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SHORELINE MAPPING OF TELUK NIPAH USING DIGITAL SHORELINE ANALYSIS SYSTEM (DSAS) IN ARCGIS WITH TIDAL CORRECTION

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ABSTRACT

Shoreline characterization using remote sensing technologies is a useful tool to determine the historical shoreline changes of a specific coast. Tidal variation is one of the important factors that should be considered in the shoreline mapping exercise. However, the tidal correction has often been neglected due to the need to access the historical tidal data series for the study site. As a result, the accuracy of the shoreline mapping without tidal correction is ambiguous. Hence, this study aims to establish the historical shoreline mapping of Pantai Teluk Nipah, Pangkor Island, Malaysia, with a tidal correction, using ArcGIS software. For 30 years of the study period, Landsat satellite imageries were processed via ArcGIS to quantify the shoreline change rate. Based on the previous shoreline mapping study without the tidal correction, transect 23 of Pantai Teluk Nipah has undergone severe erosion where the erosion rate is up to –6.83 m per year. With consideration of tidal correction, the shoreline erosion rate at the same transect has reduced to –3.87 m per year, which is consistent with the current beach condition at Pantai Teluk Nipah.

Keywords: *coastal, shoreline extraction, remote sensing, tidal effect, erosion, coastal retreat, tidal correction*

INTRODUCTION

Pantai Teluk Nipah is one of the most visited recreational beaches in Pangkor Island, Malaysia. The beach was severely confronted by a series of storm waves in November 2017, resulting in severe coastal erosion destruction to buildings and temporary shelters along the beach. The first shoreline mapping of Teluk Nipah was conducted by Foo [1] in 2019. From his results, the most severe erosion happened at the southern cell of Pantai Teluk Nipah, recording a rate of –6.83 m per year. This erosion rate requires further validation. Therefore, tidal correction is necessary to fix the discrepancies caused by tidal level changes. The tidal correction exercise requires the details of the tidal condition when the satellite image was taken. In this study, an attempt is made to reproduce the historical shoreline of Teluk Nipah using the same technological tool and with a tidal correction.

Study Area

This research will focus on the area of Teluk Nipah shorelines is shown in Figure 1. Teluk Nipah is a mild-sloping sandy beach that is 1500 meters long. The stretch of the Teluk Nipah shoreline can be further divided into two coastal sub-cells, namely the northern cell and the southern cell. Commercial development along the coast of Teluk Nipah is extensive owing to anthropogenic behaviour and the influence of the coastline. Dense development along the coastline which brings enormous pressure in the southern cell of Teluk Nipah.

Figure 1 Location and Aerial photographs of Teluk Nipah shoreline
Source: Google Maps

Coastal Erosion in Teluk Nipah

Manjung Municipal Council (MPM) has raised awareness of the coastal instability of Teluk Nipah after the storm in 2017. It is clear that the beach at Teluk Nipah was relatively healthy and overlaid with soft fine sand as shown in Figure 2. The beach width was considerably suitable and the protection intervals between the coastal buildings and the shoreline were within an acceptable range. In short, before the major storm incidents in 2017, the beach was resilient and in a healthy state.

In Teluk Nipah's northern coastal region, it is unquestionable that extreme coastal erosion has breached the coastal area's stable state as the temporary barrier structure, gabion blocks constructed by MPM, is disintegrated to shelter the chalets. Apart from the eroded protection structure, the destructive wave activities have crumbled the temporary shelters and the infiltration of seawater has eroded and scoured the footings of the public shelter.

Shoreline Data Analysis

Remote Sensing by GIS Approach

Remote sensing and Geographic Information System (GIS) technologies have contributed to changes in coastal geomorphological research, such

Figure 2 Beach condition at the northern cell of Teluk Nipah prior to the 2017 storm events

as Shoreline Change Analysis using DSAS in Nam Dinh, Vietnam, Shoreline Change Analysis using End Point Rate and Net Shoreline Movement Statistics in Elmina, Cape Coast and Ghana Coast, Shoreline Changes Assessment in Merjerda, Tunisia, Shoreline Changes Mapping in the Province of Bushehr [2]-[5]. With remote sensing technology, it is cost-effectiveness, decrease human error and avoidance the analytical nature of conventional field techniques thus, this method is desirable. In this study, ArcGIS, established by the Environmental System Research Institute (ESRI), will be used in the extraction phase on the shoreline and ArcGIS reliability has been validated by a previous study [6]-[8].

Digital Shoreline Analysis System

The Digital Shoreline Analysis System (DSAS) is a GIS-based system developed by the United States Geological Survey (USGS). A multisource approach for coastline mapping and identification of shoreline changes. This extension extends the normal functionality of the ArcView GIS to include historical shoreline change analysis. DSAS measures gaps between the shoreline positions during defined periods of time. This provides the basic data to calculate the shoreline changes. The historical trend of these shoreline changes is based on indicators of the shoreline geometry. The system controls the following coastline characteristics: historical coastline dynamics, shoreline change, development and evolution of gulls, cliff retreat and erosion, shoreline measurement and modelling [9].

Quantifying Shoreline Change Rate

Single-Transect based Method

A reference datum will be self-defined and plotted along the coastal shoreline in Single-transect approach. The difference between the contemporary shorelines with the self-defined baseline will be calculated and Digital Shoreline Analysis System will compute the rate of shoreline changes. The distance between each transect is subjected to the morphology of a shoreline. Nevertheless, it is obvious and relevant that the shorter the distance between each transect, the higher the accuracy of the shoreline analysis. Allen et al. [10] described the beaches as fair and linear features with a high level of consistency in the alongshore direction; hence a considerable distance between each transect is acceptable. In short, the transect method is adequate for the practice of quantifying shoreline movement rates. Figure 3 shows the illustration of the mechanism for the Single-Transect based method.

