# MAPPING THE MANGROVE VULNERABILITY INDEX AND POTENTIAL IMPACT PREDICTION USING GEOGRAPHICAL INFORMATION SYSTEM

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## DEDICATION

*This is especially dedicated to..*

*My Husband (Mohamad Faizal Bin Mohsin)*

*Ayah and Ibu (Hj Ahmad and Hajjah Ann)*

*My Daughters (Faiezun, Faheemah, Fariha, Fadia, Afiyah)*

*Siblings (Syakireen, Faizal Shazwan, Ana, Meme)*

*Last but not least,*

*Arwah Bapak, Mohsin Bin Sayuti and Arwah Kak Fauziah (Al fatihah)*

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# ABSTRACT

This study aims to investigate the spatial distribution of mangrove growth. The objectives of this study were to create maps that will lead to decision-making in the Mangrove Vulnerability Index (MVI), establishes an accurate GIS database to classify the GIS-based MVI maps for Pulau Kukup, Tg. Piai and Sg. Pulai Riverbanks and to predict the potential impacts due to sea-level rise. Vulnerable meaning exposes to the possibility of being attacked or harmed, either physically or emotionally. Environmental vulnerability as a function of exposure to impacts and the sensitivity and adaptive capacity of ecological systems towards environmental tensors. Climate change, especially sea level rise, contributes to coastal mangrove ecosystems, making it essential to introduce interventions to mitigate risk by strategic management preparation. The approach to ranking and evaluating the susceptibility of mangrove systems involves physical, biological, and threat elements, which are focused on approaches developed to address existing research issues. This includes evaluating the wellbeing of mangrove trees, the integrity of surrounding environments, the future effects of human impacts, and environmental considerations in different mangrove settings. MVI is classified into three main categories, which are the Physical Mangrove Index (PMI), Biological Mangrove Index (BMI), and Hazard Mangrove Index (HMI) that develop from the surrounding study area. PMI considers the physical of the mangrove itself, which includes Mangrove Species and Mangrove Height. BMI interpreted factors to contribute to the mangrove: canopy, Normalized Difference Vegetation Index (NDVI), distance to the coastline, soil and geomorphology type, tidal range, elevation, and salinity. HMI measure exposes component indicated Wind, Wave, Rainfall, and Industrial Activity, Shipping and Villages. The vulnerability assessment classification results reveal that very low, low, moderate, high, and very high vulnerability. The ability to monitor and predict vulnerability is beneficial to ecosystems that could be affected, especially mangroves. MVI not a one-time assessment within the framework of a thesis, but rather a starting point from long-term continuous monitoring act as guidance to obtained findings effectively evaluate the complexities of environmental issues.

# ABSTRAK

Kajian ini bertujuan untuk menyiasat sebaran ruang pertumbuhan bakau. Objektif kajian ini adalah untuk menghasilkan peta hasil bagi Indeks Kerentanan Bakau (MVI), mewujudkan pangkalan data Sistem Maklumat Geografi (SMG) yang tepat, untuk mengklasifikasikan peta MVI berdasarkan SMG bagi kawasan kajian iaitu Pulau Kukup, Tg. Piai dan Tebing Sg. Pulai dan meramalkan kesan kenaikan paras laut. Makna rentan ialah mendedahkan kemungkinan diserang atau dicederakan, sama ada fizikal atau emosi. Kerentanan alam sekitar merupakan pendedahan terhadap impak dan kepekaan dan keupayaan adaptif sistem ekologi terhadap tekanan persekitaran. Perubahan iklim, terutama kenaikan paras laut, menyumbang kepada ekosistem bakau pesisir, menjadikannya penting untuk mengurangkan risiko dengan penyediaan pengurusan strategik. Pendekatan dalam menetap dan menilai kerentanan sistem bakau melibatkan elemen fizikal, biologi, dan ancaman serta elemen kawalan manusia, yang kedua-duanya tertumpu pada pendekatan yang dikembangkan untuk menangani masalah penyelidikan sediada. Ini termasuk menilai kesihatan pokok bakau, integriti persekitaran, kesan impak masa depan terhadap manusia, dan pertimbangan perbezaan persekitaran bakau. MVI diklasifikasikan kepada tiga kategori utama, iaitu Indeks Mangrove Fizikal (PMI), Indeks Bakau Biologi (BMI), dan Indeks Bakau Ancaman (HMI) yang berkembang dari sekitar kawasan kajian. PMI merupakan fizikal bakau itu sendiri, yang merangkumi Spesies Bakau dan ketinggian Bakau. BMI mentafsirkan faktor-faktor yang menyumbang untuk bakau iaitu kanopi, Indeks Vegetasi Perbezaan Normalisasi (NDVI), jarak ke garis pantai, jenis tanah dan geomorfologi, jarak pasang surut, ketinggian, dan kemasinan laut. Ukuran HMI memperlihatkan komponen ancaman iaitu Angin, Ombak, Hujan, Aktiviti Perindustrian, Perkapalan dan Desa. Keputusan pengkelasan penilaian kerentanan, menunjukkan kerentanan sangat rendah, rendah, sederhana, tinggi dan sangat tinggi. MVI bukan pentaksiran tunggal dalam rangkakerja tesis, tetapi merupakan titik permulaan yang berupaya memantau dan meramalkan kerentanan jangka panjang yang bermanfaat untuk ekosistem yang boleh terjejas.

