MORPHODYNAMICS OF THE TELUK NIPAH SHORELINES

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ABSTRACT

The coastal retreat is one of the most common problems taking place at littoral zones, and it will only become an issue if the area is overwhelmed with commercial developments and anthropogenic activities. The coastal erosion experienced by the shoreline of Teluk Nipah, which is located at the west of Pangkor Island in Malaysia, has triggered some levels of attention among the local authorities and community. The root cause of the erosion and shoreline retreat rates remain uncertain, is due to the unavailability of records studies on beach morphodynamics in the past. Hence, this study aims to assess the decadal shoreline changes of Teluk Nipah by using remote sensing technology. Landsat satellite imageries, which ranges from 1990 to 2018, have been acquired for quantification of the shoreline change rate at Teluk Nipah using a GIS software - ArcGIS. The analysis results indicated that the shoreline is dynamic and unstable between the 1990s to 2010s. The most populated area of the shoreline experienced critical erosion that requires immediate attention by the stakeholders.

Keywords: *Coastal morphology, coastal retreat, erosion, littoral zone, remote sensing*

INTRODUCTION

The coast is the area where land meets the sea and the shoreline is the fringe of land at the edge of a large body of water. Under the influence of environmental processes, the shorelines are prone to a series of alterations. Some plausible reasons for shoreline changes include extreme weather, seawater level rise, natural coastal processes and anthropogenic activities [1]. It is conspicuous that the natural coastal processes which alter the topology of coastal areas are reliant on the beach form, wave and sediment characteristics [2]. The states of the shoreline dynamics can be classified into three categories, erosion, accretion and equilibrium state. In the phase of erosion, the wind, tidal currents and wave action will carry the sediments away from the dune, beach or land [3]. Ironically, the sediments will return to the coastal area as in the event of accretion. The beach is considered as in stable condition where a state of 'dynamic equilibrium' is attained [4]. Hakkou et al. [5] emphasized that the alteration on the morphology of coastline is considered as one of the most dynamic coastal processes within a coastal area. The dynamism of a shoreline elevates when a coastal zone encounters with the occurrence of extreme storm events.

Teluk Nipah Beach, which is one of Malaysia's most popular recreational public beaches is located in Pangkor Island. The shoreline retreat has been happening gradually over the years. The shore erosion becomes worse ever since the occurrence of the extreme storm event in November 2017, putting Teluk Nipah in the endangered state. The critical state of the recreational beach has triggered concerns by the local authorities and the coastal community. In 2018, the coastal engineering team of Universiti Teknologi PETRONAS was invited by the local authorities to evaluate the severity of the coastal erosion problems at Teluk Nipah and to develop coastal restoration efforts. Therefore, this research study aims to assess the coastal morphodynamics of the beach of Teluk Nipah in Pangkor Island by using remote sensing technology and identify the potential root cause of the coastal erosion at the shoreline of Teluk Nipah. This study is a vital initiative in urging a sustainable coastal management plan for the beach.

PROJECT BACKGROUND

Coastal Erosion at Teluk Nipah

Teluk Nipah, as shown in Figure 1, is a 1500 m long sandy beach and is recognized as the most visited recreational beach on the island. The extent of Teluk Nipah is relatively obvious with the existence of a pair of natural headlands sheltering the beach on both ends. Giam Island and Mentagor Island partially shelter this mild-sloping beach with clear water and fine white sand. The commercial development alongshore of Teluk Nipah is considerably dense due to the overwhelmed anthropogenic activities and littoralization effects. Restaurants, homestay, resort, hawker stalls and commercial shop units built along the coastal road and some of them are relatively close to the shoreline.

The stretch of Teluk Nipah shoreline can be divided into two coastal sub-cells, namely the northern cell and the southern cell, as illustrated in Figure 1. Figure 2 shows the coastal developments along the shoreline at the northern and southern cells. In the northern cell (Figure 2a), the beach width, i.e. the distance from the shoreline to the coastal road, varies from 35 to 70 m. Most of the development is located at the south of the northern shoreline. For the southern coastal cell (Figure 2b), the beach at the north is considerably narrow, whereas that at the south is relatively broad. The northern beach is currently under enormous pressure due to rapid development and other anthropogenic activities.

Teluk Nipah shoreline was relatively healthy before 2017 storm events. The beach width was considered ideal, and the buffer distances between the coastal infrastructures and the shoreline were mostly within the acceptable range. However, during the end of the year 2017, the occurrence of storm events at Pangkor Island has caused beach lowering, exposed tree roots, fallen trees and structural damages to the coastal infrastructures. Teluk Nipah beach becomes vulnerable since then. Due to coastal erosion, part of the Teluk Nipah shorelines retreat significantly, and the buffer zone widths fall short of the minimum setback requirement prescribed by the Department of Irrigation and Drainage (DID) of Malaysia, i.e. 60 m from the mean high-water spring.

