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ASSESSMENT OF COASTAL EROSION RELATED TO WIND CHARACTERISTICS IN PENINSULAR MALAYSIA

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Abstract

Malaysia is a maritime country that is located north of the Equator. Hence, it is prone to monsoon changes all the time. Monsoon in Malaysia has contributed to a lot of wind-related disaster. Currently, the most alarming wind-related disaster would be coastal erosion. Although it is a natural phenomenon mainly caused by wave motion, the source of wave power is highly dependent on wind characteristic. This wind induced disaster has caused extensive financial loss and destruction of environment. Hence, this study was conducted to investigate the relationship between wind and coastal erosion in Peninsular Malaysia. The eroded locations were gathered by extensive review from prime media and mass media. They were analysed from the year 1984 to 2016 by using image layering technique. The changes in shoreline orientation were determined by observing the changes of the shoreline at a specific area. The wind directional distribution diagram was created using the data from the nearest meteorological station. Both of these parameters were compared and analysed. The result from the empirical investigation shows a good agreement between wind direction and shoreline orientation. Therefore, the shoreline orientation is highly influenced by the changes of wind characterization.

Keywords: Coastal Erosion, Wind Direction, Wind Engineering,.

1. Introduction

Malaysia is situated between the latitudes 1° and 7° north and longitudes 107° and 119° east. It consists of West Malaysia and the East Malaysia that is separated by the South China Sea with a shoreline length approximately 4,809 km [1]. Peninsular Malaysia is surrounded by the South China Sea on the east and the Straits of Malacca on the west with a shoreline length of approximately 1,972 km [2]. Malaysia is a maritime country that is located north of the Equator. Hence, its wind flow is dominated by two major monsoons that are the Southwest monsoon from late May to September and Northeast monsoon from November to March along with one Inter monsoon season from April and October [3-5]. Due to this monsoonal season, wind related disaster have increased rapidly over the last few years in Malaysia [4] including coastal erosion which is classified as one of the wind-induced disaster since it combines wind and water hazards [6].

Currently, this wind-induced disaster is becoming a serious threat to Peninsular Malaysia's shoreline. This can be proved by the increment of coastal erosion cases for the past several years [7-9]. The government's initiative in improving the shoreline protection structures with high costing proves again that coastal erosion is a serious threat to Peninsular Malaysia [10]. Studies on coastal erosion was conducted by the Malaysia Government in 1984 by commissioning the National Coastal Erosion Study (NCES) [1]. The studies proved that almost 30% of Malaysia's coastline (including Sabah, Sarawak and Federal Territory of Labuan) is undergoing erosion; prompting the government to execute an erosion control plan. [11].

Based on the National Coastal Erosion Study (NCES), the authority has classified coastal erosion into these following three categories: [1, 2, 11] (a) Category 1 – Critical; coastline that is affected by the coastal erosion that caused damage to the shore based facilities and major economic loss; (b) Category 2 – Significant; coastline that would be affected in a time period of 5 to 10 years which can put shore based facilities to endangerment if no action is taken; (c) Category 3 – Acceptable; coastline that is under developed that might cause minor economic loss if the erosion continues. The result of National Coastal Erosion Study is tabulated in Table 1. The result shows that 52.7 % of Peninsular Malaysia coastline is undergoing coastal erosion. The result proved that three decades ago, 52.7% of Peninsular Malaysia coastline underwent coastal erosion; which is more than half of the Peninsular Malaysia's coastline length. Furthermore, latest coastal erosion studies at Tanjong Piai find that the phenomena has been continuing to this day [12].

According to Prasad and Kumar, the impact of coastal is land loss in terms of economic or ecological value [13]. In Malaysia, Ann stated that coastal erosion results in economic and social consequences; especially in Peninsular Malaysia [1]. In Peninsular Malaysia, most of the agricultural lands are seriously threatened by breached sea water that damages the crops, housing and the public facilities and coastal roads that are destroyed structurally resulting in transportation delay and destroyed beaches which may have contribute to a major downfall in the tourism industry [1]. In brief, coastal erosion has been an alarming issue for the past three decades due to wind flow pattern in Malaysia. Before finding a solution to this wind-induced disaster, we first need to understand the relationship of wind and coastal erosion. Hence, the main objective of this research is to: (a) determine and construct the database of coastal erosion in Peninsular Malaysia and; (b) study the relationship between wind direction and coastal erosion direction.