Rate of Shoreline Change Analysis

End Point Rate (EPR) is calculated by dividing the distance of shoreline movement by the time elapsed between the earliest and latest measurements (i.e., the oldest and the most recent shoreline). The disadvantage is that in cases where more than two shorelines are available, the information about shoreline behaviour provided by additional shorelines is neglected. Thus, changes in sign or magnitude of the

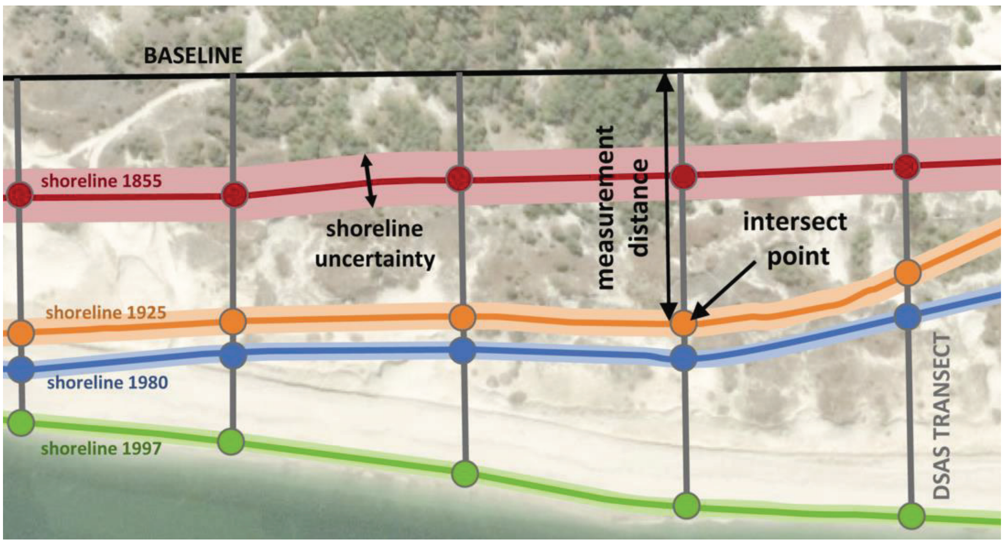

Figure 3 Mechanism of Single-Transect based method
Source: Digital Shoreline Analysis System (DSAS) User Guide Ver. 5.0

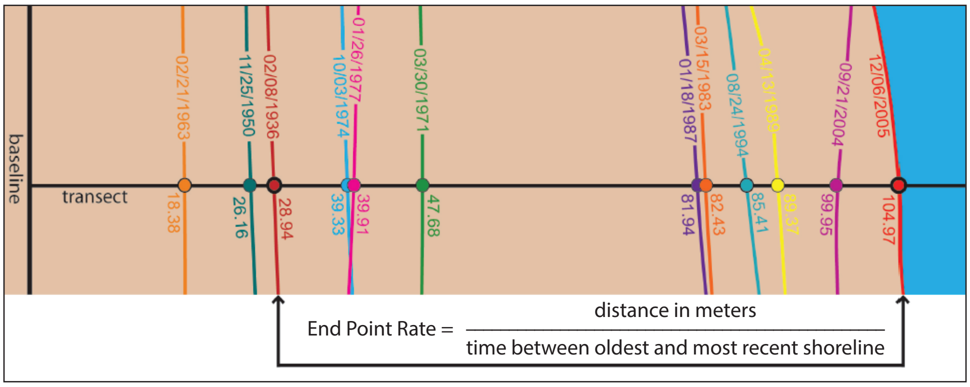

Figure 4 Illustration on the computation of endpoint shoreline change rate
Source: Digital Shoreline Analysis System (DSAS) User Guide Ver. 5.0