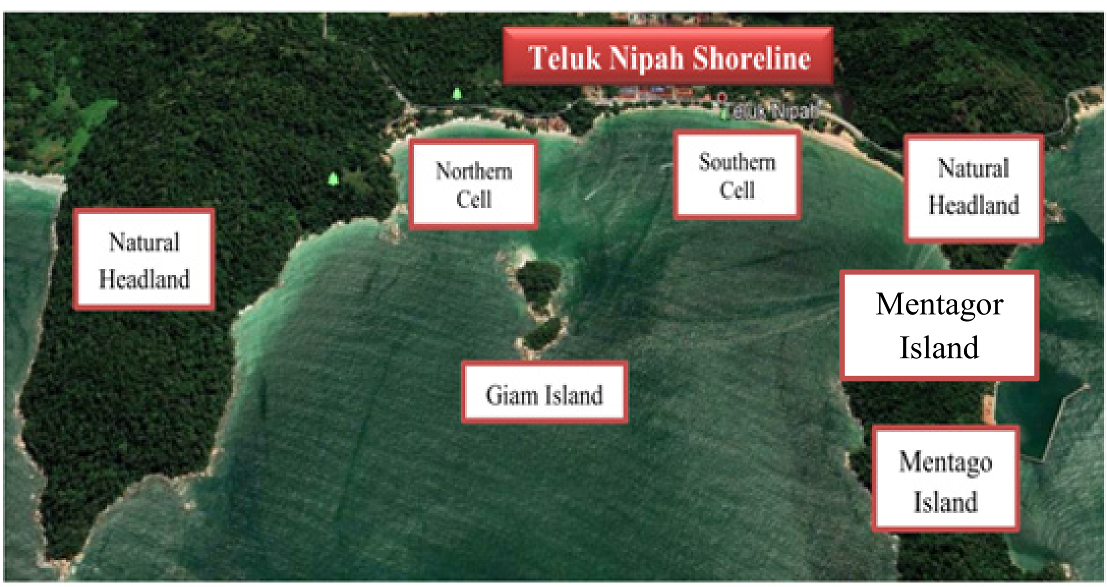
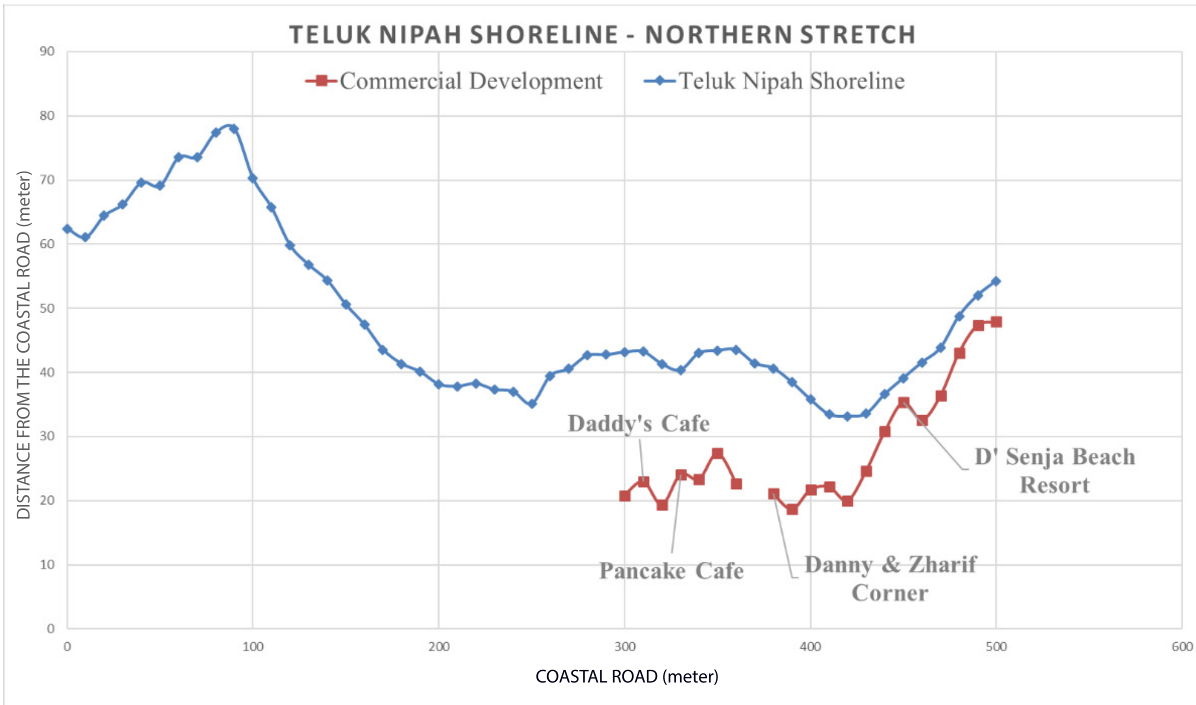
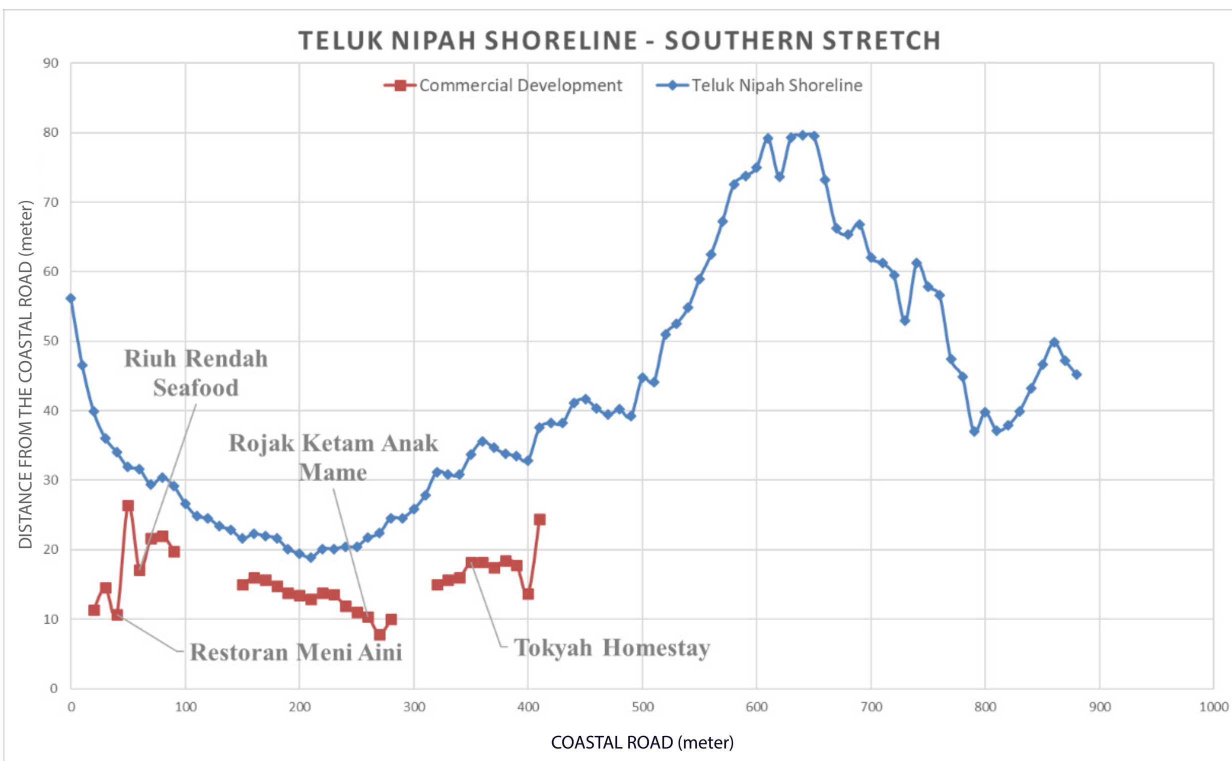