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# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

Mangrove is a salt-tolerant tree and sheltered tropical shores, islands, and estuaries. The world's largest mangrove area is set at 6.8 million hectares in Southeast Asia. The most extensive mangrove areas are Indonesia, Malaysia, Myanmar, Papua New Guinea, and Thailand (Figure 1.1). Malaysia harbours approximately 12 percent of Southeast Asia's mangrove area and is mainly found along the Sabah coast (57 percent) (Faridah Hanum et al., 2012). Over the last 35 years, mangrove regeneration in the Straits of Malacca has provided an excellent model system for studying how to stand dynamics change over time. Assessment of forest structure, biodiversity, and biomass along a natural mangrove development chronosequence provides valuable information for determining how long it takes mangrove restoration to return to a natural baseline condition when the exact stand age is known (Azman et al., 2021)

The mangrove stabilization provides important prevention of erosion shoreline. By acting as buffers collecting downstream washed objects, it helps maintain land level through the accretion of sediments to counter the loss of deposit. Mangrove is also valuable for treating effluent as it absorbs nutrients such as nitrates and phosphates (Figure 1.1). It can improve water quality through the filtration of sediments and pollutants. Besides that, mangrove absorbs carbon dioxide to lessening the impact of global warming. It also functions as buffer zones in extreme weather cases, such as storms and hurricanes to protect and shield the coastline from property damage and loss of life.

The wetlands range in size, catchment area, human population, and economic growth level. Multiple, direct stresses are imposed by economic sectors and practices in and near coastal wetlands and their catchments (Newton et al., 2020). They also serve as sources of medicine, fuel, food, and building materials for local people. For thousands of years, mangroves became collecting products and resources for construction materials, charcoal, medicines, firewood fibres and dyes, food, and others. Mangrove has been filtering for salt and aerial roots, facilitating the occupied mineral salt watering area where other plants cannot sustain themselves. Figure 1.2 shows healthy mangrove forests taken by aerial photos.

Figure 1.1 Mangrove absorbs the nutrient.

Figure 1.2 Healthy mangrove forest

Mangrove woodland, salt marshes, and reed beds offer more extensive and diverse environments for juvenile fish refuge on a structural basis. Some of these habitats are still reduced in nursery supply since they are completely exposed at low tide (Whitfield, 2017). High tide increases water salinity, the tide decreases, heat evaporation and salinity increase. Meanwhile, these soils will be washed out by sea, bringing them back to salinity levels equivalent to water. Mangroves are also exposed to temperature and desiccation increases and are then cooled and flooded by the low tide. For mangroves to thrive in this climate, they must also withstand rainfall, salinity and temperatures, and environmental factors (Mildred, E, 2012). The definition of a fully preserved coastal zone is shown in Figure 1.3.

