



GIS-BASED ASSESSMENT OF MANGROVE RESPONSE TO SHORELINE CHANGE ALONG THE COAST OF KUKUP ISLAND, JOHOR

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ABSTRACT

Shoreline and mangrove form a dynamic ecosystem to coastal area. They support and supply various foods and protections for the purpose of environmental friendly and biological balancing around the world. A dynamic phenomenon like shoreline requires the presence of spatial and temporal data to represent and visualize the object's shape and their positions over time. This study is significant to provide a first view of the interaction and response of mangrove species to shoreline change. It utilized the use of multi-sources spatial data to provide shoreline positions between 1997 and 2011. GIS technology along with remote sensing has been proved to be a potential approach to integrate multi-sources spatial data thus enables the derivation of multi-dated shoreline positions. Statistical computation using Digital Shoreline Analysis System (DSAS) was applied to determine the rate of shoreline change along the Coast of Kukup Island. Findings show that the shoreline along the northwest of island appeared to move backward with the rates of shoreline erosion varied between 5.45 m/yr and 9.33 m/yr. However, accretion activities occurred along the northern and eastern areas of island ranged between 0.05 m/yr and 4.58 m/yr. Mangrove profile study revealed that *Rhizophora apiculata* was the dominant species inhabit along the shoreline of Kukup Island. Comparison of *Rhizophora apiculata* physical characteristic and shoreline change rates demonstrated a significant correlation, suggesting that the maturity of mangrove trees found in the area help to reduce the erosion effects. The species that equipped with various advantages enable this mangrove to survive the harsh conditions that come from the ocean and terrestrial. Therefore, the integration of GIS, remote sensing, and statistical method has efficiently improved the analysis of shoreline change and mangrove response due to its cost-effectiveness and data maintenance.

Keywords: shoreline, mangrove, GIS, DSAS, statistical method.

INTRODUCTION

Coastal zone is a gradual transition region occurs through time. Kay and Alder (2005) summarized the definition of a coastal zone as coastal area contain both land and ocean components, have land and ocean boundaries that are determined by the degree of influence of the land on the ocean and the ocean on the land, and are constantly changing in width, depth, or height. It is characterized by the interaction of beaches, mangroves, estuaries, marshes, and fringing, makes it one of the most productive and diverse ecosystem on earth. Coastal components create a dynamic area which is rich in nutrients and sediments that provide a range of foods to different wildlife, organisms as well as fish that inhabit in this area. Migratory birds, macaques, shellfish, and fungi species can be found dominantly live in this area. Apart from providing foods and habitats to different species of animals, these areas are also well known for their capability for protection against storm surge, tsunamis, tides and hurricanes. These create a unique ecosystem for the purpose of environmental friendly and biological balancing.

Dynamic phenomena like shoreline with sediment moving continually, accreted and eroded here and there (Eluyodin *et al.*, 2012; Poulus and Chronis, 2001) requires the presence of spatial and temporal data to

represent and visualize the object's shape and their positions over time. The changes in shoreline position have resulted in the declining of mangrove forest. Located along the shoreline and characterized by the prop roots that tolerate to different salinity and moisture changes to distinguish their dominants towards certain area, it is estimated that 102,000 ha of worldwide mangroves forest were annually lost between 2000 and 2005, by direct and indirect causes of natural threats and human-induced (Omo-Irabor *et al.*, 2010). Droughts, floods, and geological erosion has threatened mangroves ecosystem around the world (Omo-Irabor *et al.*, 2010) and relative sea level rise has been identified as a major factor contributing to recent losses of mangroves and other tidal wetlands (Gilman, 2004). Mangroves formed a highly dynamic and productive ecosystem, providing various resources of foods, timber, fuel and medicine (Giri *et al.*, 2007), as well as offering conducive places for numerous animals breeding.

Changes and events occur in this dynamic phenomena according to Fedra and Feoli (1998), could be modeled and represented by spatially distributed models that describe environmental phenomena in one (for example, in river models), two (land, atmospheric and water quality models, models of population dynamics), or three dimensions (again air and water models). Accurate



predictions of changes to coastal ecosystem area and health, including its response to climate change effects such as projected relative sea level rise, enables advanced planning appropriate for specific sections of coastline to minimize and offset anticipated losses, and reduce threats to coastal development and human safety (Titus, 1991; Mullane and Suzuki, 1997; Ellison, 2004; Gilman *et al.* in press).