Figure 1 Teluk Nipah shoreline



(a)



(b)

Figure 2 Coastal cells of Teluk Nipah (a) northern cell (b) southern cell

In the northern cell of Teluk Nipah, the coastal erosion invaded the steady-state of the coast when the gabion block in providing shelter to the chalets was disintegrated (Figure 3). Consequently, it led to the scattering of the rocks, which are contained initially within the steel cages of gabion blocks, all over the beach area. Thus, the serenity of the beach had turned into an atrocious and unsafe place to walk. Aside from the damaged protection structure, the aggressive wave actions also crumbled the temporary shelters, and the intrusion of seawater undermined the footings of the public shelters. The aftermath of erosion is evident at the northern cell as the tree roots exposed to the atmosphere due to the beach lowering effect, though the reinforced concrete slab of the coastal food court was severely degraded.

Remote Sensing and Geographical Information System (GIS) Approach

Remote sensing has been increasingly prominent in the study of various phenomena of the earth process system with its recent technological advancement. The remote sensing approach has been perceived as one of the typical applications for evaluating the shoreline changes [2]. Remote sensing technology have been applied to study the coastal morphodynamics of Cape Henry at West Virginia, USA [6], shoreline extraction for Kuala Terengganu coastal zone [7], modelling of coastal wetlands at Pudong New Area (PNA) at Shanghai, China [8], mapping spatial distribution and biomass of coastal wetland vegetation in Indonesian Papua [9] and deriving mangrove changes in Matang Mangrove at Perak, Malaysia [10],[11]. Remote sensing

(a)

(b)

Figure 3 Traces of coastal erosion at the beach of Teluk Nipah
(a) Damaged gabion blocks (b) Scattering of gabion rocks

procedure has expedited the mapping process of the coastal region, where the analysts are able to collect information directly from images onto the maps. Geographical Information System (GIS) is a system designed to capture, store, integrate, analyse and display data which are spatially referenced to the Earth. The cooperative interaction between GIS and remote sensing limits the needs of actual on-site surveying efforts. In this research study, the morphodynamics of Teluk Nipah shorelines is assessed through the remote sensing and Geographical Information System (GIS) approach.