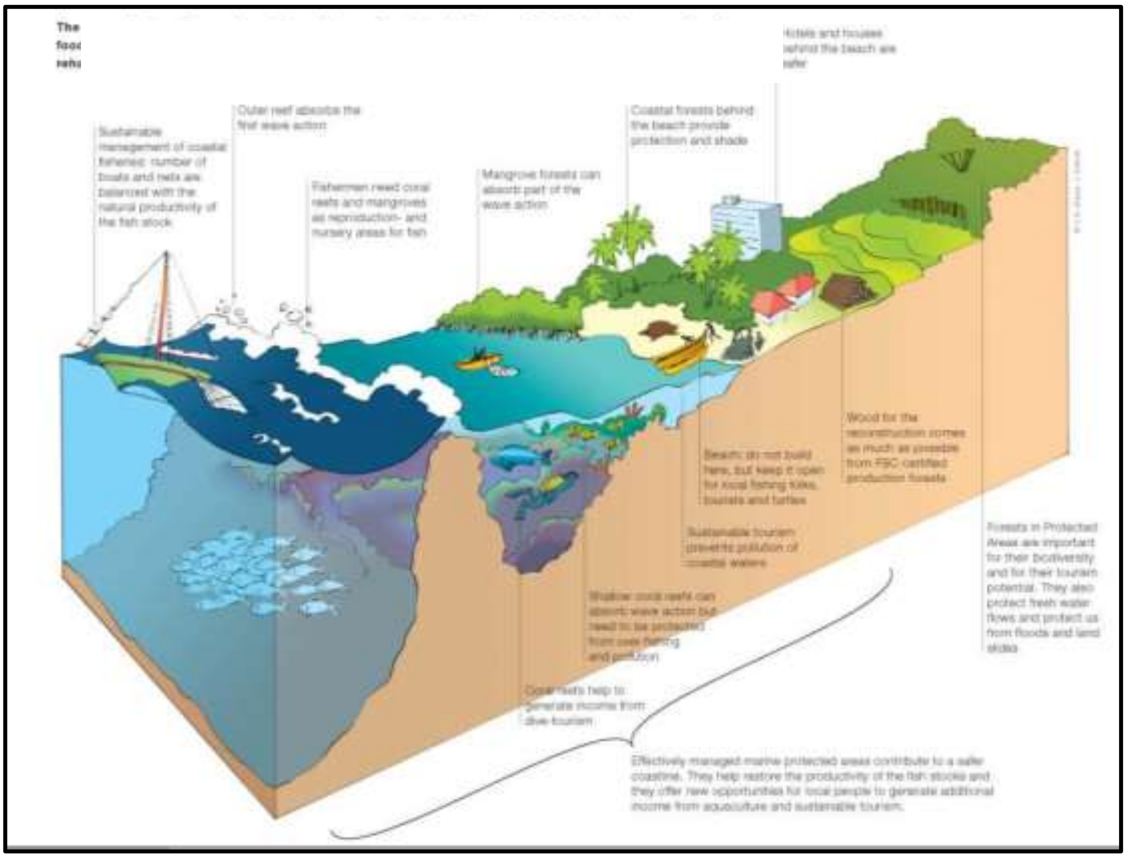

Figure 1.3 The concept of perfect reconstructed coastal zone

### 1.2 Statement of Problem

Experts are attempting to understand how Earth's climate change and rising sea levels have impacted mangroves? How do we predict the outcomes and impact of the sea-level rise to mangrove then adapt and mitigate accordingly? Vulnerable meaning exposes to the possibility of being attacked or harmed, either physically or emotionally (oxford dictionary, 1948).

One of the most disastrous consequences of climate change is sea levels. A minor rise in sea level may influence natural coastal environments (Din et al., 2019). Because of predicted climate change in the twenty-first century, the sea-level evolution along the Peninsular Malaysia and Sabah–Sarawak coastlines is being studied for the twenty-first century. The highest sea-level increase occurs in Peninsular Malaysia's northeast and northwest provinces and Sabah's north and east sectors along the Sabah–Sarawak coastline (Ercan et al., 2013).

Many countries worldwide in the South Pacific are experiencing an increase in sea-level 2 mm per area. (Furukawa and Baba, 2002 and Gilman et al., 2006b). Based on Figure 1.4, IPCC (2007) predicted global average surface warming for the end of the 21st century.