Many conducted researches have integrated GIS and other technologies such as Image Processing Systems (IPS); Remote Sensing (RS) with Data Management, Data Analysis and Modeling seems to be a very practical method in data management (Fedra and Feoli, 1998). Some of GIS frameworks and models such as developed by Fedra and Feoli (1998), Van Zuidam *et al.* (1998) and Hennecke (2004) help to provide first view of GIS modeling in coastal zone studies. GIS and RS have been widely used to process and analyze multi-sources spatial data, to combine and compare satellite images of different time of the same area as well as a tool for storing, manipulating and displaying large quantities of geographic data (Eluyodin *et al.*, 2012). To support multi-dated shorelines analysis, Digital Shoreline Analysis System (DSAS) as an extension for GIS analysis is capable to compute the rates of shoreline change, as well as to detect the position of shoreline change in the near future, either the shorelines will continually to erode or accrete over some times. DSAS also helps to ease the daunting task of traditional shoreline analysis which depending on manual calculation and visual interpretation.

As there is still lacking information that exclusively emphasize on the interaction of mangrove response towards shorelines change, this study is significant to provide a first view of the interaction and the relationship and response of shoreline and mangrove species. This research aims at the integration of GIS, remote sensing as well as statistical analysis to study both shoreline change and mangrove response. It utilized the use of multi-sources spatial data to provide shoreline positions between 1997 and 2011.

MATERIALS AND METHODS

Study area

The study area took place at Kukup Island National Park, Johor, the largest isolated mangrove island located 1 km offshore from the south-western tip of the state of Johor, Peninsular Malaysia. Figure-1 illustrates the location of Kukup Island National Park, Johor. Kukup Island is a small mangrove island (647.2 ha) surrounded by mudflats (800 ha) with mature mangrove in the interior, rapidly accreting zones on the west coast, and eroding along the south-east coast. It is a home to about 18 'true' mangrove plant species, which represents very rich species diversity if compared to other far larger mangrove areas in Peninsular Malaysia. Apart from maintaining the physical protection, this island becomes a habitat to various flora and fauna. There are six rivers located around this island.



Figure-1. Kukup Island National Park, Johor.

Data collection

Data collection consists of the acquisition of primary and secondary data. It involved with the acquisition of a number of spatial and non-spatial data such as remotely sensed images, topography maps, and mangrove samples. Ground survey and mangrove profile survey were conducted to collect mangrove species in the study area.

Shoreline change analysis

DSAS was used to perform the calculation of shoreline rate-of-change statistics (Thieler *et al.*, 2009). In DSAS, statistics were computed by merging different historical shorelines into one layer. Three statistics were used to study shoreline change and rates of shoreline change. Net Shoreline Movement (NSM), End Point Rate (EPR) and Linear Regression Rate-of-Change (LRR) was used to study the shoreline change. These analytical methods provide a quick run-times for statistics calculation which involved many shoreline data.

Mangrove analysis

The main features use for the analyses was from the images of root system, leaves and the seedling. Data recorded from clinometers measurement were transformed using a standard equation to obtain the absolute height. Circumferences data recorded too during the survey were transformed to DBH using a standard equation. The location of sampled tree from GPS was transferred into GIS application for better representation and further analyses. Statistical analyses were then carried out to understand the relationship relies between the mangrove characteristics with shoreline changes. The mangrove characteristics used in this study was indicated as the Diameter at Breast Height (DBH) and the tree height. The mangrove characteristics served as the dependent variable and shoreline changes rate was the independent variable. A linear regression analyses was performed using Microsoft Excel Software 2007, to identify the significant relationship between the two parameters. The selected



transect line for landform interaction analyses were based on the nearest distance of the line to the mangrove tree.

Comparison of shoreline change rate and mangrove physical characteristics

Based on the findings of shoreline change, comparison will be made to identify their relationship toward the mangrove physical characteristics. It is important to reveal the significance of shoreline change to the physical characteristics of mangrove community in Kukup Island.

