Geospatial Analysis of Coastline Erosion Along Pulau Tuba, Langkawi

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Abstract. The erosion in Malaysia has brought attention to many authorities especially the coastline in the eastern part of Peninsular Malaysia. Although the erosion in the northern part of Peninsular Malaysia does not receive as much attention as the eastern part of Peninsular Malaysia, however, the issue should not be neglected. High spatial resolution satellite imageries were used for the extraction of coastline and classification level of erosion rate along with the Pulau Tuba. The coastline data was extracted using two different methods known as Maximum Likelihood (ML) and On-Screen Digitizing (OSD) in the determination of the best approach of coastline detection from the Sentinel-2 data of the year 2016 and 2019. Furthermore, the level of erosion is made based on the physical and economic parameters outlined by the National Coastal Erosion Study 2015 (NCES). Due to some inevitable constraints of Movement Control Order by the Malaysian government due to the COVID-19 pandemic, physical observation data of Pulau Tuba were collected via Google Maps. The information acquired includes type of coastal geomorphology, land use, development on the area, activities conducted, and adaptation of erosion if any. These data were utilized to determine the erosion rate and categories using the proposed model by NCES for five divided management units (MU) of the Pulau Tuba areas utilizing Erdas Imagine and ArcGIS software. The analysis found that the ML approach has under-detected the coastline length between 3.19% to 45.0% as compared to OSD for both years of 2016 and 2019. Rate of erosion for Pulau Tuba based on the NCES approach found that the highest erosion rate occurred at the MU1 (Pulau Dayang Bunting- Pulau Tuba causeway) with 2.91% and classified as K1 (critical erosion category) with a value of 4.39 m/yr⁻¹ and the highest accretion rate at the MU3 with 3.06%. The critical erosion category was associated with the MU that has significant development and on-going activities that occurred in the area especially in MU 4 (Pulau Tuba) and MU 5 (Teluk Berembang). Other than that, the high number of erosions occurred in that section is due to the exposure of waves, wind, currents, and tides.

1. Introduction
The coastline is known as a meeting point between the land and the oceans. It consists of cliffs, capes, beaches that are at the end of the land. Coastline always changes constantly due to the rise fall of the...
Coastline might change over time due to natural causes, climate change, and human activities. Other than that, the coastline area is also affected due to the lack of awareness about the importance of coastline conservation. They utilize all the resources that can be obtained from nature without considering the effect in the long run [3]. If the area is not monitored or activities held excessively and development built without consent, it can cause significant pressures to the coastal area such loss of biodiversity, the land becomes contaminated due to the hazardous substances and marine litter [4]. These are only a few of the factors that contribute to the erosion of the coastline. The main factors that caused this coastal erosion is caused by waves, rip currents over wash, and other factors that resulting from an overall gain or loss for the volume of beach sand due to erosion and accretion [5, 6, 1, 11-13].

Previously without the advancement in technology, it might be hard to collect the coastal data as the dynamic of the oceans are constantly changes and also the uncertainty of climate prediction. But the technology developed in this era such as Remote Sensing and GIS is adequate to carry out the process to determine the coastline changes without needing to visit the field. Maximum Likelihood is a method that is used in Remote Sensing to classify the coastal land use. The method operates when a pixel with the maximum likelihood classified is designated into the corresponding class [7]. This type of method is used since it is the easiest technique to extract the coastline from the remotely sensed imageries obtained [9]. Based on [3], it is stated that the process of measuring the coastline is by digitizing the coastline of Morib coast Carey Island. This method is performed by drawing a line of the coastline at the intersection between water and land by the operator manually. The higher accuracy of this method can be achieved by zooming properties and digitizing by the same analyst. The downside of using this system is that it happened to be very time-consuming especially when there is a large area that needs to be covered [8].