Table 1. Eroding shoreline in Peninsular Malaysia. [2]

State	Shoreline Length (km)	Eroded shoreline Length (km)	Percentage (%)
Perlis	20	14.5	72.5
Kedah	148	43.5	29.4
Pulau Pinang	152	63.2	41.6
Perak	230	140.2	61.0
Selangor	213	151.9	71.3
Negeri Sembilan	58	24.5	42.2
Melaka	73	36.7	50.3
Johor	492	234.8	47.7
Pahang	271	125.4	46.3
Terengganu	244	152.4	62.5
Kelantan	71	52.1	73.4
TOTAL	**1972**	**1039.2**	**52.7**

2. Overview of Coastal Erosion

Coastal erosion is the deportation of coastal material; away from the coast due to wave forces that causes the coastline to wash away its land [14]. Coastal erosion and accretion process are interrelated as they shape the coastlines as a part of natural occurrences [15]. Naturally, beaches or coastline will encounter cycles of erosion and deposition for prolonged periods of time to stabilise the mean position of local sediment budget. This process is called the dynamic equilibrium state. It would experience changes if it encounters any interference or interruption to the prevailing coastal process that may lead to the increment or decrement of the local sediment budget [11].

2.1. Beach equilibrium profile theory

The repercussion of sediment and wind-induced wave on the beach profile equilibrium could be explained by the combinations of the following relationship to develop equilibrium beach profile theories [16]:

Wave energy per unit surface area: $E = \rho g H_2/8$ (1)

Energy flux: $F = EC_g$ (2)

Group velocity: $C_g = \sqrt{gh}$ (3)

Spilling breaking assumption: $H = kh$ (4)

The uniform energy dissipation per unit volume for a given grain size is $D.(d)$ is as following in terms of energy conversion:

$$\frac{1}{h}\frac{dF}{dy'} = -D_*(d) \quad (5)$$

By substituting, the earlier four relations into Eq. (5) the following equation would be obtained:

$$\frac{d\left(\frac{1}{8}\rho g k^2 H^2 \sqrt{gh}\right)}{dy'} = -hD_*(d) \quad (6)$$

The substituted equation is the derivative and is simplified; it forms dissipation per unit volume:

$$D_*(d) = \frac{5}{16}\rho g^{3/2} k^2 h^{1/2} \frac{dh}{dy'} \tag{7}$$

Rearranging the equation would produce the final beach equilibrium theory equation; that is as following:

$$h(y) = \left(\frac{24 D_*(d)}{5\rho g \sqrt{g k^2}} \right)^{2/3} y^{2/3} = A(d) y^{2/3} \tag{8}$$

2.2. Wind-wave relationship towards coastal erosion

Waves can be defined as the reaction of wind friction on the sea surface. The surface of the water attempts to stretch because of wind reaction on its surface that causes the water molecules to navigate in the direction of the wind continuously, causing wave. The wind speed has a limit of its own over the time or distance that might not cause large waves and is referred to the fully developed sea condition. [17, 18].

Wave energy formula as per Eq.1 can be done as following [19]. The potential energy and kinetic energy can be defined by using Airy theory. The total wave energy is shown as:

$$E = E_K + E_P = \frac{\rho g H^2 L}{16} + \frac{\rho g H^2 L}{16} = \frac{\rho g H^2 L}{8} \tag{9}$$

The total average wave energy:

$$\overline{E} = \frac{E}{L} = \frac{\rho g H^2}{8} = \frac{1}{8}\rho g H^2 \tag{10}$$

Winds bound the earth at various points that leads to different atmospheric activities. These immeasurable interactions and movement causes wind not to stay constant for any period of time [20]. This results in waves moving at various frequencies, phases and amplitudes due to the variability of the wind forces on the sea [21]. The involvement of wind in wave generation could be proven by using the JONSWAP project formula. Eq.11. shows the correlation between the effect of wind speed and wave height [22].

$$H_{rms}^2 = 1.6 \times 10^{-7} u_{10}^2 x / g \tag{11}$$

In brief, the above correlation could be used to prove the influence of wind in wave generation. The variety of waves that breaks on the shore also results in various levels of coastal erosions; again, depending on the wind force. It also proves wind directions set the course of the wave direction [21].