RESULTS AND DISCUSSIONS

Shoreline change analysis

Shoreline change analysis has been carried out in the northeast of Kukup Island which approximately covered a 4.0 km of coastline area. Three baselines were developed along the coast where the samples of mangrove trees were collected through ground survey and analyzed. Cast transect were built at a spacing and length of 50 m and 200 m respectively. This enable a total of 68 transects cast along these baselines and used for analysis purpose. Figure-2 shows the distribution of baselines, transects and shorelines positions for the entire study area.

NSM indicates the distance between the oldest and youngest shoreline features for each transect. NSM computation shows that there were significant movements

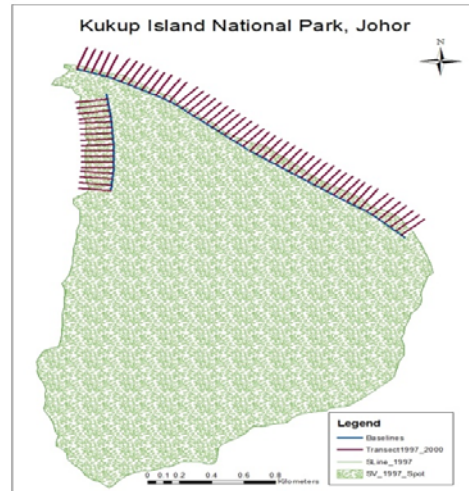


Figure-2. Distribution of transects, baselines and shorelines positions for the entire study area.

occurred in the entire study areas of shorelines. This is based on the total distance movements of shorelines calculated between the time span of 1997-2011. Figure-3 illustrates the Net Shoreline Change between 1997 and 2011.

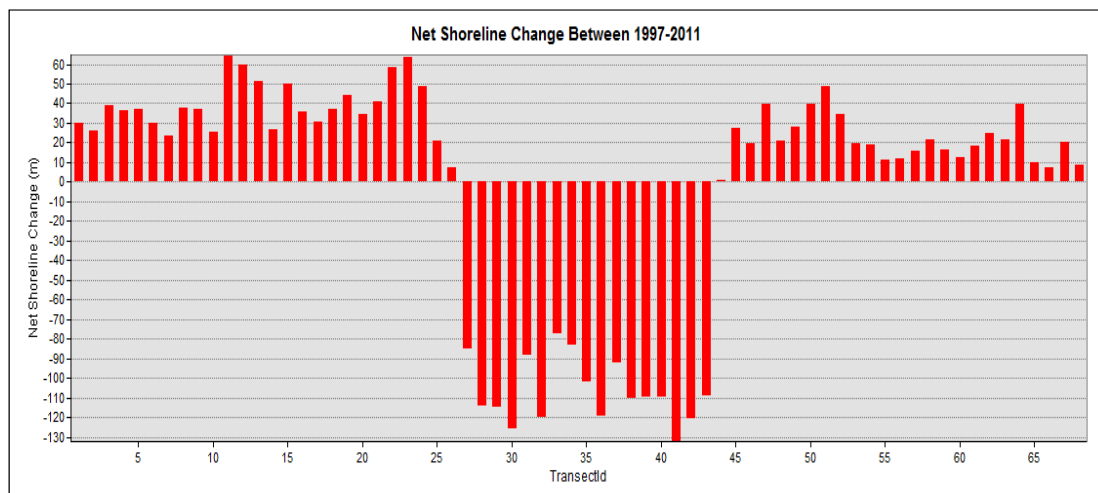


Figure-3. Net shoreline change between 1997 and 2011.

As baselines were created onshore, the minus (-) symbol in the NSM indicates the shoreline backward movement that happened along this shore. Transect cast along the shorelines revealed two distinguish parts of the northern Kukup Island has experienced different movements. Statistics demonstrated that shoreline located along the northwest of Kukup Island appeared to move backward as shown by TransectId 27 until TransectId 43.

The distance of the movements varied, with the highest recorded movements distance was 132.17 m. The rates of shoreline erosion in this area varied between 5.45 m/yr - 9.33 m/yr.

TransectId 1 to TransectId 26 and then continued by TransectId 44 until TransectId 68 which cast along the northern to the eastern of Kukup Island has shown the occurrence of deposition activity along this shoreline.