RESEARCH METHODOLOGY

In this study, the remotely sensed data, i.e. Landsat-5 TM, Landsat-7 ETM+ and Landsat-8 OLI/TIRS satellite data was acquired from the open-source. A total of 28 years (1988 – 2018) of satellite images had been acquired from the United States Geological Survey, USGS Department. The resolution of the satellite imagery was 30 m. The shoreline extraction practised in this research adopted the approach of bands combination between Tasseled Cap and Normalized Difference Vegetation Index (NDVI). Table 1 summarises the band combinations applied in the shoreline delineation process.

After the extraction of shorelines from the satellite imagery, the change rates between the extracted shorelines were computed by the Digital Shoreline Analysis System (DSAS). The single transect-based method was adopted in calculating the shoreline change rate. Each transect cast along the shoreline represented a particular profile along the shoreline. In this study, a total of 33 transects perpendicular to the shoreline with an interval spacing of 100 m were distributed along the shore of Teluk Nipah. The locations of these 33 transects are delineated in Figure 4. Two shorelines change rates, which were the endpoint rate (EPR) and linear regression rate (LRR), were computed in quantification on the shoreline change rate. The EPR was computed by dividing the net shoreline movement with the time elapsed between the oldest and latest measurements, while LRR change was computed based on the least square regression line fitting to all the shoreline points for a single transect.

After the acquisition of Landsat Satellite images from USGS, rectification works, such as fixing scanline errors and filtering images with dense cloud cover, were carried out to improve the accuracy of the works. The project preceded with georeferencing the satellite images and classifying the land cover and water body through the approach of band

Table 1 The band's combination of Tasseled Cap and NDVI for the shoreline extraction process

Satellite Imagery Format	Bands Extracted	
	Tasselled Cap	**NDVI**
Landsat 4-5 TM	• Band 1 to Band 5 • Band 7	• Band 3 and Band 4
Landsat 7 ETM+	• Band 1 to Band 5 • Band 7	• Band 3 and Band 4
Landsat 8 OLI/TIRS	• Band 2 to Band 7	• Band 4 and Band 5

Notes:
1. The band combination in Tasselled Cap consists of blue, green, red, Near Infrared (NIR), Short-wave Infrared (SWIR) 1 and Short-wave Infrared (SWIR) 2.

2. The band combination in NDVI consists of red and Near-Infrared Band (NIR) only.

combination between NDVI and Tasseled Cap. Then, quantification on shoreline change rate through DSAS was implemented to obtain the rate of erosion and deposition of the shoreline of Teluk Nipah. Lastly, the project ended with the study on the plausible sources of erosion through interviews and scientific interpretations. The overall project workflow is described in Figure 5.

RESULTS AND DISCUSSION

Shoreline Change Rate Analysis

As mentioned in Research Methodology, the decadal shoreline change rates of the 33 transects established along the Teluk Nipah shore were computed using two approaches, i.e. the endpoint rate (EPR) and linear regression rate (LRR), in this study.

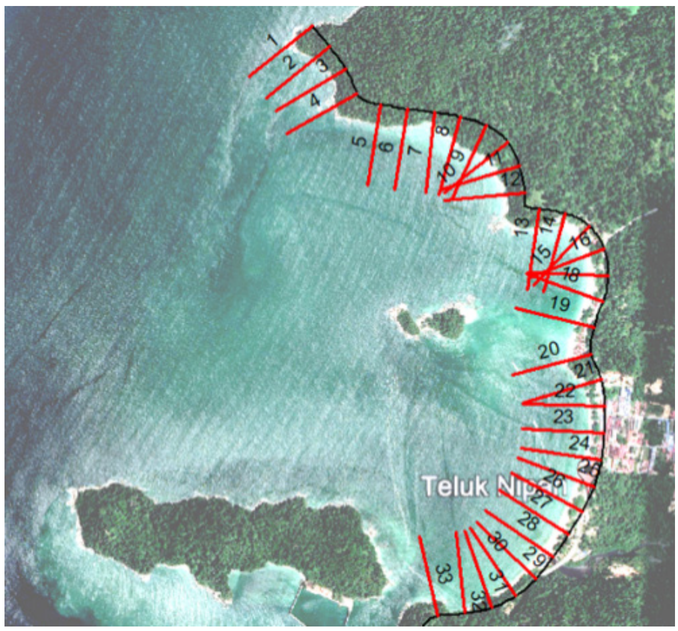


Figure 4 Transects normal to the Teluk Nipah shoreline with an interval spacing of 100 m