Based on the study made by NCES 1985, it is stated that about 1390 km which is approximately 29% of the coastal zone will experience a different level of erosion severity [9]. To categorize the level of severity, two parameters are taken into consideration; physical and economic [10]. It is standard made by the National Coastal Erosion Study (NCES) to classify the spread of coastlines that are eroding. The severity category is depending on the relationship between the economic significance of risk and the rate of erosion. The higher value of economic and physical significance of risk, the higher the rate of erosion thus increasing the severity of erosion. NCES is also responsible to classify the level of erosion into 3 categories; (Category 1, K1), (Category 2, K2) and (Category 3, K3) [10].

Remote sensing and GIS techniques are used in this study to map the extent of coastal erosion between the year 2016 to 2019 based on Sentinel-2 data at Pulau Tuba Langkawi as it can assist to identify the corrosion and sedimentation happened at that area in 3.8 years period of time. The coastal area is important for the community in Pulau Tuba they do fishing as their main life sustainability. Since the area is not fully developed, it is believed that the region still rich with its flora and fauna with less damage came from human activities. The objectives to identify geomorphology along the Pulau Tuba coastline through data observation and collection. Next is to determine the accretion and erosion along
the coastline using RS and GIS techniques. Other than that, is to quantify the coastal erosion rate based on its physical and economic parameters outlined by NCES 2015.

2. Study Area
Langkawi Island is the largest island in Malaysia out of 99 islands and it is located in the north-western part of Peninsular Malaysia. Langkawi is famously known as one of the best places in Malaysia that become a must-visit by tourists. Since it becomes the center of attraction, the development in that area is increasing thus affecting its coastal environment due to human activities other than natural factors. Due to its geographical location, Langkawi is one of the most regions affected by monsoon through heavy rain thus led to high coastline erosion that needs serious monitoring to maintain its sustainability. There is another island of Langkawi that not many people know which is Pulau Tuba hence, the area is selected to determine the rate of accretion and erosion of its coastline (Figure 1).

3. Data and Methodology

3.1 Coastline extraction for the years 2016 and 2019
The data used is Sentinel-2A satellite imagery. This type of data is used because it offers a high spatial resolution image and there is plenty of platforms that are accessible such as USGS, Sentinel Hub, Copernicus Open Acess Hub, and various more [11]. It provides a high spatial resolution that is between 60 m to 10m. Most of the Sentinel images are already pre-processed and corrected. The satellite image that will be using is the year 2016 and the year 2019 that were acquired from the USGS website to determine the rate of changes between both years. The method in this study was used to determine the coastline changes in Pulau Tuba between the years 2016 and 2019. Few techniques were used and the results will be compared to each other to determine which method is the best to rate the erosion and accretion of the coastline. The flow of work for this study is shown in Figure 2.

For this research study, three types of different techniques were used to determine the coastlines, erosion, and accretion that occurs in Pulau Tuba between the years 2016 and 2019 which are, Maximum Likelihood, On-screen Digitizing were utilized to identify and delineate the coastline and NCES
guidelines were used to determine the erosion categories. Maximum Likelihood is one of the popular and the most used method by the researcher to detect the changes in the coastline. The expression is created to assign the pixels into the classification of the land area and water bodies. The formula of Maximum Likelihood classification was shown as follow (Equation 1);

\[ L_k = \frac{P(k|x)}{\sum_i p(i) * p(x_i)} \]

Where;
\( P(k) \) = prior probability of class k
\( P(y/k) \) = conditional probability to observe X from k.

(1)

Furthermore, on-screen digitizing (OSD) is used to extract coastline by the digitization of the coastline of Pulau Tuba in Sentinel-2 satellite imagery. In ERDAS Imagine, a vector layer was added to enable the line of the coastline to be traced and digitized. The vector layer is in shapefile which can be exported to ArcMap (Figure 3).
3.2 Computation the rate of erosion and accretion