However, the rates of shoreline deposition in this location were slower, and varied only between 0.05 m/yr and 4.58 m/yr. The highest deposited area recorded was on Transect Id 11. Table-1 describes the shoreline change and change rates for the period 1997 and 2011 represented by EPR and NSM statistics.

Table-1. Statistics of shoreline changes for period 1997-2011.

Statistic	Year (m/y)	1997-2011
EPR	Mean	-0.29
	Standard Deviation	4.14
	Maximum	4.58
	Minimum	-9.33
NSM	Mean	-4.04
	Standard Deviation	61.15
	Maximum	64.86
	Minimum	-132.17

Land backward movements that occurred along the northwest of Kukup Island were influenced by the wind and waves that continuously hit the shore which is situated across the open sea. Exposed shore becomes a subject to ocean swell, making the shore eroded with the higher rates from its original position. Though erosion occurred in this area, eroded materials such as the clayey

alluvial soil and vegetations resulted in a builds up of mudflat. This mudflat is expanding through the years along the west coast of this island. As it accreted rapidly, the seabed became shallow by years as more sediments were trapped under the water and mudflat formed along the coast.

While NSM showed that the land deposited on the northeast coast, statistic revealed that the rates of the land movements along the shores range only between 0.05 m/yr and 4.58 m/yr. Deposition were less formed in this area compared to the erosion rates on the northwest part of Kukup Island. It shows that the accretion could be lead by the sediments that washed away from the Ular River and Solok River. The shore which is situated across the Strait of Kukup is averted from wind and waves that come from the open sea. Alluvial deposited along the shore was capable to be retained by the vegetation's roots that inhabits along the shore, making it resistant towards waves and winds.

Mangrove physical characteristics

Mangrove data such as their species, height, and DBH were collected through mangrove profile survey. Finding revealed that *Rhizophora apiculata* was the dominant species inhabit along the shoreline of Kukup Island. This species could be found at each plot through the sampling survey. The total of mangrove species being sampled along the shoreline is described in Table-2. Figure-4 illustrates the compositions of mangrove species found at Kukup Island shoreline.

Table-2. Mangrove species found at Kukup Island shoreline.

No	Species	Total
1.	<i>Rhizophora apiculata</i> (Bakau Minyak)	54
2.	<i>Rhizophora mucronata</i> (Bakau Kurap)	13
3.	<i>Xylocarpus moluccensis</i> (Nyireh Batu)	5
4.	<i>Bruguiera gymnorrhiza</i> (Tumu Merah)	2
5.	<i>Bruguiera cylindrica</i> (Bakau Putih)	2
6.	<i>Bruguiera parviflora</i> (Lenggadai)	2
7.	<i>Avicennia officinalis</i> (Api-api Ludat)	1
8.	<i>Xylocarpus granatum</i> (Nyireh Bunga)	1

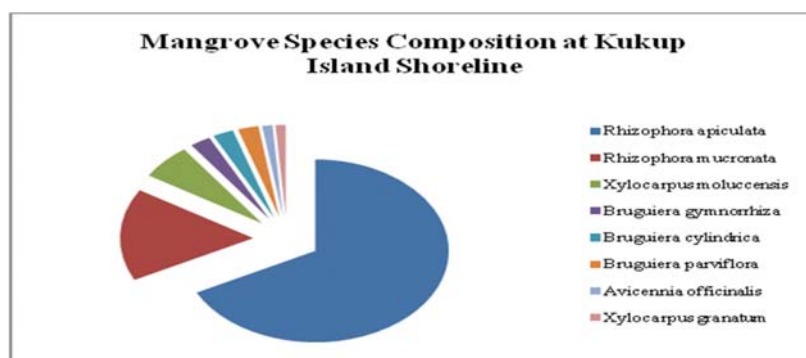


Figure-4. Mangrove composition at Kukup Island shoreline.

Relationship of mangrove physical characteristics and shoreline change rates

Analyzing mangrove physical characteristics toward the changes in shoreline position were conducted using regression analysis. Mean diameter at breast height (DBH) and mean height of *Rhizophora apiculata* were applied to study the correlation between the mangrove and shoreline change rates. DBH and tree height represent the maturity of the mangrove in term of allometric relations. It is used to examine how an individual tree changed during the growth from seedling to adult tree (Aiba and Kohyama, 1997). Result shows that the interaction between mangrove physical characteristics and shoreline change rates are varies. However, further study on the correlation of determination (R^2) at each area indicated best fitting between DBH and height of *Rhizophora apiculata* and shoreline change rates.