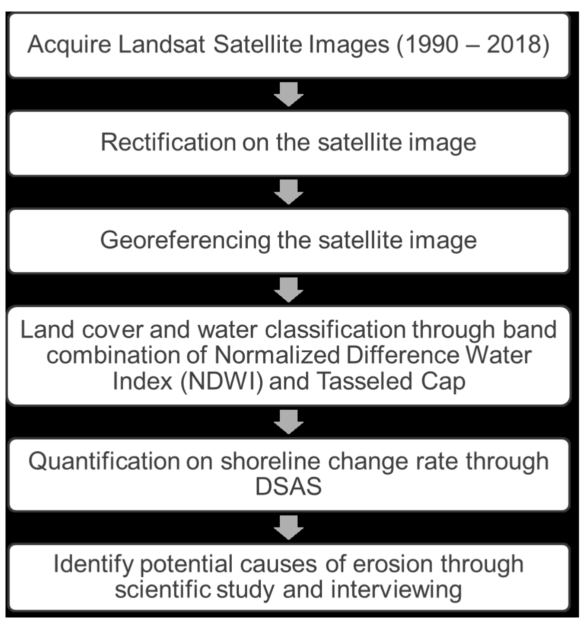


Figure 5 Project workflow

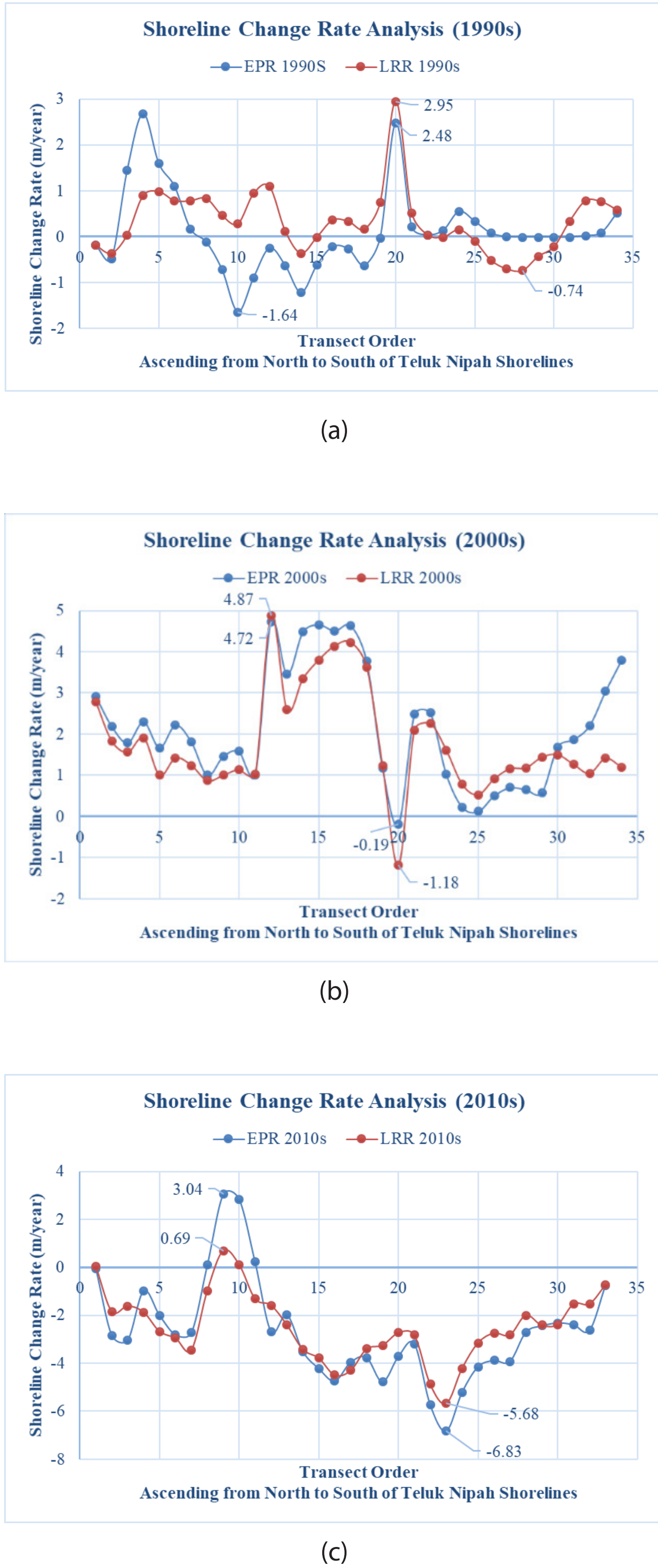


Figure 6 Shoreline change rate analysis (a) 1990s (b) 2000s (c) 2010s

Figure 6 depicts the graphical analysis of the decadal shorelines change rates of Teluk Nipah in the 1990s, 2000s and 2010s using EPR and LRR approaches. Based on the overall trendlines of the decadal EPR and LRR change rates in the 1990s (Figure 6a), even though the shorelines of Teluk Nipah are dynamic; they are relatively stable as the occurrence of erosion and accretion are quite consistent over a series of the transects. In other words, the shoreline is claimed to be in an equilibrium state. The maximum erosion rate goes up to – 1.64 m/year whist the maximum accretion rate reaches 2.95 m/year. During the 2000s (Figure 