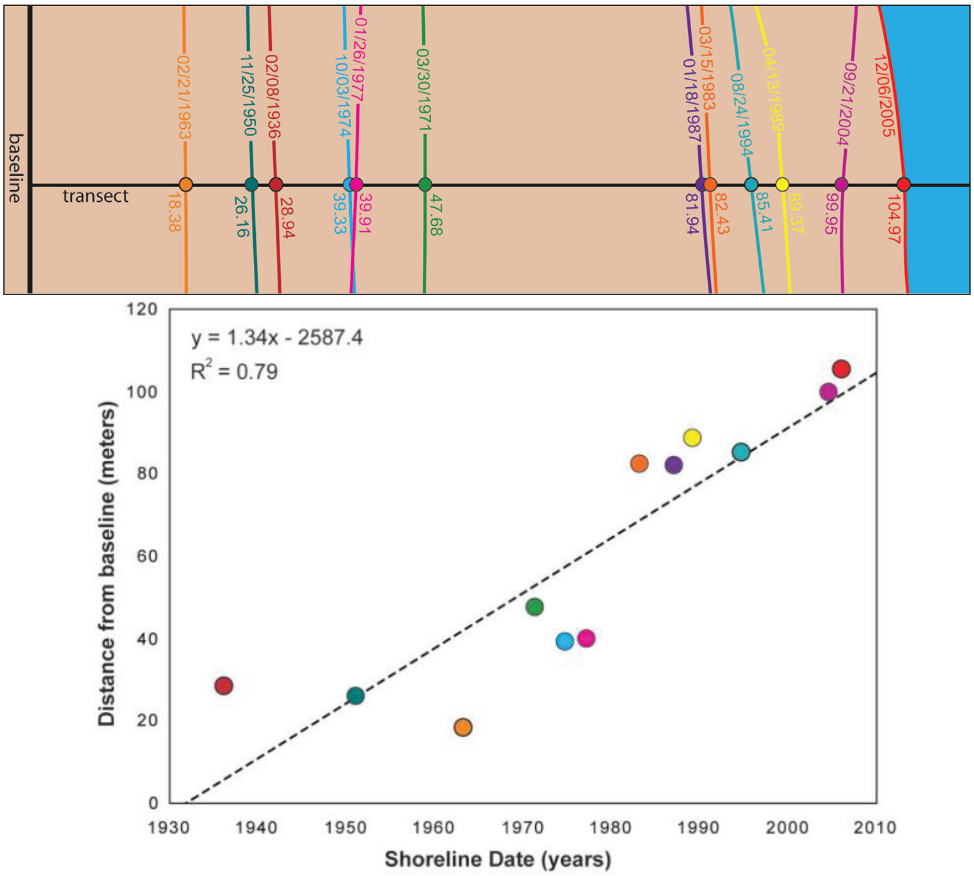

Figure 5 Illustration on the computation of line regression shoreline change rate
Source: Digital Shoreline Analysis System (DSAS) User Guide Ver. 5.0

shoreline movement trend or cyclicity of behaviour may be missed. This method is shown in Figure 4.

Linear Regression Rate (LRR) rate-of-change statistic can be determined by fitting a least-squares regression line to all shoreline points for a transect. The rate is the slope of the line. The method is purely computational, and it is based on accepted statistical concepts and easy to employ. This method is shown in Figure 5.

Tidal Correction Method

Tidal correction starts by seeing the tide height between the date of the image recording and the date of the tidal predictions. The need for tidal correction considers the extent of the influence of fluctuations in sea level height at highs and lows which are caused by the coastal slope and the image's spatial resolution. Evaluation of the impact of tidal correction is performed by contrasting the location of the tidal-corrected shoreline with that of the shoreline not adjusted for tides. Differences in the position of the two shorelines reflect the impact of tidal change—shoreline shift calculation when there are differences in tidal conditions between the test shoreline and the shoreline reference. Wicaksono et al. [11] has done tidal correction analysis on shoreline mapping in Jepara Regency, Indonesia using the right triangle theory and Equation (1) shown in Figure 7.

METHODOLOGY

Data Collection

In this study, the remotely sensed data, i.e., Landsat-5 TM, Landsat-7 ETM+ and Landsat-8 OLI/TIRS satellite imagery was acquired from the open-source. A study period of 30 years (1990–2010) of satellite images had been acquired from the United States Geological Survey(USGS) Department. The resolution of the satellite imagery varies from 15 metres to 30 metres [12].

Rectification of Satellite Images

After acquiring satellite imagery, rectification works for the satellite images, such as filtering images without cloud cover and fixing scanline errors to improve the precision of shoreline delineation while the software detects the shorelines. The shoreline extraction practised in this research adopted the approach of bands combination with Tasseled Cap and Normalized Difference Vegetation Index (NDVI). Satellite images with clear shoreline boundaries after rectification were chosen for comparison in this study.

Shoreline Delineation

Shorelines from the year 1990 until 2019 were extracted using the Digital Shoreline Analysis System (DSAS) which is an extension tool in ArcGIS. The single transect-based method in the system is used in calculating the shoreline change rate. Each transect casted along the shoreline will represent the profile at the Teluk Nipah shoreline. In this study, 33 transects with a spacing of 100 metres had been casted along the coastline, as shown in Figure 6.

Quantification of Shoreline Change Rate Analysis

Two types of quantification methods were selected to compute shoreline change rates, which are

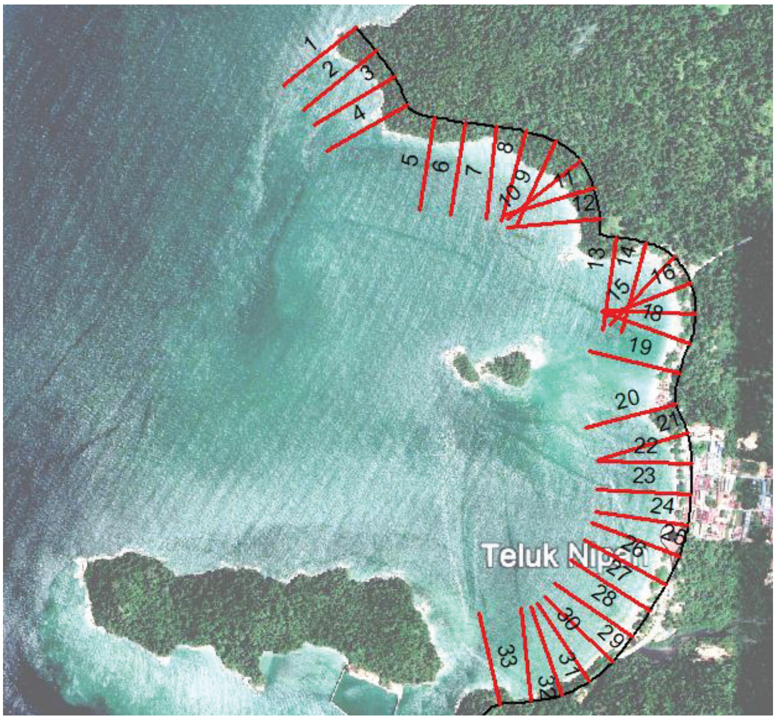

Figure 6 Transects along Teluk Nipah shoreline with 100 m intervals
Source: USGS EarthExplorer (04° 13' 56"N, 100° 32' 39"E)

