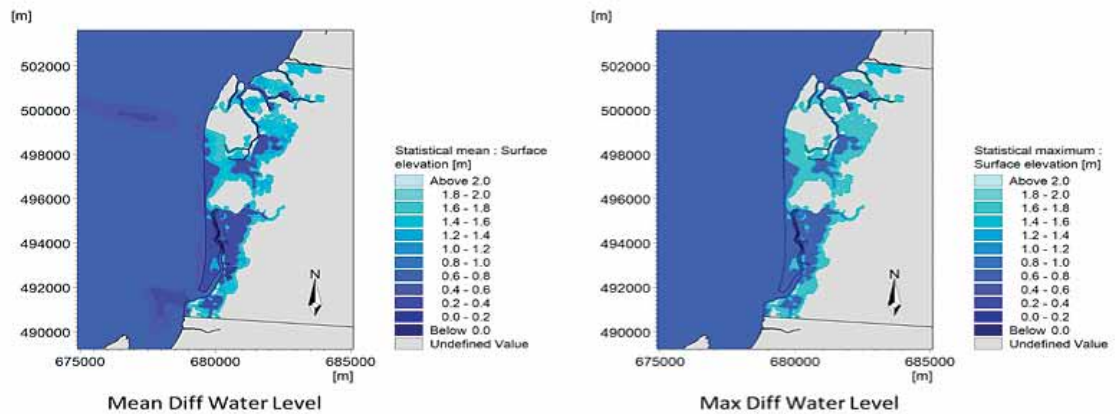


Figure 12. Difference of Mean and Maximum Water Level – Existing vs. SLR 2100.

The model output for the risk of inundation area for projected years is shown in **Figure 13**. With the increasing level of surface water level intrusion, the area of inundation is projected to increase. The result is shown in **Table 2**.

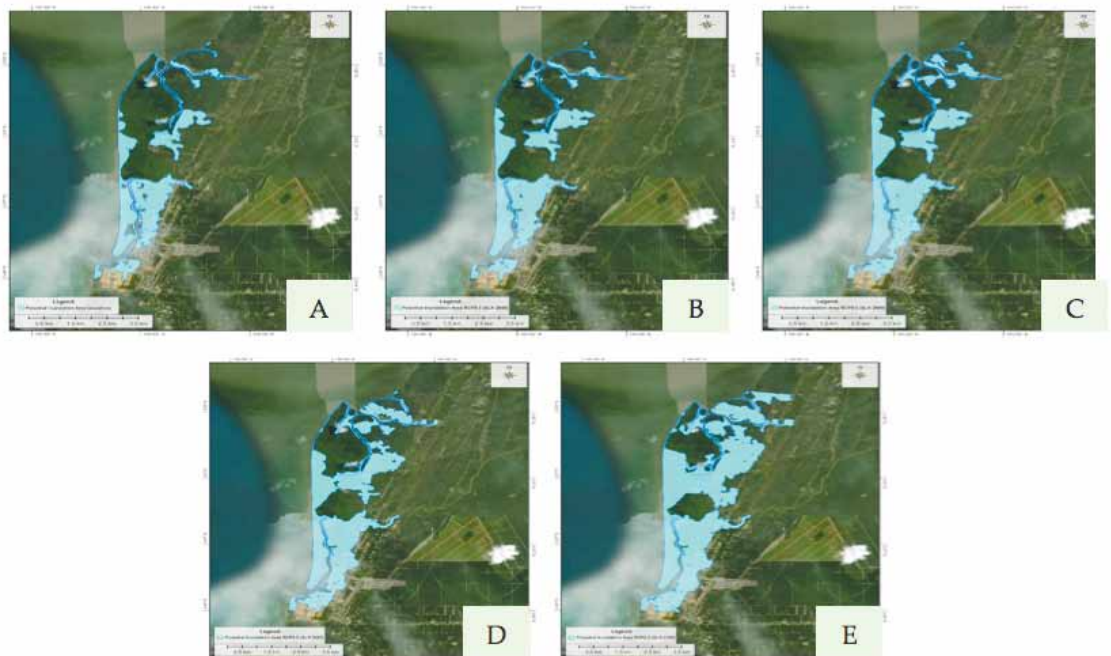


Figure 13. The Image Shows the Results of the Simulation of Sea Level Rise According to Respective Conditions; (A) Baseline, (B) SLR 2040, (C) SLR 2060, (D) SLR 2080 and (E) SLR 2100. The Blue Polygon Represents the Risk of Inundation Area According to RCP8.5.

It was projected that in 2100, an additional 982.16 ha would be affected by sea level rise. Therefore, mangrove forests within the area should be monitored and secured. The total area affected due to inundation of SLR is described in **Table 2** as follows:

Table 2. Summary of Projected Inundated Area due to SLR In Accordance to SLR Scenario.

Scenario (Year)	Total Area Inundated (km ²)	Total Area Inundated (ha)	Projected Additional Area Inundated (ha) (SLR year – Baseline)
Baseline	7.636	763.64	-
SLR 2040	9.178	917.76	154.12
SLR 2060	10.649	1,064.9	301.26
SLR 2080	13.036	1,303.6	539.96
SLR 2100	17.458	1,745.8	982.16

7. Mitigation Measures

Several mitigation measures can be implemented to reduce the impact of sea level rise. Mangrove replanting can be done with suitable species that can adapt to the changing environment. Hardy mangrove species can withstand the high tides and waves at the front and mangrove that can be reproduced quickly will be planted behind to shore up the coastline. Saplings encourage more natural growth of mangroves and replace those already lost. Mangrove or bamboo wood poles can be erected as front barriers to dissipate the wave energy. This method also might promote sedimentation in the area. However, potential wildlife threats such as monkeys should be monitored.