The rate of erosion and accretion in the Pulau Tuba coastline are computed by using the formula that is already defined by NCES (2015). This equation uses the attribute table collection in the On-Screen Digitizing method since this process does not contain any mathematical model, unlike the Maximum Likelihood. The erosion and accretion of the Pulau Tuba can be determined by overlapping the digitized line of coastline in 2016 and the coastline in 2019 and it will form a polygon. If the blue line that represents the year 2019 is in front of the black line it means that the accretion occurred at that zone whilst if the black line is in front of the blue line, it shows that erosion happened (Figure 4). The rate of erosion and accretion of the coastline can be computed by using the equation stated below:

\[
\text{Erosion or Accretion Rate} = \frac{\text{Width of the Coast Range Per Year}}{(3.8)}
\]

(2)

3.2.1 Categorization of Erosion Rate

Based on [10] three (3) erosion categories classification were used to determine the severity of the erosion. The categories range from critical (K1), significance (K2), and acceptable (K3) (Table 1). The rate of erosion also depends on the other two (2) parameters which are physical score and economic score [10]. The intensity of erosion is said to increase if the score of physical and economic parameters also increases. For example, the erosion that occurred in Section 5 is higher compared to the other section.
due to the activities and development happening in that area. Table 1 below describes the category of erosion. The erosion rate along Pulau Tuba can be computed based on the physical score and economic score outlined by [10]. Through these parameters, the severity of erosion can be identified and proper action can be taken by the authorities. The calculation was made by using ArcGIS and Microsoft Excel as the calculation can be generated automatically once the formula is inserted.

| Table 1. Description of erosion category outlined by NCES 2015. |
|---------------------------------------------------------------|
| **Category** | **Description** |
| K1 (Critical) | Gradual retreat of the coastline at a scale of more than 4 m / year with relatively reasonably dense human settlement, with significant public infrastructure and facilities providing some commercial/industrial activities. |
| K2 (Significance) | Retreatment of the coastline at a rate of more than 1 m / year but less than 4 m / year with the commonly sparsely populated area, with fairly small public infrastructure and facilities serving certain agricultural activities. |
| K3(Acceptable) | Less than 1 m / year slowly retreating coastline with generally no human settlement and low agricultural activity, and also not served by public infrastructure and facilities. |

3.2.2 Physical and economic parameter scoring
For physical parameters, it is calculated based on the physical erosion rate obtained from the satellite images. Due to its contrast in the rate of erosion along the coastline, therefore median retreat rate analyzed was used for erosion categorization. Table 2 shows the scoring of a physical parameter that is outlined by NCES 2015. The economic parameter is based on the economic value of the area of coastline eroding. Details weightage and rating used to score the economic parameter based on its categorization can be found in the study by [10].

| Table 2. Scoring for physical parameters. |
|------------------------------------------|
| **Parameter** | **Description** | **Erosion Rate (m/year)** | **Physical Erosion Score** |
| Rate of coastline retreat Low | 0.99 | Actual erosion rate (m/year) |
| Medium | 1.00 to 1.99 | 2 points |
| | 2.00 to 2.99 | 3 points |
| | 3.00 to 3.99 | 4 points |
| High | ≥ 4.00 | 5 points |

4. Results and Analysis

4.1 Geomorphology characteristics observation
Geomorphology characteristics observation is made to determine the geomorphology and identify the economic activities carried out along the coastline as it is one of the factors that caused erosion of the coastline. Supposedly, physical observation should have been made through site visit at Pulau Tuba and marked a few points along the coastline to have a better view on the geomorphology and activities held thus the level of erosion can be classified more accurately. Due to some constraints that appeared while this study is still on-going, therefore the physical observation was made via Google Earth with the establishment of five (5) management units (MU) to determine the state and condition of the study area (Figure 5).

From the study area observation using Google Earth data as stated in Table 3, the cause of erosion can be described generally either from the natural process or through human activities. Mostly, the
difference in levels of erosion depends on the characteristics of the waves during monsoon season and human intervention such as development, fishing activities, and tourism business. All these factors played a crucial role in the erosion along the coastline.