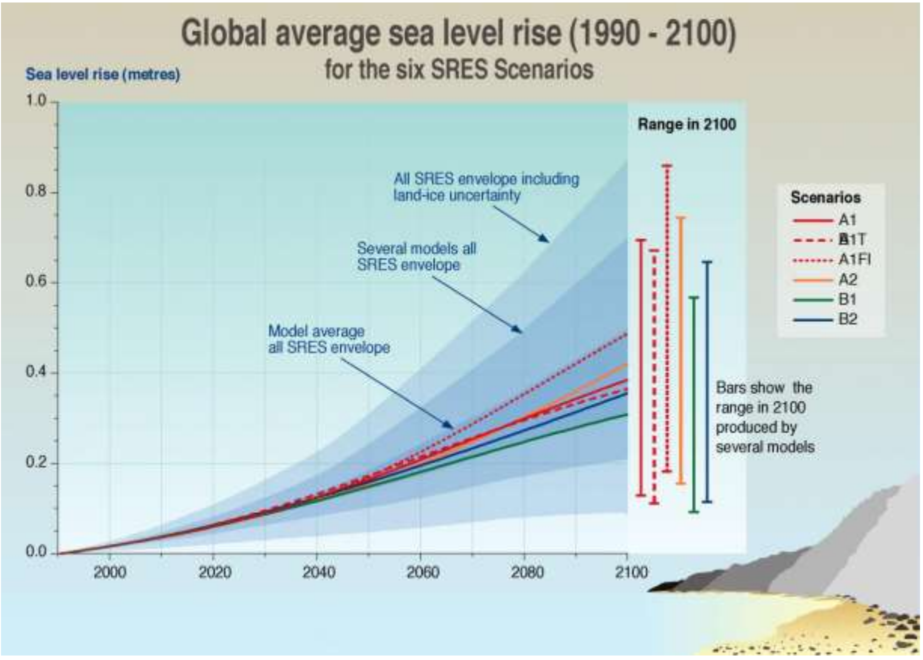


Figure 1.4 Global average sea-level rise (1990-2100)

Figure 1.5 shows specific possibilities for the SLR response of mangroves (Gilman et al., 2006b). In the meantime, Figure 1.5 A had no change in the sea level, and the mangroves will remain in the same place. Figure 1.5 B, where the sea level is rising, mangroves decrease, which causes mangroves and land borders to move to the sea.

Figure 1.5 C Based on the capacity of individual valid mangrove species to colonize new environments at a rate that keeps pace with the speed of the relative sea-level rise, the slope of adjacent land, and the existence of barriers to land migration. Some sites may revert to narrow mangrove fringes or undergo extirpation from land boundary mangroves, such as seawalls and other shoreline defense structures.