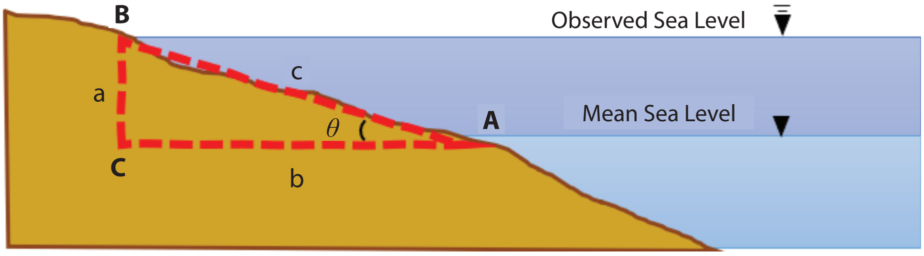

Figure 7 Right-Triangle Theory applied in this study

the End Point Rate (EPR) and Linear Regression Rate (LRR) have been adopted and computed in this study area. The computed shoreline change rate was exported to Microsoft Excel file for adjustment of shoreline position by applying the tidal correction.

Tidal Correction

The tidal correction would be based on Right Triangle Theory [11],[13]. Tidal height readings were obtained from the "Malaysian Tide Tables" for 30 years provided by the National Hydrographic Centre, Royal Malaysian Navy. It includes the prediction of times, heights of high, low water, the hourly heights and the tidal streams. The closest station to Pangkor Island is in Lumut, Perak. Figure 7 shows the mechanism of the Right Triangle Theory applied in this study. As in equation (1) is used to determine the original shoreline position (A) by substituting tidal differences level (a) and beach slope (θ) into the tangent equation to obtain differences in shoreline position (b). It is then added back to the actual shoreline position (C) to find the shoreline position with respect to Mean Sea Level. The observed sea level is estimated based on the simultaneous capture time of the satellite image and a tide table is used to find out the range of water level to be adjusted using Standard Tidal Curve to predict the approximation of seawater level of capture time for satellite imagery.

$$tan\ \theta = \frac{a}{b} \tag{1}$$

where,

a = tidal difference between the highest (Landsat imagery) minus the water level at MSL

b = value of shoreline shift at the highest tide (Landsat imagery)

θ = slope angle of the beach measured

Project Workflow

Figure 8 prescribed the overall project workflow of this study. First, data collection has to exquisite 30 years of free satellite data from the USGS website and highlight the Area Of Interest (AOI), Teluk Nipah in Pulau Pangkor to extract the images before processing the data into the analysis. Shoreline extraction was then determined by DSAS in ArcGIS to be exported

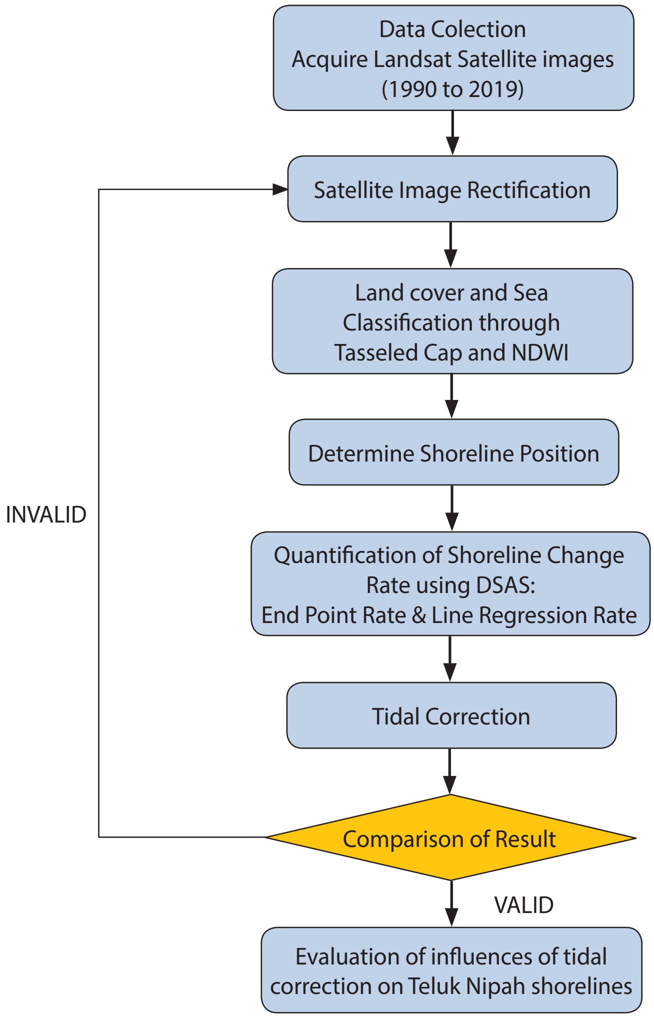

Figure 8 Project workflow

as a shapefile. Results of extracted shorelines were categorized into 3 decadal categories for EPR and LRR for quantification of shoreline change rate and tidal correction were made accordingly. The result would be rejected if the shoreline change rate increased and satellite images would be reselected to proceed for result comparison. All the results are exported into Ms Excel for tidal correction. Lastly, results will be evaluated based on graph trends.