3. Methods

In this study, four phases of methodology were applied to study the relationship between wind direction and coastal erosion direction. The methodology was separated into coastal erosion data collection, wind data collection, and shoreline changes analysis.

3.1. Coastal Erosion Data Collection

The initial step of this research is the review of coastal erosion cases in Peninsular Malaysia. The evidential data were collected from newspaper articles, news videos, social media and other relevant prime media. [7-10] Keywords such as "coastal erosion" and "shoreline erosion" were used to explore and collect coastal erosion cases in Peninsular Malaysia [23]. The erosion cases were then categorised into the following categories (table in Appendix B) to show the authenticity of coastal erosions in Peninsular Malaysia [24]. The cases of coastal erosion were then tabulated along with their authenticity. These locations were then mapped into public domain satellite imagery software [25] and enhanced separately in another decent mapping to show the overlapping locations.

3.2. Shoreline Changes Analysis

In order to investigate the coastal erosion occurrence in the mapped locations, public domain satellite imagery had been used to identify the shoreline changes. Previously, satellite imaging was used in wind engineering study to estimate the roughness length in Malaysia [26]. In this study, two satellite images were used for each location that is associated with coastal erosion cases. The images taken were for year 1984 and year 2016, a difference of 32 years. These images were then enhanced so that the image observation would be clearer. The shore line was then drawn in both images, represented by the yellow line for the year 1984 and the red line for the year 2016. Next, the images were layered together using the Geographical Information System (GIS) software. The evaluation of this processed satellite image showed the shoreline orientation and prove the erosion activity that has taken place in the location for the duration of 32 years [27].

3.3. Wind Data

The study areas are mainly located in coastal areas. Hence, hourly wind data was collected at the nearest meteorology station to the coastal erosion locations. The coordinates of meteorological station that is used for data collection is shown in Appendix C. A one-year period of wind data was collected to study the characteristics of the wind and was sufficient for the research [5]. The wind data collected hourly consisted of wind speed and wind direction. Only the hourly wind direction data was processed and the distribution of wind direction was calculated for the whole year. The wind direction distribution was then changed into percentage value. Based on the calculation, wind rose diagrams were produced to show the percentage of wind distribution in all the directions. Table 2 shows the example of calculating the percentage of wind direction distribution.

3.4. Wind and Coastal Erosion Relationship Analysis

This final analysis was conducted for all the locations with erosion cases. Firstly, the wind rose diagram that shows the wind directional distribution was developed with 16 directions. These directions could also be represented as angle of measurement (degree). The major wind directional distribution percentage was identified. Next, by using the image layering technique in the public domain imagery software, the processed satellite image that shows the shoreline changes and a compass with detailed angle markings were layered together. The right adjustment in the opacity of the images would enable us to view both layered images clearly. The compass was positioned in the deepest and most visible part of the shoreline that is eroding based on the processed satellite image. Finally, the layering of the compass and processed satellite image was used to estimate the angle (erosion direction) of the coastal erosion. The estimation was done by comparing the layering image with the wind rose that represents the wind directional distribution. The comparing was done by observing the highest wind directional distribution angle with the deepest part of the eroded shoreline angle. The directional angle of both this data was tabulated and analysed.

Table 2. Processing of Wind Direction Distribution percentage.

Direction (Degree)	N	NNE	………	NW	NNW
Wind Direction per hour ↓					
Total Hour (Daily)	... h	… h	… h	… h	… h
Total Hour (1 year)	8766 h	8766 h	8766 h	8766 h	8766 h
Percentage (%)	…%	…%	…%	…%	…%

4. Results and Discussion

The review of coastal erosion cases in Peninsular Malaysia shows 51 coastal locations undergoing coastal erosion. However, locations with heavy land reclamation were not considered in this study. These locations were then mapped with their reference code as shown in Fig. 1. The list of locations with and their authenticity category is attached in Appendix A. The wind and coastal erosion relationship analysis was carried out in all of 51 locations. Several analysis examples are shown in Fig. 2 Pantai Sabak (Kelantan), Fig. 3 Tanjung Piai (Johor), Fig. 4 Tanjung Piandang (Perak) and Fig. 5 Pantai Cherating (Pahang).