6b), it is evident that the Teluk Nipah shorelines experienced a major increase in the beach width. The maximum accretion rate and the maximum erosion rate are approximate + 4 m/year and – 1.18 m/year, respectively. In the 2010s, it is evident that from Figure 6c that Teluk Nipah has experienced severe shoreline retreat, particularly at the southern cell starting from Transect 12 to Transect 33. At Transect 23 (the centre of the commercial hub at Teluk Nipah), the annual erosion rate reaches as high as 5 m. The erosion is considered critical at this point. To further evaluate the morphodynamics of the coastal zone at Teluk Nipah, critical profile analysis has been undertaken. The results are presented in the following section.

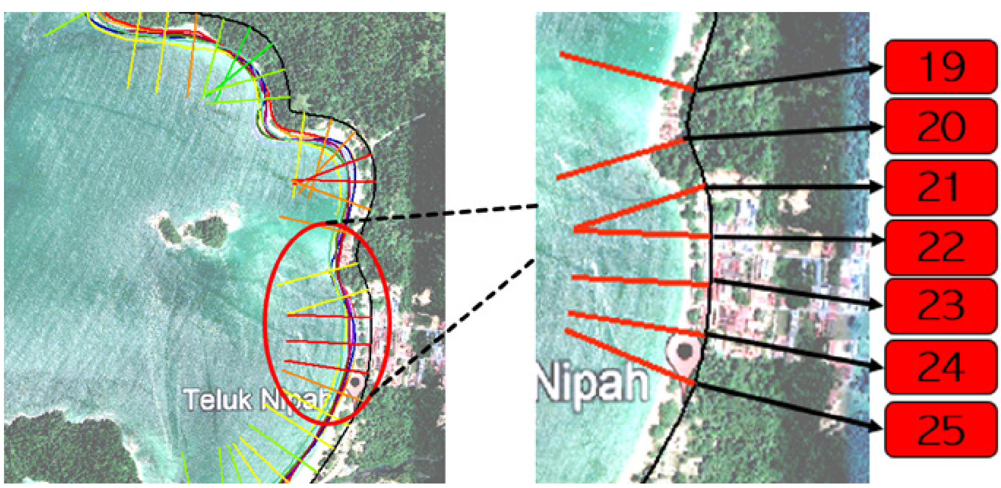
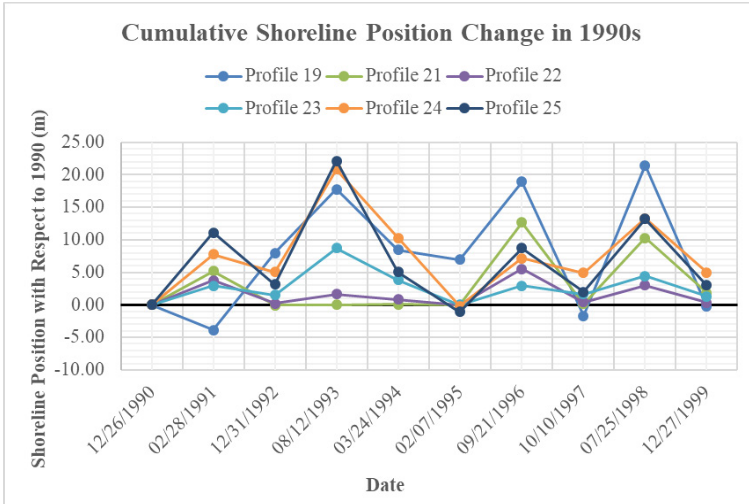