RESULTS AND DISCUSSION

Delineated Shorelines

The delineated shorelines were categorised into 3 classes of decades, which are the 1990s, 2000s and 2010s. Illustrations of the delineated shoreline for respective decadal periods are shown in Figure 9 from the 1990s, 2000s and 2010s. The derived multi-decadal shorelines show that the historical morphology changes over the decades are considered uniform as there are no major changes in the shape and orientation of the Teluk Nipah shores. Nevertheless, the shorelines have undergone shifts in either landward movement (coastline retreat) or seaward movement (sediment deposition).

Shoreline Change Rate

End Point Rate (EPR) Shoreline Change Rate and Line Regression Rate (LRR) Shoreline Change Rate was selected as it was done in the previous study for ease

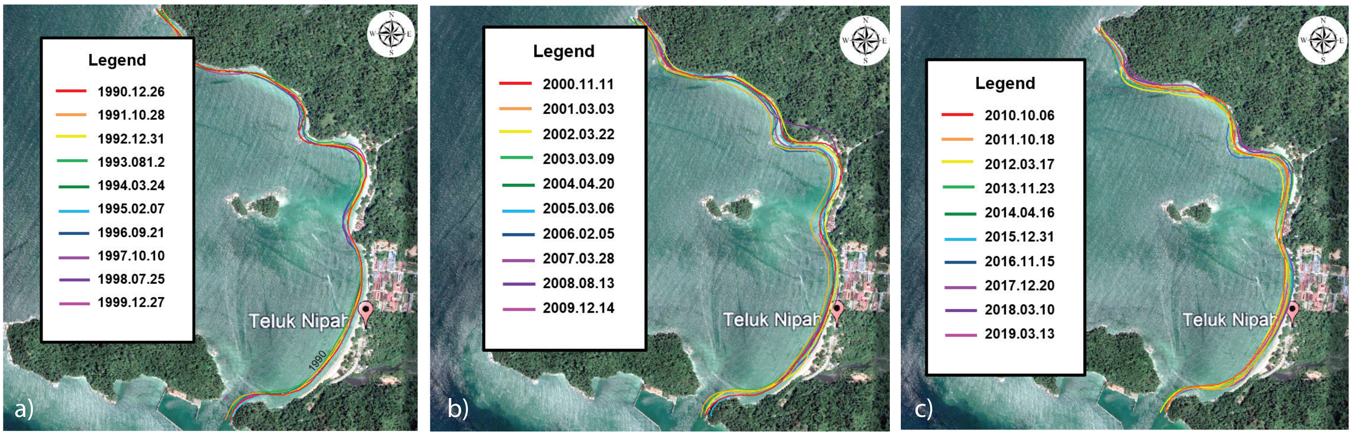

Figure 9 Delineated shorelines in the a) 1990s, b) 2000s and c) 2010s

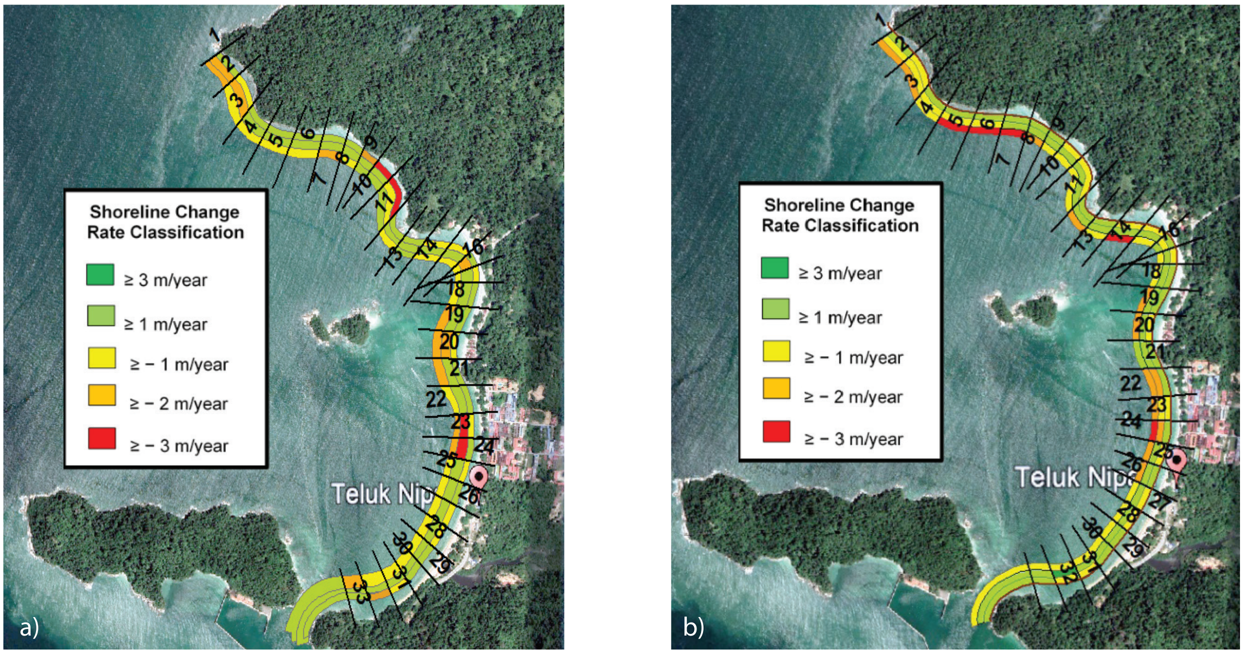

Figure 10 Comparison of 3-decadal shoreline change rate using a) End Point Rate and b) Line Regression Rate

of comparison. The computed multi-decadal shoreline change rate study is shown in graphical presentation under the classification of 3 different decades in EPR and LRR in Figures 10a and 10b. Figures 11, 12 and 13 represent the comparison of shoreline change rate with the previous study for End Point Rate while Figures 14, 15 and 16 are the comparisons of shoreline change rate using Line Regression Rate. It is conceived that EPR has higher fluctuation in trendline movement compared to LRR as it is only considered the newest and oldest shoreline in the calculation, whereas LRR takes all the delineated shoreline into consideration which makes it has lower fluctuation in the graph compared to EPR.