The *red* shore line (representing year 2016) which falls behind the *yellow* shore line (representing year 1984) proves that these locations had undergone major erosion and a natural geomorphology process, which caused large displacement of land. These images were then analysed and compared with the wind directional distribution; as mentioned in the analysis method. The computed wind directional distribution diagram shows two types of majoring wind directions. The first type is the wind rose showing only one major wind direction and the other is the wind rose showing two major wind directions. All the computed wind rose diagrams are attached in Appendix D.

Form the wind rose, only major wind directions from the seaside are considered in this analysis, while the major wind direction from inland is neglected. The acceptance of these charts was compared with the approximate monsoon flows before they were used for the analysis purpose in this study. From the observation and the analysis conducted, it shows that the erosional activity could be highly related to the wind direction from the sea side.

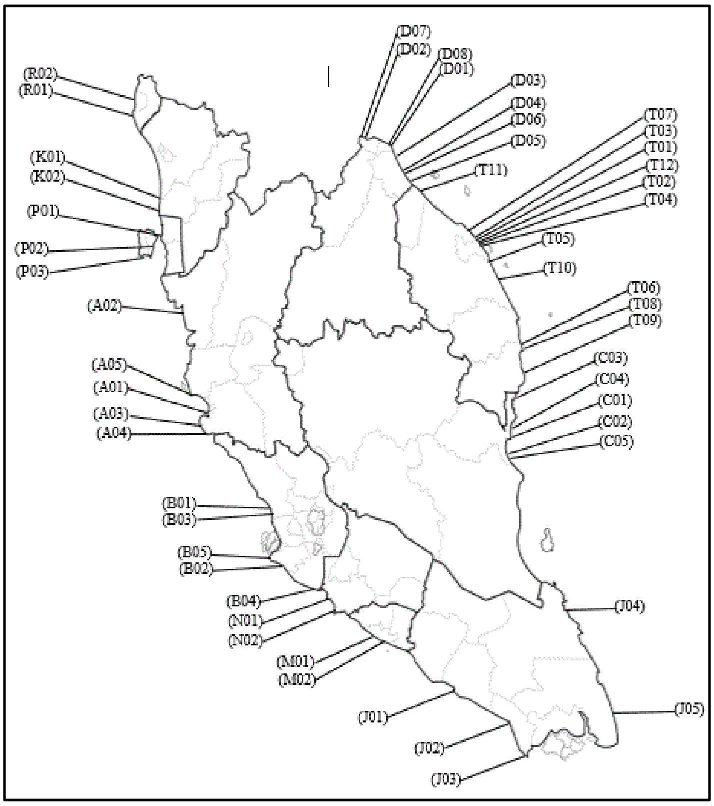

Fig. 1. The location of coastal erosion in Peninsular Malaysia.

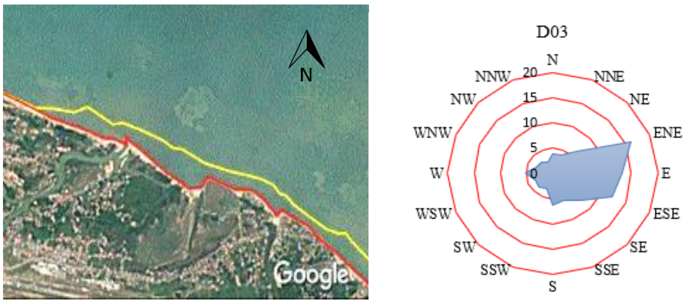

Fig. 2. Pantai Sabak, Kelantan (Base map source: Public Domain).

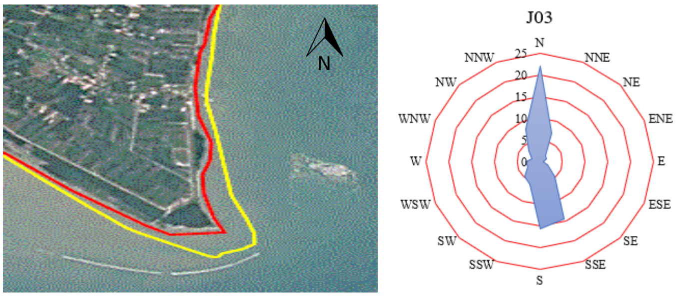

Fig. 3. Tanjung Piai, Johor (Base map source: Public Domain).