Figure 7 Critical profile analysis for Transects 19-25

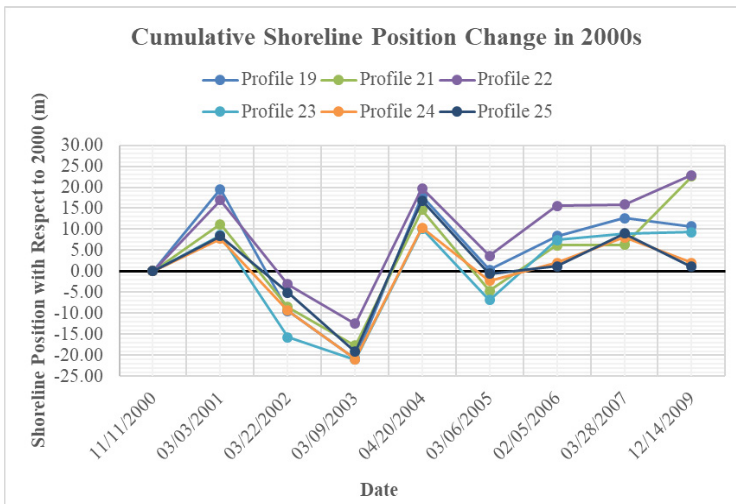
Critical Profile Analysis

Transect 19 to Transect 25, as shown in Figure 7, are identified as the critical transects as the region is considered as the focal point of commercial development and other anthropogenic activities. Restaurants, beach resorts, shop units and other buildings are constructed along this critical littoral zone. Meanwhile, coastal zone ranged from Transect 1 to Transect 18 experienced relatively less commercial development as no commercial units are encountered within this area. Likewise, the southern part of Teluk Nipah, ranges from Transect 26 to Transect 33, displays no signs of severe erosion.

Figure 8a shows the cumulative shoreline position change of the 1990s shorelines in relative to the earliest shoreline in the decade, which is 1990, at Transect 19 to Transect 25. Based on the graph, it can be interpreted that the 1990s shorelines confined between Transect 19 and Transect 25 experienced accretion of different extents. The same observations are found for the 2000s shoreline, except for a period of 2002 and 2003 in which the stipulated area was subjected to erosion. Overall, the shorelines confined between Transect 19 and Transect 25 are of good states during the 1990s to 2000s. Nevertheless, the good state of the shore deteriorates significantly in the 2010s (Figure 8c). It is evident that the shoreline profiles of the critical zones have moved landwards starting from 2013, and the downward trends of the beach profiles continue in the subsequent years without any signs of improvement. Hence, the shore of the most populated and most commercialised area in Teluk Nipah requires immediate rehabilitation efforts by all the stakeholders.



(a)



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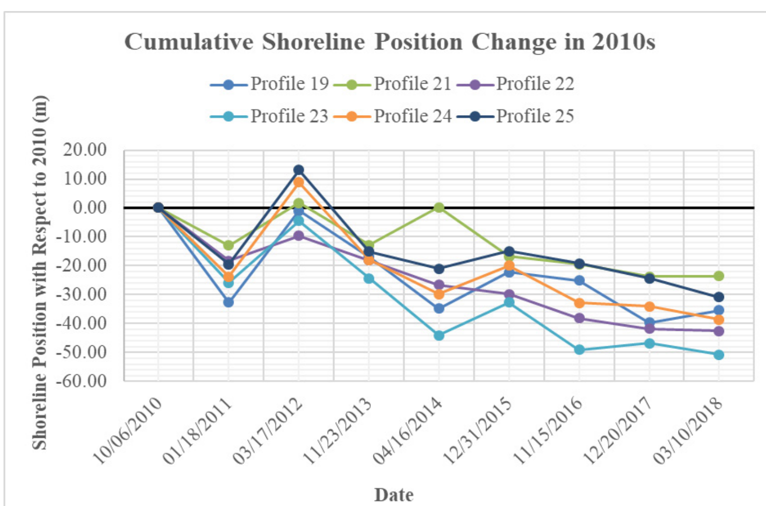

(c)

Figure 8 Cumulative shorelines position changes (a) 1990s (b) 2000s (c) 2010s

It is worthwhile to note that the findings of this research are subjected to uncertainties resulted from the low resolution of the satellite imagery (30 m) and the tidal fluctuation factor. Henceforth, improvements and correction factors should be further applied in future research.

Potential Course of Coastal Erosion

Soil samplings were performed at the berms and swash zone of both cells, as well as the river at the southern cell. The grain size distribution of the soil samples was assessed using sieve analysis. Figure 9 presents the grain size distribution curves of the five soil samples taken at various locations along Teluk Nipah. The sediment grain size of the beach of Teluk Nipah ranges from 0.23 to 1.35 mm. The grain size is uniform and well-distributed. It is learnt that the sediment of the northern cell is finer than that of the southern cell, and the sediment at the swash zone is courser than that at the berms. During site investigations, it was found that the top sand of the southern beach is covered by a thin layer of fine sand of brighter colour. It is believed that the fine sand was carried from the beach at the northern cell via alongshore sediment transport.

The extreme storm event in November 2017 had brought rainfall of 520 mm to Pangkor Island. Denoting the annual rainfall statistics in 2017 in Figure 10, the month of November received the highest precipitation compared to the other months of the year. The strong offshore wind caused a storm surge at Teluk Nipah, causing inundation of 30 to 40 m inland and flooding most of the coastal infrastructure and roads. Not only that, but the storm surge also poses a loss of a large amount of sand at Teluk Nipah resulting in beach lowering, undermining of the structures, exposure of tree roots and fallen trees. The sand was drifted away by the wind waves and never return to the shore again. The single storm event has significantly altered the beach profiles of Teluk Nipah, and the profile change may affect the hydrodynamic regimes of the beach.