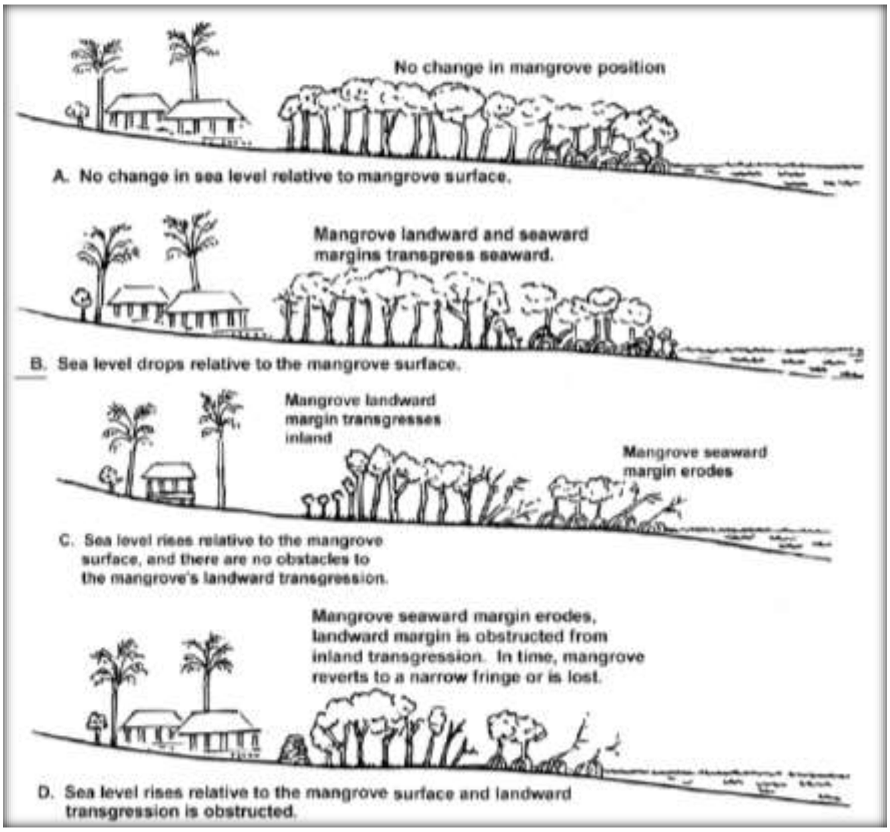


Figure 1.5 General scenario response to relative sea-level rise for mangrove adapted from Gilman et al. (2006b)

Geographical Information System (GIS) is a key technology for visualizing sea level rise, mangrove scenarios, potential impacts (potential mangrove loose sites, coastal erosion, appropriate levee presence, has implications on wetland), and modeling how sea-level rise can increase the frequency of tidal floods (Wright, 2011). GIS is a tool for making decisions based on the human view of thought. GIS provides maps with a table of contents that allows users to add layers of information in real-world locations. It is also a system for analyzing, managing, and displaying geographic information. GIS supports three (3) main views for working with geographic data. (Figure 1.6)

1. Geodatabase view: it contains database datasets that present geographic information models (such as raster, feature, topology, network, etc.)
2. Geovisualization views: A set of brilliant GIS map views related to the Earth's surface.
3. The Geoprocessing view: is a set of GIS transformation tools that recently developed another geographic dataset from existing data ( ESRI, 2004).

Figure 1.6 The perspective of GIS (ESRI, 2004)

The method of detecting and tracking an area's physical features by analyzing its reflected and transmitted radiation from a distance is known as Remote Sensing (RS), typically from satellite or aircraft (Chandra et al., 2020). Although GIS, with the support of RS data, has been commonly used to classify and track mangrove change at various spatial and temporal scales, studies on mangrove change in Malaysia are insufficient. Effective mangrove management requires awareness of forest distribution and improvements to establish conservation policies. Mangrove tracking has recently become a typical usage of RS satellites. The RS may collect knowledge over vast fields, generate repetitive measurements over a location, and allow full use of the electromagnetic spectrum for quantitative and qualitative measures over mangroves, which are the most compelling factors (Omar et al., 2019).

## 1.3 Objectives

This research aims to investigate the spatial distribution of Mangrove growth. It is to develop a map that will produce decision-making in Mangrove Vulnerability Index. The study focuses on the following objectives.

1. To establish an accurate GIS database.
2. To classify the GIS-based Mangrove Vulnerability Index maps for Pulau Kukup, Tg. Piai and Sg. Pulai.

3. To predict the potential impacts due to sea-level rise.

## 1.4 Research Question

Three objectives are the focus of this research. The thesis is driven by research issues, as seen in Table 1.1, to accomplish the analysis's ultimate objective. The research questions form the foundation of this thesis, determining the literature review, methodology, analysis, and recommendations for this research.

Table 1.1 Research Question for this research

| No | Objectives | No | Research Question |
|---|---|---|---|
| 1. | To establish an accurate GIS database. | 1. | How to develop the Accuracy and Precision database for the GIS database? |
| | | 2. | What data is needed in this study? |
| 2. | To classify the GIS-based Mangrove Vulnerability Index maps for Pulau Kukup, Tg. Piai and Sg. Pulai. | 1. | What are the Parameters that contribute to Mangrove Vulnerability Index? |
| | | 2. | What are appropriate methods to create GIS-based Mangrove Vulnerability Index maps |
| 3. | To predict the potential impacts due to sea-level rise. | 1. | How exactly Earth’s climate change and sea-level rise affected mangroves' cultivation? |
| | | 2. | How to predict the outcomes with the impact of sea-level rise to mangrove? |
| | | 3. | How can we observe mangrove growth and affect the surrounding area? |

### 1.5 Scope of the study

The study focused on developing the Mapping Vulnerability Index and Potential Impact prediction using GIS. This study only involves 3 study areas, namely Pulau Kukup, Tg. Piai and Sg. Pulai. Each study area is different in terms of mangrove species, location, and under Johor National Park protected area and declare as RAMSAR (Convention on Wetlands of International Importance Especially as Waterfowl Habitat).