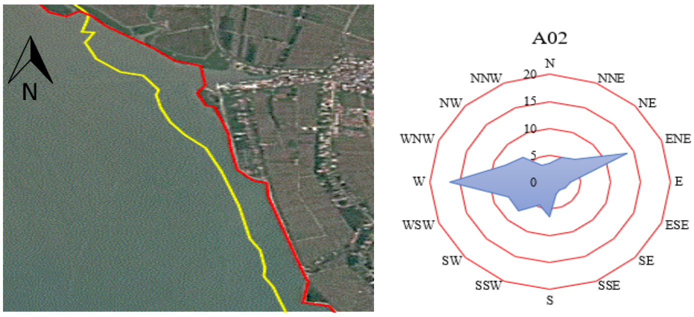

Fig. 4. Tanjung Piandang, Perak (Base map source: Public Domain).

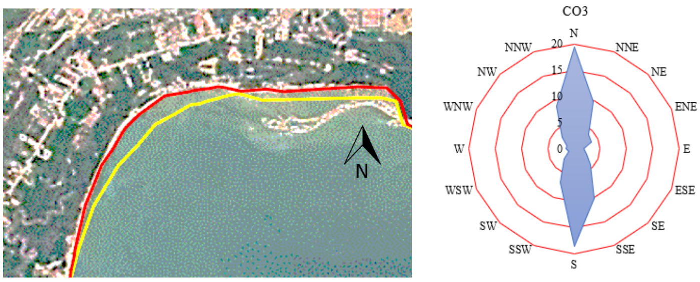

Fig. 5. Pantai Cherating, Pahang (Base map source: Public Domain).

The data are tabulated in angle of measurement (degree) to show the relationship between wind direction and erosion direction. Initially, 51 locations were found to be undergoing coastal erosion. However, during the analysis it was found that 7 locations could not be analysed due to lack of visibility erosion sign. These locations were not taken into the analysis of this research. The visibility of erosion in these locations are not clear due to certain possible factors; for instance, heavy land reclamation, active natural geomorphological processes, or the mild level of erosion. Table 3 shows the data tabulation for the wind and erosion relationship analysis. As mentioned above, only 44 locations were tabulated out of 51 locations. The data proves that most of the erosion directions are similar to the wind directions. Some of the tabulated data shows that the erosion directions differ with an angle of 10 degrees or less compared to the wind direction, but in more extreme cases, some of the data shows angle difference of more than 10 degrees.

Based on the tabulation shown in Table 3, a graph of wind direction against erosion direction was plotted. The graph was plotted in a best-fit line to produce the regression analysis as shown in Fig. 6. A total of 44 points were used to plot this graph. Nevertheless, due to the similar angle of measurement, some of the points have overlapped. From the graph, slight deteriorated data points can be observed. These deteriorations might be the result of a difference in angle between wind direction and erosion direction. The difference of a 10-degree angle is still highly acceptable because it is still within the wind directional distribution range; but the difference of some data that are more than 10 degrees is very less likely to be acceptable unless the wind direction distribution angle is wide. The erosion direction here represents the occurrence of erosion as directed by the wind direction. In this study, the erosions are considered alongshore because the analysis was done solely based on the wind direction.

Basically, in this study, the empirical method was implemented to estimate the wind and coastal erosion relationship. Previously, Ilena [23] conducted an empirical investigation of thunderstorms in Romania and Noram [26] conducted a semi empirical study on roughness length. The empirical method was adapted into this research because it only contains quantitative information as research method; compared to semi empirical method, which needs both the quantitative and qualitative information. Based on this approach, we evaluate the effect of wind direction to coastal erosion process. The relationship between wind direction and erosion direction is proven by the graph of Wind Direction against Erosion Direction as shown in Fig. 6. In fact, the correlation between Wind Direction and Erosion Direction shows a very good correlation with the regression analysis of $R^2 = 0.9$.

Table 3. Wind and erosion direction along Peninsular Malaysia.