End Point Rate

Figure 11 depicts the graphical analysis for the comparison of shoreline change rate with consideration of tidal effect and previous study in Morphodynamics of Teluk Nipah in the 1990s. Based on the overall trendlines of both change rates, it is interpreted that EPR with tidal correction line is relatively stable as the occurrence of erosion and accretion events are considered in equilibrium, whereas the previous EPR line has a higher fluctuation between the erosion and accretion rate. The maximum accretion rate using EPR shoreline change rate after tidal correction reached 2.21 m/year while the erosion rate reached –1.60 m/year. The maximum erosion rate used for the previous EPR goes up to –1.58 m/year whilst the maximum accretion rate reaches 3.19 m/year. Based on Figure 12, it's the EPR in the 2000s after tidal correction. The rate of shoreline change analysis is relatively equilibrium compared with the previous rate without considering the tidal effect. The shoreline change rate with tidal correction is comparatively healthy as the maximum erosion and accretion rate are almost equal, which are 2.42 m/year and –2.77 m/year, respectively, whereas the previous EPR shoreline change rate has a relatively unstable pattern as the maximum accretion rate has hit 4.72 m/year while erosion rate has only –0.19 m/year. It is conceived that Pantai Teluk Nipah has experienced severe coastline retreat starting from the 2010s. Based on the graphical representation in Figure 13, the pattern of both trendlines is mostly negative as erosion has occurred at the specific transects. The corrected shoreline rate has a relatively stable pattern compared with the previous EPR rate without tidal correction. It is evident that transects ranging from 12 to 33, where the majority of them represent the southern cell of the study area, have experienced coastal erosion issues. The erosion rate before the tidal correction was severe, where it reached around –6.83 m/year at Transect 23, whereas the maximum erosion rate after the tidal correction was –3.76 m/year at Transect 18, which has a comparatively lower intensity of erosion rate in the 2010s. It is believed that the severe erosion rate starting from the 2010s was due to the commercial developments. By applying tidal correction, the result is happened to be relatively reliable and convincing as the most severe erosion rate has reduced from –6.83 m/year to –3.76 m/year, which is almost 3 meters indifference.