Mangrove Vulnerability Index (MVI) is classified into three main categories, which are Physical Mangrove Index (PMI), Biological Mangrove Index (BMI), and Hazard Mangrove Index (HMI) that develop from the surrounding study area. PMI includes Mangrove Species and Mangrove Height, while BMI considers canopy, NDVI, distance to the coastline, soil and geomorphology type, tidal range, elevation, and salinity. HMI involves Wind, Wave, Rainfall, and Human Activity Industrial, Shipping and Villages.

In this study, researcher was using ArcGIS software to design and develop spatial and attributes databases within the study area. ArcGIS is a convenient software that is eligible for various types of database design and multi-tools for decision-making. It also integrates many kinds of data in the science of geography. The policy of MVI mapping needs information on the predictable development may anticipate and details to these stages.

Stage 1 First stage is a Planning Stage involving management in mangrove mapping in implementing GIS. Study area, data compile, GIS applied method defined in this stage.

Stage 2 Development geographical Spatial and Attribute data from various agencies to set up MVI databased. Cost dan accuracy of data is the main issue to consider in this stage.

Stage 3 Analysis techniques use spatial and non-spatial attribute data to answer questions about mangroves. It is the spatial analysis functions that distinguish GIS from other information systems.

Stage 4 The decision-making method, supervised and unsupervised, proved by increasing data quality and usability, contributing to better MVI decisions.

Lastly, the final maps were produced based on MVI, PMI, BMI, and HMI. MVI Map verifies by Very Low, Low, Moderate, High, and Very High Vulnerability Index. A highly vulnerable Mangrove area or potential mangrove loss area will be monitoring, defined, and calculated.

## 1.6 Significance of the study

The study's main aim is to develop a map with high accuracy in predicting mangrove vulnerability index and indicate sensitivity mangrove, expected time, and possible damages. The approaches of the ranking system for vulnerability assessment of mangrove systems integrate Physical, Biological, and Hazard with human management components, using GIS methods.

Mangrove forests are significant for the ecological and socio-economic production of coastal land. Harada et al. (2002) conducted a hydraulic tsunami impact assessment using five different models, including mangrove, coastal and wave-dissipating structures, breakwater rock, and buildings. It indicates that mangrove is an effective solution for the other four versions. Mazda et al. (1997a) estimated that six-year-old mud forests of 1.5 kilometres in diameter decrease tidal waves from one meter of high open sea to 0.05 meters on the coast by twenty times.

With the popularization of GIS in decision making, related technology will help significantly in the management and analysis of these large volumes of data, allowing for a better understanding of processes and management of human activities to maintain world economic vitality and environmental quality.  It will increase the detail of the representation.

GIS maps are the way to communicate to users in any direction, zoom in or out, and change any information contained in the map. GIS is designed to perform sophisticated calculations for tracking or predicting future earth activities. It helps the user manage, acquire, visualize spatial, analyze, and thematic oceanic data through a map view.

### 1.7 Study Area

This research study area is divided into three different research areas: Kukup Island, Riverbanks of Sungai Pulai, and Tanjung Piai. These three areas are Particularly Sensitive Sea Area (PSSA) to protect the wetlands of international importance, gazetted under the Convention on Wetlands of International Importance or RAMSAR, and as National Parks under the Johore State. The primary ecosystems present in these areas are mangroves and intertidal mudflats, which support significant fisheries, aquaculture, and tourism sectors.

#### 1.7.1 Kukup Island

Kukup Island is located in the southernmost part of Johor, Malaysia. It is 1km off the shore of the state of Johor. Mangroves and mudflats entirely cover it. To promote the preservation of this unique mangrove habitat, Pulau Kukup is declared as a RAMSAR site on 31 January 2003 (Ramsar List, 2015). In 1997, it was protected as a national park under the Johor State Park Corporation Enactment 1989. Kukup Island or Pulau Kukup is one of the biggest inhabited mangrove sites in the world. There are various species of wildlife in the national park (http://johor.attractionsinmalaysia.com/Kukup-Island-National-Park.php).