Location	Wind (deg.)	Erosion (deg.)	Location	Wind (deg.)	Erosion (deg.)
R/01	225	230	C/02	180	170
K/01	247.5	250	C/03	180	180
K/02	247.5	235	C/04	180	180
P/03	270	230	C/05	0	0
A/01	270	240	T/01	22.5	22.5
A/02	270	260	T/02	22.5	22.5
A/03	270	260	T/03	22.5	22.5
A/04	270	260	T/05	22.5	22.5
A/05	270	250	T/07	22.5	22.5
B/01	270	270	T/09	0	10
B/02	270	280	T/10	22.5	22.5
B/03	270	270	T/11	67.5	67.5
B/04	270	270	T/12	22.5	22.5
B/05	270	270	D/01	67.5	67.5
N/01	270	270	D/02	67.5	67.5
N/02	270	270	D/03	67.5	67.5
J/01	180	180	D/04	67.5	67.5
J/02	180	150	D/05	67.5	67.5
J/03	180	170	D/06	67.5	67.5
J/04	180	160	D/07	67.5	67.5
J/05	180	160	D/08	67.5	67.5
C/01	180	180	M/01	180	170

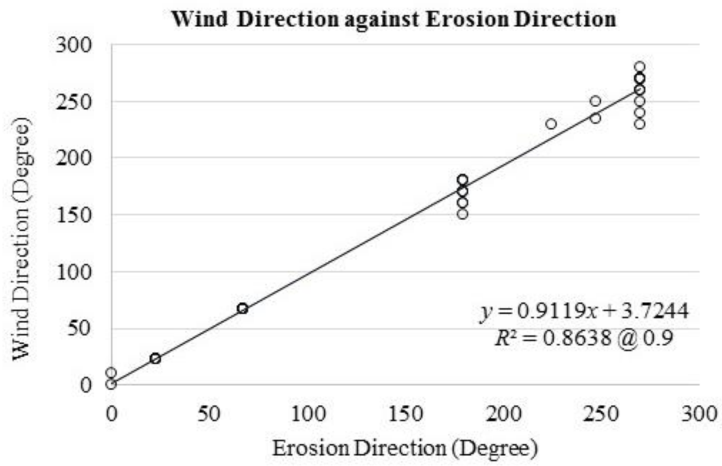

Fig. 6. Wind Direction against erosion direction.

5. Conclusions

In this paper, an extensive review of coastal erosion cases in Peninsular Malaysia was conducted. These reviews were used to identify the locations of erosion in Peninsular Malaysia. The usage of image layering technique and empirical based analysis allowed the study of the relationship of wind direction and coastal erosion direction in these locations. Results show a very good correlation between wind direction and erosion direction.

Theoretically, the direction of the wave and the energy of the wave is stimulated by the wind direction and wind speed together. This demonstrate that wind is one of the dominant factors that contributes to wave energy despite the indication (analysis of this study) that coastal changes are being identified solely from wave energy; making wind a secondary parameter. Wind is the main underpinning data in the forecast of coastal changes. This empirical method result shows a sound agreement; that coastal erosion direction is parallel with the major wind direction. The agreement shows that the accuracy of this method is highly function able but is still limited to certain circumstances.

Further studies are recommended; observing coastline orientation and the effects of wind speed on erosion especially for maritime countries like Malaysia.

Nomenclatures

A	Profile scale factor
D	Water depth, m
E	Total wave energy in one wave length per unit crest width, J/m²
$\overline{Ep}$	Potential energy per unit length of wave, J/m²
$\overline{Ek}$	Kinetic energy per unit length of wave, J/m²
g	Gravitational acceleration, 9.81 m/s²
H	Local wave height, m
H_{rms}	Root mean square of measured wave heights, m
h	Local water depth, m
k	Breaking index, (Around: 0.8)
L	Wavelength, m
u_{10}	Wind speed at 10m above the sea surface, m/s
x	Fetch length based on the wind speed, km
y'	Leeward (towards shore) orientated distance, km
y	Seaward (towards sea) orientated distance, km

Greek Symbols

ρ	Mass density of water (salt water = 1025 kg/m³)

Abbreviations

DID	Department of Irrigation and Drainage Malaysia
NCES	National Coastal Erosion Study of Malaysia
SWL	Sea Water Level
WP	Wilayah Persekutuan

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Appendix A

Authentication category of coastal erosion

Category	Specification
Authentic	Pictures or video erosion that shows the damages of infrastructure along and newspaper cuttings.
Strong	Photos of coastal erosion.
Weak	No evidence, the causes of coastal erosion is not justified.