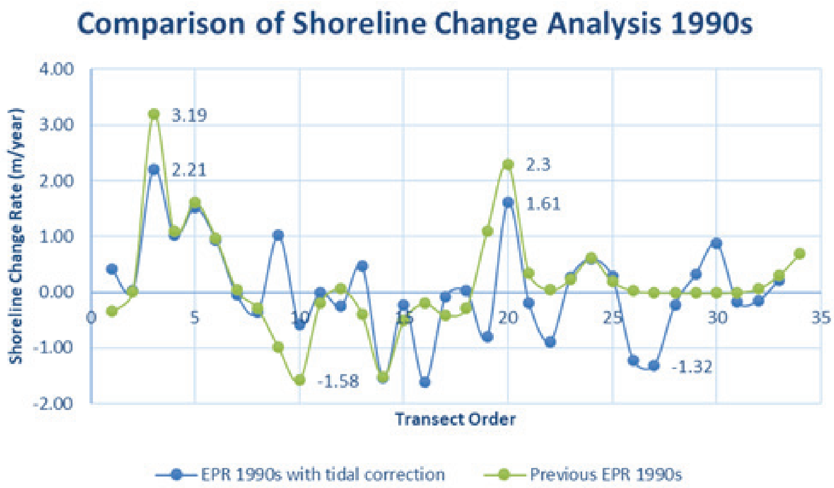

Figure 11 Comparison of EPR shoreline change rate analysis 1990s

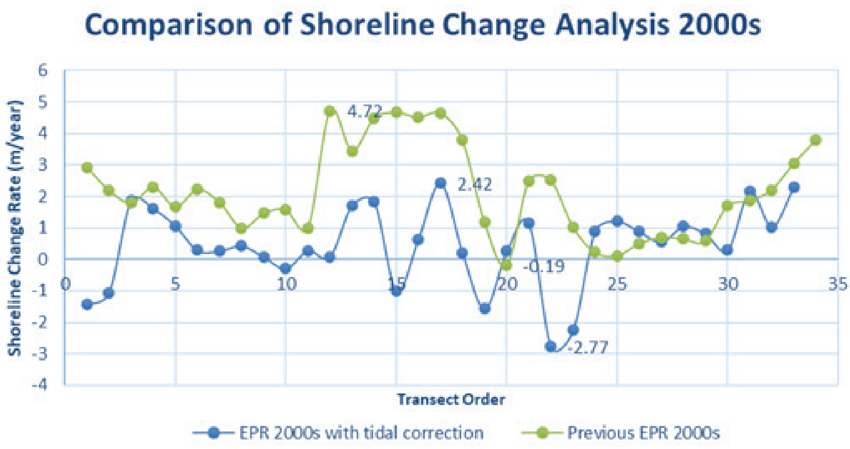

Figure 12 Comparison of EPR shoreline change rate analysis 2000s

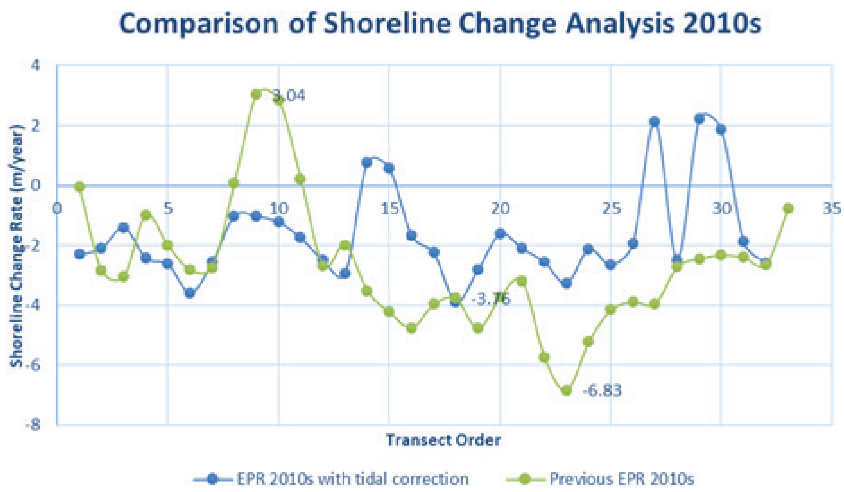

Figure 13 Comparison of EPR shoreline change rate analysis 2010s

Line Regression Rate

Linear Regression Rate (LRR) rate-of-change statistic can be determined by fitting a least-squares regression line to all shoreline points for a transect. The rate is the slope of the line [14]. Figure 14 represents the comparison of shoreline change analysis with consideration of tidal effect and previous result in Morphodynamics of Teluk Nipah in the 1990s using Line Regression Rate (LRR) [1]. Based on the overall trendlines of both change rates, it is interpreted both trendlines using the LRR have a similar pattern compared with the trendline in EPR. The graph showed that LRR with tidal correction is relatively stable as the occurrence of erosion and accretion events are considered in equilibrium, whereas the previous LRR accreted in the northern cell and middle stretch of Teluk Nipah. The maximum accretion rate using LRR shoreline change rate after tidal correction reached 1.85 m/year, while the erosion rate reached –1.52 m/year. The maximum erosion rate used for the previous LRR –is 0.78 m/year whilst the maximum accretion rate reaches 2.74 m/year. According to Figure 15, the LRR in the 2000s after tidal correction is more stable and equilibrium in the graph presentation as it shows a smaller fluctuation in the value between erosion and accretion rate. The shoreline change rate with tidal correction is comparatively healthy as the maximum erosion and accretion rate are reasonable, which are 3.29 m/year and –1.74 m/year, respectively, whereas the previous LRR shoreline change rate has a relatively unstable pattern which is similar to the EPR in the 2000s. From the northern cell to the middle stretch of Teluk Nipah, which are Transects 1 to 19 are experiencing accretion where the maximum accretion rate has hit 4.87 m/year while the erosion rate has only –1.18 m/year. Based on