![Figure 5. The study area and its management unit](image)

### Table 3. Geomorphology of the study area.

| Coastal Area / Vulnerability Level | Features / Characteristics |
|------------------------------------|-----------------------------|
| 1. Part 1 Low vulnerability         | Impacts on Coastal          |
|                                    | - Moderate waves with low erosion levels. |
|                                    | - Plants: Mangroves         |
|                                    | Features exit near coastal  |
|                                    | - Geomorphology: muddy coast|
|                                    | Development:                |
|                                    | *Causeway from Pulau Dayang Bunting-Pulau Tuba, Restaurant, Utilities: Electricity (Pulau Tuba TNB), residential area|
|                                    | - Activities & facilities:  mini-mart |
|                                    | Adaptation Measures        |
|                                    | - No adaptation measure was taken |
|                                    | Impacts on Coastal         |
|                                    | - Moderate waves with a low erosion level |
|                                    | - Plants: Mangroves        |
| 2. Part 2 Medium vulnerability     | Features exit near coastal  |
|                                    | - Geomorphology: muddy coast / sandy coast |
|                                    | Development:                |
|                                    | *Jetty Selat Lubuk Chempedak, Homestay (DPauh, Private Residence A’s D Tuba) |
|                                    | -Utilities: Electricity    |
|                                    | -Activities & facilities:  |
|                                    | * Tourism activities       |
**Existing resort (± 3 units)**

**Adaptation Measures**
- Unidentified

### 3. Part 3
#### High Vulnerability

**Impacts on Coastal**
- High waves with a high erosion level
- Plants: Mangroves

**Features exits near coastal**
- Geomorphology: Sandy coast
- Development: -
  - *MAREC UiTM Perlis, Restaurants, Resorts/Homestays, Klinik 1 Malaysia*
- Utilities: Electricity
- Activities & facilities:
  - *Tourism activities, Existing resort/homestays (± 6 units), Research center for UiTM*

**Adaptation Measures**
- Unidentified

### 4. Part 4
#### High Vulnerability

**Impacts on Coastal**
- High waves with a high erosion level
- Plants: Mangroves

**Features exits near coastal**
- Geomorphology: Sandy coast
- Development: -
  - *Hotels/Resorts/Homestays, Main road about 290m from the sea, Residential, Jeti Pulau Tuba, Internet Centre*
- Utilities: Electricity
- Activities & Facilities
  - *Tourism activities*
  - *Existing hotels/resort/homestays (± 6 units)*

**Adaptation Measures**
- Unidentified

### 5. Part 5
#### High Vulnerability

**Impacts on Coastal**
- Plants: Mangroves

**Features exit near coastal**
- Geomorphology: Sandy coast
- Development: -
  - *Residential, Guesthouse, Restaurants, Jetty*
- Utilities: Electricity
- Activities & Facilities
  - *Tourism activities*
  - *Fishing activities*

**Adaptation Measures**
- Unidentified
4.2 Comparison of coastline extraction approaches between ML and OSD

Through supervised classification, the Maximum Likelihood was selected for the parametric rule. The accuracy assessment was performed with 100% accuracy obtained due to the ML techniques classified as the LULC categories into two main classes (i.e. land and water bodies). Figure 6 below is the result obtained from the classification for both years. The length of the coastline for the year 2016 and 2019 will be compared to determine if there is any erosion took place in the area. Table 4 shows the length of the coastline for both years. On-screen digitizing is said to be more accurate compared to the other computerized method as the digitized line is much closer to the coastline on the ground. From the digitized coastline, the total coastline length in Pulau Tuba for the year 2016 is approximately 26.73 km. For the year 2019, the total length is approximately 25.85 km.