Apart from alongshore sediment transport and the occurrence of extreme storm events, it is also believed that the commercial developments within the buffer zone of Teluk Nipah have interrupted the existing natural coastal processes. Ever since the construction of public amenities and hawker units within Transect 21 to Transect 23 in 2010 (*See* Figure 7),

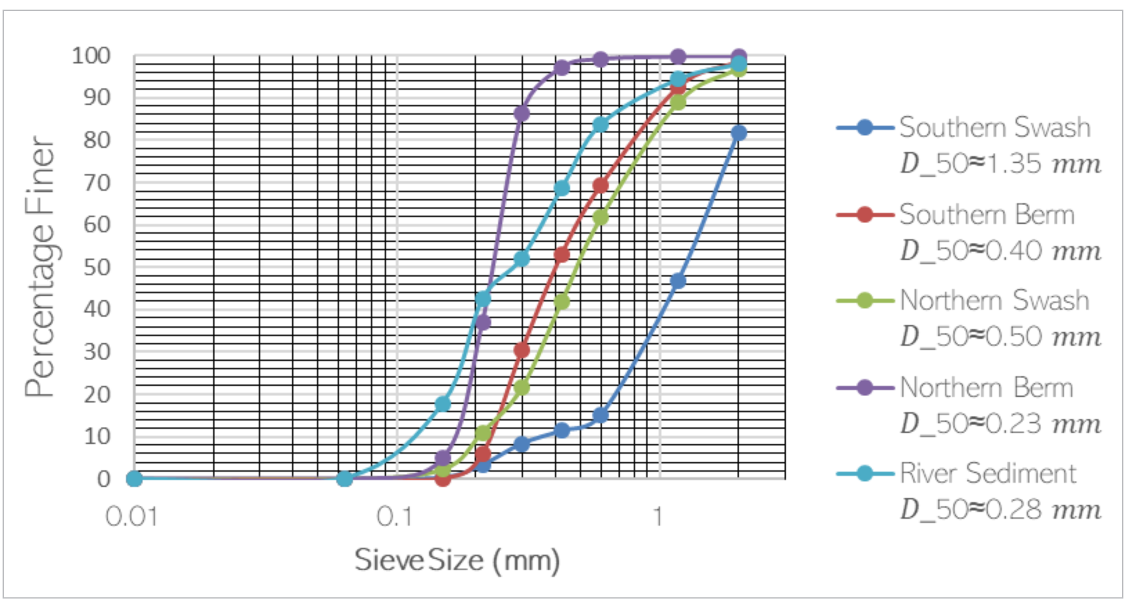

Figure 9 Sediment grain size distribution curves for the beach of Teluk Nipah

the shoreline of Teluk Nipah experiences a significant retreat, as shown in Figure 8c. Hence, it is suggested that the anthropogenic activities have also contributed to alterations on the coastal morphology at Teluk Nipah. All in all, the plausible sources of erosion at Teluk Nipah are identified as the extreme storm events, the commercial development plans and the longshore sediment transport processes.

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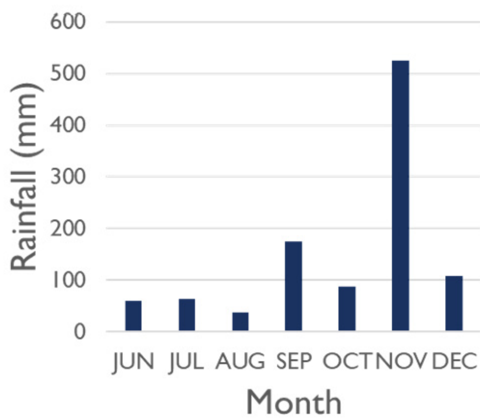

Figure 10 Monthly rainfall in Pangkor Island from June to December 2017

CONCLUSIONS

This research study aimed at evaluating the morphology of Teluk Nipah, Pangkor Island, Malaysia, after the storm event in November 2017. A multi-decadal assessment on the historical shoreline changes was conducted using remote sensing and GIS approach. The results that the shoreline of the 1990s was relatively stable as compared to the shorelines in the 2000s and 2010s. The shoreline of the 2010s experienced an erosion rate of as high as 5.0 m/year in the most populated area. The possible sources of erosion at the beach of Teluk Nipah include the extreme storm events, the commercial development plans and the longshore sediment transport processes. Adequate engineering solutions, for instance, beach nourishment, should be proposed as one of the mitigation steps in curbing the occurrence of shoreline retreat to ensure the safety and wellbeing of the public and local communities.

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