Pulau Kukup is a 6.4 $km^2$ island situated about 1 km offshore. It is the world's second-largest uninhabited mangrove island, making it one of the few intact sites of this type left in Southeast Asia. Mangroves entirely cover Pulau Kukup, and it is estimated that half of the world's 54 valid mangrove species are found on the island. The coastal strait between Pulau Kukup and the mainland is a thriving industry for marine cage culture. The mudflats are rich in shellfish and provide food and income to local people. Tourism is another use of the island, and the government supports ecotourism activities in the area. Pulau Kukup was legally gazetted as National Parks under the Johore State Park Corporation Enactment, 1989, on 27 March 1997. (Yaakob, 2014)


Figure 1.7 Satellite Image (Spot 2005) Pulau Kukup

### 1.7.2 Riverbanks of Sungai Pulai

The Riverbanks of Sungai Pulai Mangrove Forest Reserve is the most extensive riverine mangrove system in Johore. In 2003 about 9,126 ha of the Riverbanks of Sungai Pulai mangrove was designated as a RAMSAR site (Ramsar List, 2015). RAMSAR sites are wetland areas that are deemed to have international importance and are included in the List of Wetlands of International Importance. The SPMFR plays a significant socio-economic role in the adjacent 38 villages (Mohd. Hasmadi et al., 2011). Riverbanks of Sungai Pulai is managed primarily for commercial wood production using the silvicultural system that requires clear-felling trees under a 20-year rotation. About 80% of the SPMFR consists of mangrove stands less than 20 years of age. The Port of Tanjung Pelepas authority, located at the estuary, works hand-in-hand with environmental groups to conserve the estuary.

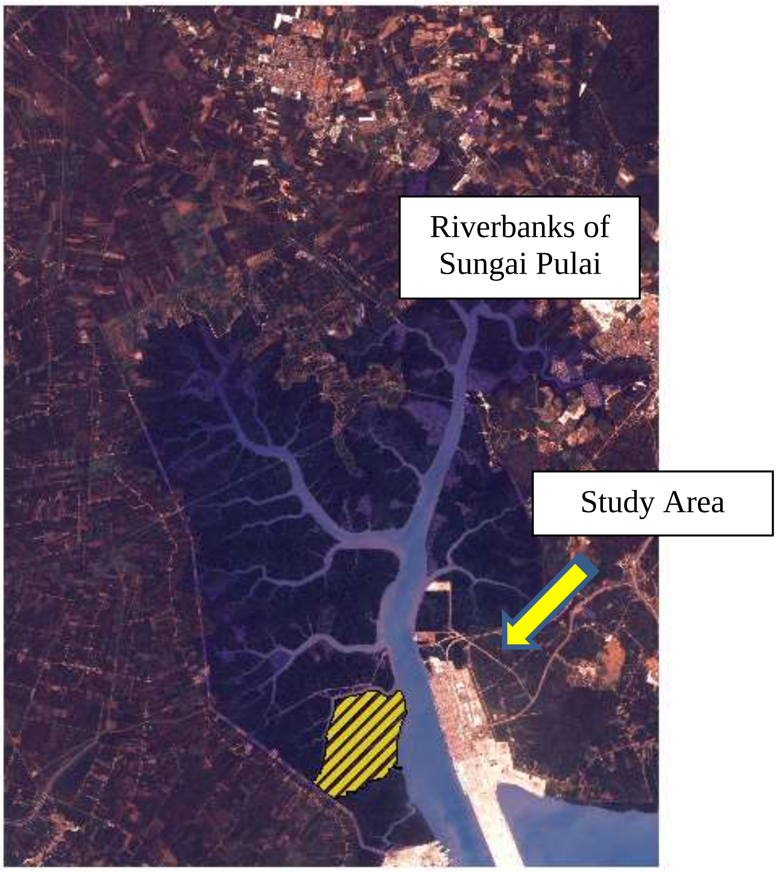


Figure 1.8 Riverbanks of Sungai Pulai

### 1.7.3 Tanjung Piai

Tanjung Piai comprises 5.2 km2 of mangroves and almost four km2 of intertidal mudflats and is the southernmost point of continental Asia. It is located in Mukim Serkat, around 90km from the city of Johor Bahru. It is also one of the most significant mangrove habitats in the whole wide world. Tanjung Piai is the home of around 20 different species of mangrove plants. There is also some wild animal there such as monkeys, mangrove crabs and various species of birds. Tanjung Piai was legally gazetted as National Parks under the Johore State Park Corporation Enactment, 26 February 2004, and as Wetlands of International Importance under the RAMSAR Convention 1971 on 31 January 2003 (Ramsar List, 2015).