Appendix B

List of shoreline location that is undergoing coastal erosion.

State	Shoreline location	Category
Perlis	R/01 Pantai Sungai Baru	Weak
	R/02 Pantai Kuala Perlis	Weak
Kedah	K/01 Tanjung Dawai	Weak
	K/02 Pantai Kuala Muda	Weak
Pulau Pinang	P/01 Lingkaran Lebuhraya Butterworth	Strong
	P/02 Pantai Gelugor	Authentic
	P/03 Sungai Batu	Authentic
Perak	A/01 Shore of Sungai Perak	Weak
	A/02 Tanjung Piandang	Weak

	A/03 Bagan sg. Tiang	Weak
	A/04 Bagan Sg.Belukang	Weak
	A/05 Teluk Rubiah	Weak
Selangor	B/01 Pantai Remis	Weak
	B/02 Pantai Morib	Weak
	B/03 Pantai Sg Sembilang	Weak
	B/04 Pantai Bagan Lalang	Weak
	B/05 Tanjung Rhu	Weak
Negeri Sembilan	N/01 Pantai Bagan Pinang	Weak
	N/02 Tanjung Lembah	Weak
Melaka	M/01 Pantai Puteri	Weak
	M/02 Tanjung Keling	Weak
Johor	J/01 Pantai Minyak Beku	Authentic
	J/02 Kampung Sri Pantai	Weak
	J/03 Tanjung Piai	Authentic
	J/04 Pantai Kampung Permata	Weak
	J/05 Api-api	Weak
Pahang	C/01 Teluk Cempedak	Weak
	C/02 Pantai Kampung Sepat	Strong
	C/03 Pantai Cherating	Strong
	C/04 Pantai Sungai Ular	Strong
	C/05 Tanjung Gosong	Strong
Terengganu	T/01 Universiti Malaysia Terengganu	Authentic
	T/02 Tok Jembal, Kuala Terengganu	Strong
	T/03 Tanjung Gelam, Kuala Nerus	Authentic
	T/04 Teluk Ketapang	Weak
	T/05 Pantai Rhu Renggeh	Weak
	T/06 Pantai Sura	Weak
	T/07 Kampung Mengabang Telipot	Authentic
	T/08 Teluk Lipat, Dungun	Authentic
	T/09 PantaI Kemasik, Kemaman	Strong
	T/10 Pantai Rusila, Marang	Authentic
	T/11 Bukit Keluang, Besut	Authentic
	T/12 Kampung Kubang Badak	Weak
Kelantan	D/01 Pantai Cahaya Bulan	Strong
	D/02 Kuala Pak Mat	Weak
	D/03 Pantai Sabak	Strong
	D/04 Pantai Irama	Strong
	D/05 Pantai Bisikan Bayu	Weak
	D/06 Pantai Balongan Bachok	Weak
	D/07 Pantai Mek Mas	Authentic
	D/08 Pantai Kundur, Kota Bahru	Authentic

Appendix C

List of meteorological station and coordinates

State	Location	Latitude	Longitude
Johor	Batu Pahat Meteorological Station	1°52'N	102°59'E
	Mersing Meterological Station	2°27'N	103°50'E
	Senai Meterological Station	1°38'N	103°40'E
Kedah	Alor Setar Meteorological Station	6°12'N	100°24'E

Kelantan	Kota Bharu Meteorological Station	6°10'N	102°17'E
Melaka	Malacca Meteorological Station	2°16'N	102°15'E
Negeri Sembilan	Tanah Merah Meteorological Station	2°39'N	101°47'E
Pahang	Kuantan Meteorological Station	3°47'N	103°13'E
Perak	Sitiawan Meteorological Station	4 °13'N	101°42'E
	Lubuk Merbau Meteorological Station	4 °48'N	100°54'E
Perlis	Chuping Meteorological Station	6°29'N	100 °16'E
Penang	Bayan Lepas Meteorological Station	5°18'N	100°16'E
Selangor	Subang Meteorological Station	3°07'N	101°33'E
	Sepang (KLIA) Meteorological Station	2 °43'N	101°42'E
Terengganu	Kuala Terengganu Meteorological Station	5°23'N	103°06'E
	Kuala Terengganu Meteorological Station	5°20'N	103°08'E

Appendix D

Wind direction distribution in Peninsular Malaysia