![Figure 6. The result of the Maximum Likelihood for both year.](image)

Table 4 indicated the huge difference between the Maximum Likelihood method and the on-screen digitizing method. For 2016, three (3) sections where the difference percentage is quite high. The three (3) sections are MU1 (45%), MU4 (28.50%), and MU5 (18.54%). In 2019, four (4) sections where the difference percentage is more than 10% which are MU1 (32.84%), MU2 (19.42%), MU4 (14.06%), and MU5 (25.40%). It shows that even though a few methods can be used to extract the coastline length, but not every technique is reliable.

| MU | Length of Coastline (m) | Difference (m) (OSD-ML) | Difference (%) |
|----|-------------------------|-------------------------|----------------|
|    | Maximum Likelihood      | On-Screen Digitizing    |                |
|    | 2016                    | 2019                    | 2016           | 2019           |
| 1  | 3592.23                 | 3883.00                 | 4443.64        | 4451.93        | 851.41         | 568.93         | 45.00           | 32.84           |
| 2  | 4166.24                 | 4497.08                 | 4105.87        | 4160.70        | -60.37         | -336.38        | 3.19            | 19.42           |
| 3  | 4334.05                 | 4260.25                 | 4243.89        | 4116.84        | -90.16         | -336.38        | 4.77            | 8.28            |
| 4  | 6878.58                 | 6849.68                 | 7417.87        | 7093.28        | 539.29         | -336.38        | 28.50           | 14.06           |
| 5  | 6782.87                 | 6542.29                 | 6432.16        | 6102.32        | 539.29         | -336.38        | 18.54           | 25.40           |
| Total | 25,753.97               | 26,032.30               | 26,643.43      | 25,925.07      | 1,891.94       | 1732.29        | 100             | 100             |
Maximum likelihood is one of the types of supervised classification where training samples were taken then classified into a corresponding class which is a water feature and non-water feature. Although the maximum likelihood technique is one of the most reliable methods used to extract the coastline, this method is unlikely to be accurate because the samples are applied to one of the most likely class, or if its likelihood value does not exceed any defined threshold. There are about 720 m of coastline erosion took place in Pulau Tuba within 3.8 years.

4.3 Rate of erosion based on technique by the NCES
Once the rate of erosion is computed, the eroded area that occurred in Pulau Tuba can be classified on a different phase of erosion; critical (K1), significant (K2), and acceptable (K3). Figure 7 shows the bar graph of the percentage of accretion and erosion on every management unit based on the rate of erosion results.

![Rate of Erosion along Pulau Tuba](image)

**Figure 7.** Rate of erosion on every location along with the Pulau Tuba, Langkawi

| MU  | Length of Coastline (m) | Accretion / Erosion Rate (m) | Percentage (%) |
|-----|-------------------------|------------------------------|----------------|
| 1   | 4451.93                 | 131.79 / 102.00              | 13.11 / 12.61  |
| 2   | 4160.70                 | 117.20 / 100.32              | 12.61 / 13.11  |
| 3   | 4116.84                 | 85.06 / 125.85               | 3.06 / 2.54    |
| 4   | 7093.28                 | 179.82 / 166.48              | 2.35 / 2.50    |
| 5   | 6102.32                 | 166.23 / 152.01              | 2.50 / 2.72    |
| **Total** | **25,925.07** | **680.10 / 646.66** | **12.61 / 13.11** |

Table 5. Percentage of coastline accretion and erosion based on erosion rate calculation.

Table 5 shows that the percentage of accretion is higher compared to the erosion which is 13.11% while erosion is at 12.61%. Such results indicate that there are more soil accretion activities occurred compared to erosion in the 3.8-year times. This is because most of the accretion occurred at MU 1 and MU 2 where it is located at Tuba Strait. These areas are protected from the high waves, tides, and current, unlike the other management unit. Additionally, most of the areas are undeveloped and densely dominated by mangroves swamps that are known to act as a natural barrier and slow down the process.
of erosion. Even though the rate of erosion is lower compared to accretion, but the percentage is quite high. This is because the area from MU 3 until MU 5 is exposed to the water breaks. Therefore, the area is more likely to experience high erosion based on the factors. The next factor that caused high erosion is the human settlement and activities held in that region. For example, in MU 5 there is a development that is used as a residential area where the area is fully equipped with facilities and utilities.