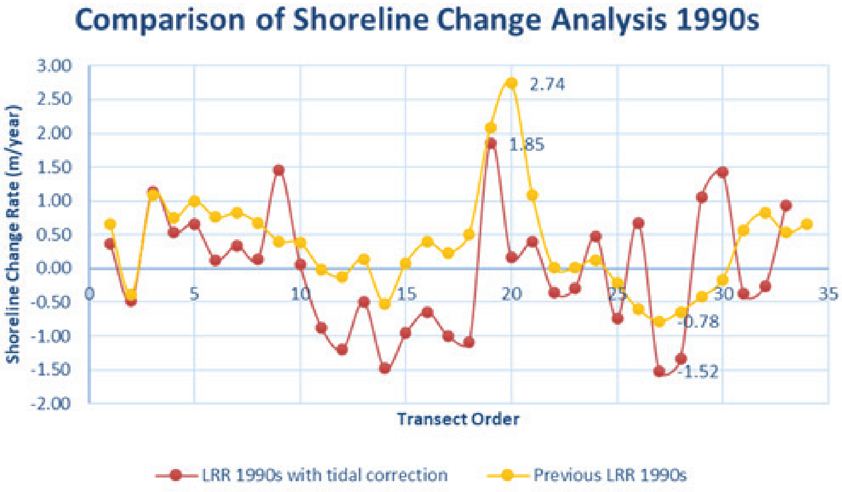

Figure 14 Comparison of LRR shoreline change rate analysis 1990s

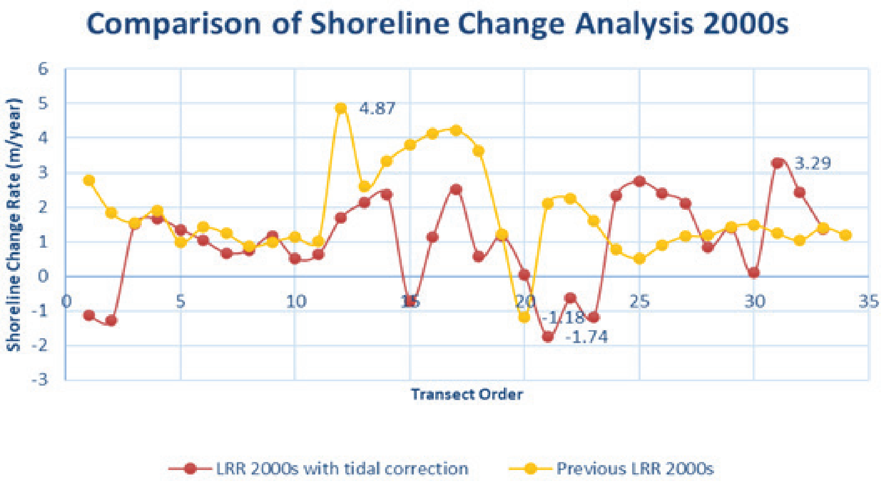

Figure 15 Comparison of LRR shoreline change rate analysis 2000s

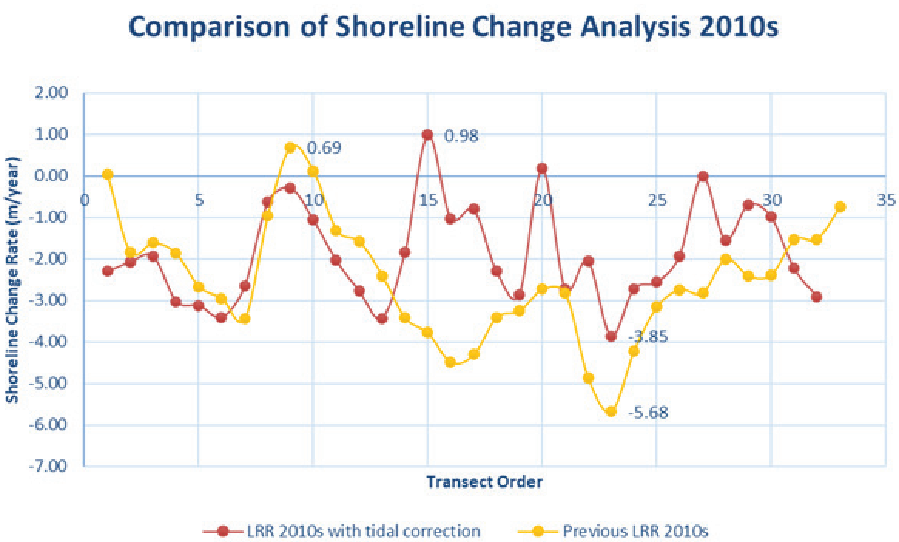

Figure 16 Comparison of LRR shoreline change rate analysis 2010s

Figure 16, it showed a similar pattern with the trendline in Figure 13. The majority of the transects are experiencing severe erosion compared with the shoreline change rates in the 1990s and 2000s. It is convincible that the development along the coastal area has caused the shoreline to retreat since the development began in the early 2000s. The erosion rate before the tidal correction was severe, where it reaches around –5.86 m/year same at Transect 23 using the EPR, whereas the maximum erosion rate after the tidal correction was –3.85 m/year at Transect 23 as well, but it has a comparatively lower intensity of erosion rate compared with the data without tidal correction.

Critical Zones in Teluk Nipah

From the result of shoreline change rate, Transects 18 to 24 have been identified as the transects that experienced critical erosion. The region is the focal point of most commercial development and anthropogenic activities. Beach resorts, restaurants, and souvenir shop units were being developed along this stretch of Teluk Nipah shoreline. Transect 23 has undergone the most severe coastal retreat as it is situated at the thinnest stretch among the Teluk Nipah shoreline. Longshore sediment transport

Figure 17 Critical coastal transects along Teluk Nipah. shoreline

occurred along the shoreline contributed to the high intensity of erosion rate in this region. Figure 17 shows the critical coastal transects in the Teluk Nipah shoreline.

CONCLUSION AND RECOMMENDATION

The outcomes and analysis have shown that the shorelines in the 1990s are relatively stable as commercial developments were not prominent during the 1990s. In the 2000s, the coastal zone was considerably stable and healthy as the majority of the shoreline did not experience severe erosion. Nonetheless, in the 2010s, the study area has experienced coastline retreat issues, specifically at the littoral zone overwhelmed with commercial developments, consequently, 7 critical zones have been identified, which are Transects 18 to 24. With the tidal correction assessment conducted in this study, the research is more accurate and convincible analysis as the erosion rate along the Teluk Nipah shoreline is not as severe in the previous study in Morphodynamics of Teluk Nipah shorelines [1]. The severity of erosion has lowered from –6.83 meters per year to –3.87 meters per year using the End Point Rate approach in Transect 23. With the Line Regression Rate approach, the erosion rate in Transect 23 has also reduced from –5.86 meters per year to –3.86 meters per year. Both of the approaches have scaled down from Category 1 Critical Erosion to Category 2 Significant Erosion according to the National Coastal Erosion Study Malaysia 2015 [15].

This research can be improved by conducting close monitoring of shoreline changes for every three months instead of 1 year for the multi-decadal assessment on the coastal morphology. By applying this approach, the erosion rate of the shoreline would be more accurate as this study used only one day of satellite image to represent the shoreline of Teluk Nipah for the particular year, which has a huge uncertainty. In addition, the use of the better resolution of satellite images could increase the definition of shoreline as the Landsat satellite imagery has only 30 meters of resolution which there is the existence of higher resolution satellite imagery to improve the precision while DSAS detects the shoreline.

Furthermore, validation of the result can be done in order to verify the accuracy of the result after tidal correction by applying the computation of Root Mean Square Analysis with purchased data. Thereafter, adequate soft engineering solutions such as beach nourishment should be proposed as one of the mitigation steps in curbing the occurrence of coastline retreat in order to ensure the safety of the public and local communities. In conclusion, this study is a vital initiative in urging a sustainable coastal management plan for Pantai Teluk Nipah.

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