Finding shows that *Rhizophora apiculata* physical characteristics of Case I and Case III were negatively correlated to the rates of shoreline change. Through shoreline analysis, Case I situated at the east coast of Kukup Island has experienced shoreline accretion between the time span of 1997 and 2011. According to Duke *et al.* (1992), it is expected that any shoreline retreat resulting in mangrove loss will be offset by sediment deposition in another location allowing new colonization and fertile sediment. The maturity of mangrove trees found in this area provide fully developed root configuration system which help to reduce the erosion effects in shoreline by trapping sediment particles and slowing down the wave action (Kathiresan and Bingham, 2001). Therefore, *Rhizophora apiculata* could withstand the impacts of wave actions and stabilize the sediment structure. Figures 5-8 show the interaction between mangrove physical characteristics and shoreline change rates.

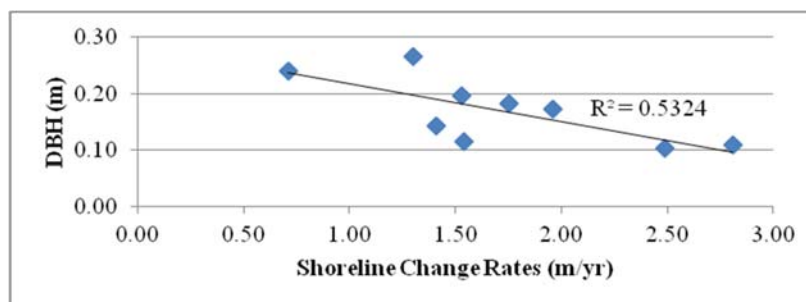


Figure-5. Relationship of diameter at breast height (DBH) and shoreline changes rates at Case I.

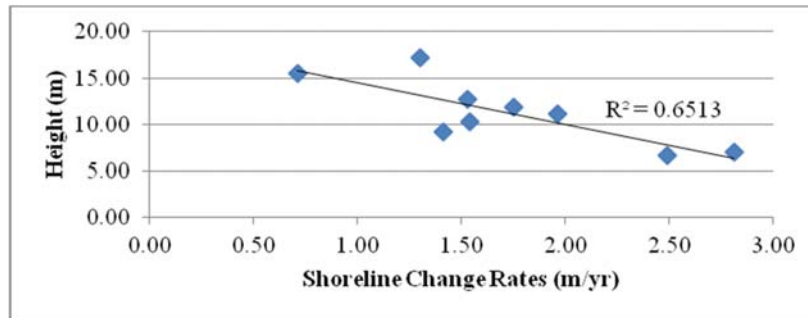


Figure-6. Relationship of tree height and shoreline changes rates at Case I.

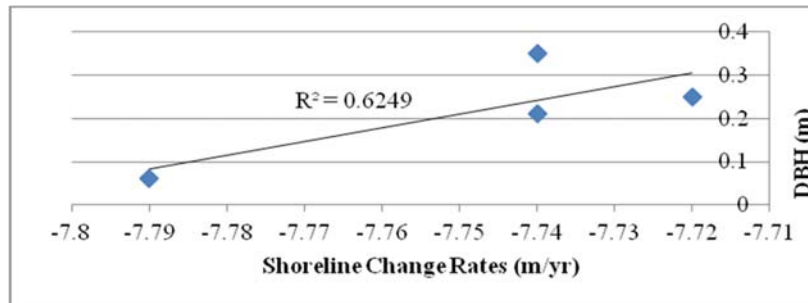


Figure-7. Relationship of diameter at breast height (DBH) and shoreline changes rates at Case III.