4.4. Rate of erosion based on physical and economic score

The erosion rate along with Pulau Tuba also can be computed based on the physical score and economic score outlined by NCES 2015. Through these parameters, the severity of erosion can be identified and proper action can be taken by the authorities. The calculation was made by using ArcGIS and Microsoft Excel as the calculation can be generated automatically once the formula is inserted. Although the calculation is computed along the Pulau Tuba coastline, only a few areas that have significant value will be shown in this section. This is because the most part in Pulau Tuba is still undeveloped and there is no human settlement occurred in the area. Other values that are insignificant will be cumulated into the assigned section and tabulated in Table 6.

**Table 6. Length of eroded coastline between the year 2016 and 2019 and each of erosion category**

| Location | Length of Eroded Coastline (m) | Rate of Erosion | Total Score | Erosion Category (K1, K2, K3) |
|-----------|-------------------------------|----------------|-------------|-----------------------------|
| MU 1      | Causeway from Pulau Dayang Bunting-Pulau Tuba | 4561.03 - 4921.32 | 4.39 - 12.50 | 1 |
|           | Mangrove swamps               | 84.48 - 0.60 - 5.00 | 3 |
| MU 2      | Pantai Jalan Selat Bagan Asam | 4747.94 - 4968.92 | 11.12 - 5.7 - 7.2 | 2 |
|           | Jetty Selat Lubuk Chempedak   | 4.39 - 12.50 | 1 |
|           | Mangrove swamps               | 84.48 - 0.01 - 5.00 | 3 |
| MU 3      | MAREC UiTM Perlis            | 4261.58 - 4197.66 | 11.36 - 4.80 - 9.60 | 2 |
|           | Pantai Pasir Panjang         | 11.44 - 4.80 - 9.60 | 2 |
|           | Mangrove Swamps              | 101.68 - 0.01 - 4.8 | 3 |
| MU 4      | Pantai Tuba 1                | 8811.55 - 8344.84 | 11.36 - 5.80 - 8.00 | 2 |
|           | Mangrove Swamps              | 152.12 - 0.01 - 5.00 | 3 |
| MU 5      | Jalan Teluk Berembang 1      | 6469.22 - 6318.51 | 15.07 - 8-12 | 2 |
|           | Mangrove swamps 1            | 12.54 - 8 - 8 | 2 |
|           | Mangrove swamps 2            | 8.88 - 8 - 8 | 2 |
|           | Mangrove swamps 3            | 107.23 - 0 - 5 | 3 |

*Red: Critical level, Orange: Significant level, Green: Acceptable level*
5. Conclusions
The research is conducted to map the extent of coastal erosion between the year 2016 to 2019 based on Sentinel-2 data at Pulau Tuba, Langkawi using Remote Sensing and GIS techniques, and outlined the coastal erosion at Pulau Tuba. Several factors caused the coastline to be eroded. But most importantly, the physical coastline retreat and economic significance of the coastline are the main factors that are linked to this problem. By acquiring satellite imagery, the changes of the coastline can be determined through the approach of remote sensing and GIS. The process can be done by using a semi-automated method such as the Maximum Likelihood or OSD. By comparison, Maximum Likelihood is the quickest technique to use for extracting the coastline along with Pulau Tuba though the result is not as accurate as on-screen digitizing due to the misclassification that occurred during the processing. Even though it takes a lot of time to digitize the coastline, but the accuracy from this method is reliable as the images are zoomed at a comfortable level while digitizing hence the distance of the coastline is much closer to the ground. Since the length of both coastlines is obtained, the level of erosion and accretion can be calculated based on the circular outlined by NCES 2015. The analysis found that the ML approach has under-detected the coastline length between 3.19% to 45.0% as compared to OSD for both years of 2016 and 2019. Rate of erosion for Pulau Tuba based on the NCES approach found that the highest erosion rate occurred at the MU1 (Pulau Dayang Bunting- Pulau Tuba causeway) with 2.91% and classified as K1 (critical erosion category) with a value of 4.39 m/yr and the highest accretion rate at the MU3 with 3.06%. The critical erosion category was associated with the MU that has significant development and on-going activities that occurred in the area especially in MU 4 (Pulau Tuba) and MU 5 (Teluk Berembang).

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