Coastal erosion arising from the sea level rise impact can be mitigated by constructing proper coastal protection structures. These structures need to be adequately designed to account for potential erosion; for example, biodegradable sacks are filled with suitable mud and put in the undercut beneath the berm. Various sizes of rocks can be installed in front to add support to the shoreline. Monitoring is recommended to ensure mitigation works are conducted promptly.

Sedimentation is anticipated to occur in the vicinity of the study area. Monitoring is recommended to ensure mitigation works are conducted promptly if the rise of water level is found to be the primary cause of sedimentation within the area.

Monitoring beach profile change is a common and effective way of measuring erosion and accretion in the area. Based on the model results, some areas along the shoreline might encounter sedimentation in the future. It is an indication of sand overtopping. A beach profile monitoring is proposed using survey transects running toward the shore from the dune to the Mean Lower Low Water (MLLW) mark. Twenty (20) survey transect lines with alongshore line intervals of 10 m extending along the beach can be done to evaluate the possible change in the beach elevation.

This may be accomplished through communication, education, and public awareness. Providing capacity development and awareness-raising activities to local communities and involving communities and stakeholders in science-based techniques to repair degraded forest locations. Communities must be involved to develop a sense of belonging and to ensure long-term conservation initiatives. Collaboration with NGOs or stakeholders in the implementation of environmental policies. Long-term commitment and synergistic collaboration should be formed.

8. Technology Development

Technological advancements have significantly enhanced the capabilities and precision of studies investigating mangrove growth in the context of rising sea levels. The technologies applications in this study are:

8.1 Remote Sensing:

Satellite Imagery and Aerial Photography: High-resolution satellite imagery and aerial photography provide valuable tools for monitoring changes in mangrove extent, canopy cover, and land-water dynamics over large spatial scales.

Unmanned Aerial Vehicles (UAVs or Drones): Drones can capture detailed, high-resolution images of mangrove ecosystems, offering a cost-effective and flexible means for monitoring changes in topography, vegetation structure, and health.

8.2 Geographic Information Systems (GIS):

Spatial Analysis: GIS allows researchers to integrate and analyse various spatial datasets, such as sea level rise projections, mangrove distribution, and hydrological parameters, facilitating a comprehensive understanding of the spatial relationships within the ecosystem.

8.3 Global Navigation Satellite Systems (GNSS):

Ground Truthing: GNSS technology enables precise georeferencing of field data and assists in ground-truthing satellite imagery, ensuring accuracy in mapping and monitoring mangrove growth and distribution.

8.4 Sea Level Monitoring Instruments:

Tide Gauges: Traditional tide gauges and more modern acoustic or radar tide gauges provide continuous records of sea level variations, aiding in understanding tidal dynamics and long-term trends.

Satellite Altimetry: Satellite altimeters measure sea surface height globally, providing high-precision data on sea level variations and trends.

8.5 Sedimentation Monitoring Tools:

Sediment Traps and Cores: Sediment traps and cores equipped with sensors help quantify sediment accretion rates around mangrove roots, contributing to the understanding of how sediment dynamics affect mangrove growth.

8.6 Aquatic Sensors:

Water Quality Sensors: Deploying sensors for parameters, such as salinity, temperature, and nutrient levels helps researchers understand the hydrological conditions influencing mangrove ecosystems and their growth.

8.7 Modelling and Simulation Tools:

Hydrodynamic Models: Numerical models simulate water flow, tidal patterns, and sediment transport, aiding in predicting how rising sea levels might affect mangrove habitats.

Mangrove Growth Models: Advanced modelling tools incorporate factors, such as sea level rise, sedimentation rates, and hydrological conditions to simulate mangrove growth under different scenarios.

8.8 Community Engagement Platforms:

Mobile Apps and Social Media: Utilising mobile applications and social media platforms for community engagement allows researchers to collect real-time data, observations, and traditional ecological knowledge from local communities.

8.9 Climate Data Platforms:

Access to Climate Data: Online platforms that provide access to historical and future climate data facilitate the integration of climate variables into studies on mangrove growth and response to sea level rise.

8.10 Collaborative Platforms:

Online Collaboration Tools: Platforms that enable collaborative work and data sharing among researchers globally, fostering interdisciplinary approaches and accelerating the pace of scientific discovery.

These technologies collectively contribute to a more comprehensive and precise understanding of the complex interactions between rising sea levels and mangrove ecosystems, ultimately aiding in the development of effective conservation and management strategies

Conclusion

Mangrove ecosystems are threatened by anthropogenic activities, including deforestation, aquaculture, and urbanisation. The destruction of mangrove habitats undermines their capacity to attenuate waves and provide other ecosystem services. Conservation efforts are crucial to safeguard these ecosystems and enhance their resilience in the face of rising sea levels.

Integrated coastal management approaches that consider both natural and human dimensions are essential. Balancing the need for development with the preservation of mangrove ecosystems requires a comprehensive understanding of the ecological services they provide, including wave attenuation.

By using MIKE 21 HD, the hydrodynamic conditions of the study area were developed to study the impact of sea level rise. The results suggested that the area of inundation is projected to increase from 763.64 ha to 1,745.8 ha in 2100. The water level can reach up to 1.6 to 1.8 m along the south coast of the study area.

In conclusion, the intricate relationship between sea level rise, mangrove forests, and the attenuation of waves underscores the importance of these ecosystems in coastal resilience. Recognising and preserving the ecological functions of mangroves contribute not only to the protection of coastlines but also to the overall health and sustainability of coastal ecosystems. As sea levels continue to rise, mangroves stand as natural guardians, offering an important solution for mitigating the impact of climate change on coastal areas.

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