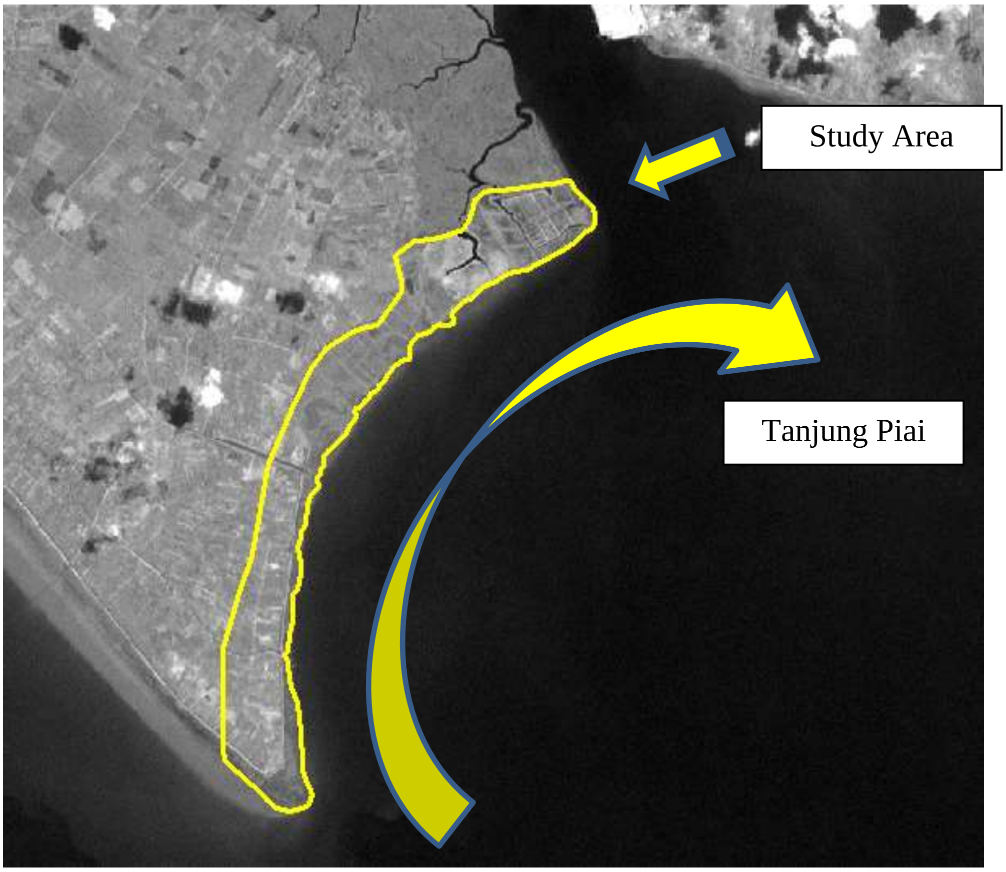


Figure 1.9 Satellite Image ETM year 2000 Tanjung Piai Area

## 1.8 Organization of Thesis Chapter

Chapter 1 provides a brief introduction and background of the vital problem and needs to be carried out. Besides, this chapter stated statement of problem, objectives, research question, scope of study, and significance of the study.

Chapter 2 reviews previous studies that are related to this research. This chapter will focus on the compilation of general concepts, definitions, and related issues associated with mangrove, elaboration methods that were used, PMI, BMI, HMI and Sea Level Rise. Description of GIS, software, reclassify method, design and develop database, conceptual databased design, logical and physical, spatial analysis are explained in this chapter.

The research methodology used in the study will be explained in Chapter 3. It also explains the data collection methods and techniques used to compile the Mangrove Vulnerability Index.

The results and discussion in Chapter 4 are focused on the objective of this research This chapter includes Implementation of Physical Mangrove Index (PMI), Biological Mangrove Index (BMI), Hazard Mangrove Index (HMI) and Mangrove Vulnerability Index (MVI). It is also including of prediction potential impacts due to sea level rise and observation using satellite image. Finally, Chapter 5 consist of Conclusion and recommendation which includes of conclusion, research contribution and recommendation to this study.

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