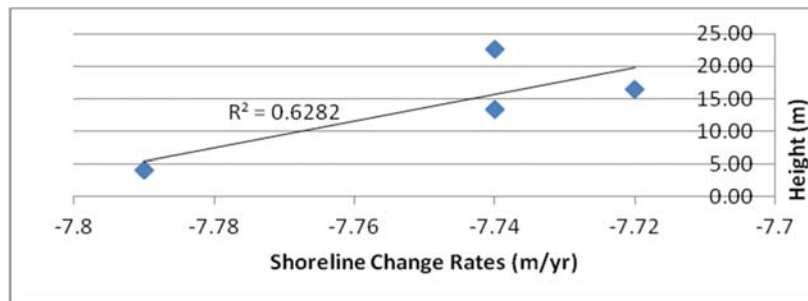


Figure-8. Relationship of tree height and shoreline changes rates at Case III.

Rhizophora apiculata physical characteristics of Case II shows a positive correlation towards shoreline change rates. Figures 9 and 10 show the interaction between mangrove physical characteristics and shoreline change rates of Case II. Despite the rising rates of shoreline change, and located along the northeast of the island, *Rhizophora apiculata* maintain their growth by displaying well-balanced physical characteristics. Located at the intertidal area, they received well-balanced sediment input and were protected from extensive wave actions.

Deposition was most prevalent in the area with the highest physical characteristic, and *Rhizophora apiculata* which equipped with various advantages enable this mangrove to survive the harsh conditions that come from the ocean and terrestrial. The plant stems and leaves slow water velocity, reduce turbulence, and increase deposition (Redfield, 1972; Christiansen *et al.*, 2000; Gedan *et al.*, 2011) while plant roots directly slow rates of erosion by stabilizing the soil substrate (Gedan *et al.*, 2011).

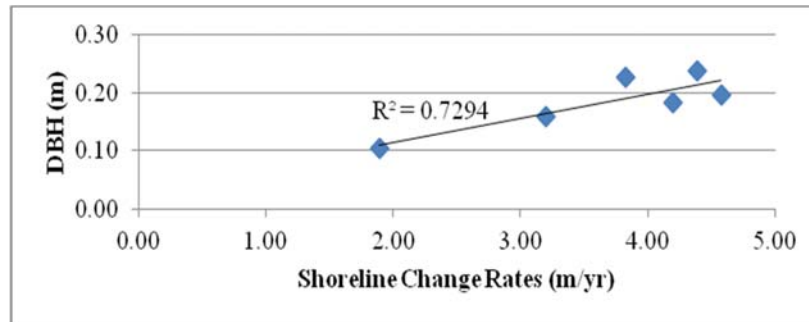


Figure-9. Relationship of diameter at breast height (DBH) and shoreline changes rates at Case II

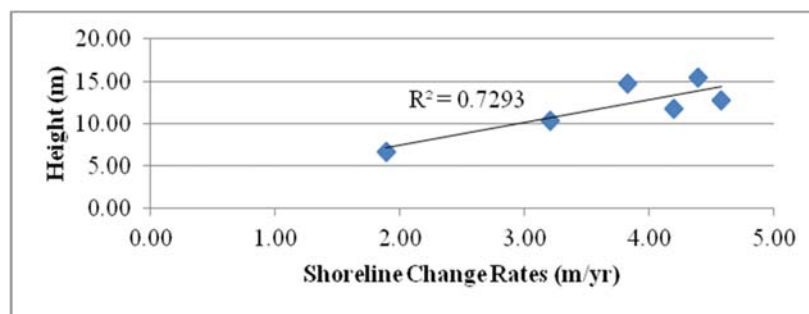


Figure-10. Relationship of tree height and shoreline changes rates at Case II.

CONCLUSIONS

Shoreline and mangrove are two common components found in coastal area. Over time, erosion and deposition occurred as a result of numerous natural processes. Study along the northern and eastern Kukup Island shoreline revealed that accretion activities frequently occurred compare to erosion. In contrast to other species, shoreline accretion enable for the colonization of *Rhizophora apiculata*. Comparison of *Rhizophora apiculata* physical characteristic and shoreline change rates showed a significant correlation, suggesting that the maturity of mangrove trees found in this area help to reduce the erosion effects. The species that equipped with various advantages enable this mangrove to survive the harsh conditions that come from the ocean and terrestrial. A detail study is still needed to be carried out in order to determine the erosion and deposition that might occurred along the shoreline of Kukup Island and it impact towards the shoreline vegetation.

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