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Modelling of Coastal Vulnerability Index Along the East Coast of Peninsular Malaysia due to Sea Level Rise Impact

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Abstract. Sea level rise is a very serious phenomena around the world and caused by expansion of sea water due to the high temperature and the melting of ice at the poles. In Malaysia, areas located on the East Coast of Peninsular Malaysia are more vulnerable to the impact of rising sea water because they are facing the South China Sea where the waves are stronger, especially during the monsoon season in November to March. The study site is along the East Coast of Peninsular Malaysia, over 675km and covered fifteen districts located along the coast. This study focuses on developing vulnerability indices on physical, socioeconomic and correlation between both parameters. The analysis of physical vulnerability index (PVI) consist seven variables namely geomorphology, shoreline change rate, coastal slope, wave height, tidal range, sea level rise change and rock type. While for socioeconomic index (SeVI) focuses on three parameters such as quality of life, economic value and infrastructures. After obtaining the index for each parameter, coastal vulnerability index (CVI) is then calculated to determine the overall vulnerability for the coastal area. For CVI, the highest index along coastal area is Kuantan and the lowest index is Tumpat.

Keyword: *Sea Level Rise, Physical Vulnerability Index, Socioeconomic Vulnerability Index, Coastal Vulnerability Index, GIS*

1. Introduction

Coastal zone is an area of major focus for human habitation and their main source of income. The impacts of a sea level rise will vary according to the local water levels due to local variations in vertical crustal movements, topography, wave climatology, long shore currents, and storm frequencies. The sea level rise will impact the coastal zone on physical, socioeconomic, ecology, biological and chemical aspect. Besides the increasing flood level risk, sea level rise also causes erosion, sedimentation deficits, inundation of low-lying areas, saltwater intrusion and biological effects [1] [2] [3].

Studies on the impact of a sea level rise has been done around the world such as in Egypt [1], Bangladesh [4], USA [5], Malaysia [6], India [2] and Australia [3]. The researchers who studied the impact of a sea-level rise in physical aspects are [7] and [8] while others studied the socioeconomic impacts [9].
Littoral states will have to respond to increasing sea level. Malaysia is a maritime state bordered by the South China Sea and the Straits of Malacca. The East Coast of Peninsular Malaysia particularly, is the most vulnerable due to its direct exposure to the South China Sea. Four states along the East Coast of Peninsular Malaysia namely Kelantan, Terengganu, Pahang and Johor are particularly exposed. The coastline of these states covers fifteen districts starting from Tumpat, Kelantan to Kota Tinggi, Johor. During the Northeast monsoon season (November-March every year), the coastal area of Eastern Peninsular Malaysia has always been vulnerable due to the large waves that batter the coastline which aggravates the problem of sea level rise [10].
In this study, the physical and socioeconomic parameters were studied. The physical parameter covers seven variables while the socioeconomic parameter focuses on three variables. This study used secondary data on physical and socioeconomic parameters collected from various government and non-government departments. Then both parameters were calculated using selected equations to find an index. The physical and socioeconomic indices are used to map the vulnerability of the East Coast of Peninsular Malaysia for coastal length of about 675 km using ArcGIS software. The vulnerability map was assigned to five ranks: very high, high, moderate, low and very low. Very high rank is the most vulnerable while the very low describes the least vulnerable. The physical and socioeconomic vulnerability index are calculated to know the stage of vulnerability due to future sea level rise.
After identifying the worst area of vulnerability, decision makers could reduce vulnerability by making choices that steer development away from high risk areas. Adaptation measures such as retreat, accommodation and protection can then be considered in future planning of the coastline.

2. Material and methods

Peninsular Malaysia covers an area of 131,573 km^2 and Sabah and Sarawak occupying an area of 73,619 km^2 and 124,449 km^2 respectively. The method started from description of study sites, covering the districts along the East Coast of Peninsular Malaysia, from Tumpat, Kelantan to Kota Tinggi, Johor. These districts face the South China Sea with large waves battering the coastal area especially during the monsoon season which normally caused havoc along the coast due to flooding and sea level rise will exacerbate this situation.
Kelantan is the northernmost state of the east coast of Peninsular Malaysia, bordering Thailand to its north and the state of Terengganu to its south. Kelantan covers an area about 15,000 km^2 with thirteen districts but only four districts face the South China Sea: Tumpat, Kota Bharu, Bachok and Pasir Puteh. Kelantan has the shortest coastline (70 km) compared to Terengganu (240 km), Pahang (209 km) and Johor (156 km).
Terengganu is situated in Peninsular Malaysia which bordered in the northwest by Kelantan, and the southwest by Pahang. Terengganu has seven districts but the only six districts are littoral facing the South China Sea. The capital is Kuala Terengganu located at the mouth of the broad Terengganu River.
Pahang is the largest state in Peninsular Malaysia and the third largest in Malaysia after Sarawak and Sabah. It is bordered to the north by Kelantan, to the east by Terengganu, to the west by Perak, Selangor, Negeri Sembilan and to the south by Johor. Pahang River is the longest river of Peninsular Malaysia. There are 10 districts in Pahang but

only 3 districts are facing the South China Sea, namely Kuantan, Pekan and Rompin. Kuantan is the capital state of Pahang.
Johor is the southernmost district in Peninsular Malaysia. Johor consists of 10 districts but only two districts facing the South China Sea which is Mersing and Kota Tinggi. The eastern coast of Johor facing the South China Sea and in the western coast of Johor lies facing the Straits of Malacca.

2.1 Physical Parameter

Physical vulnerability index for the east coast of Peninsular Malaysia coastline uses seven relative risk variables. The physical parameters can be divided into two groups namely geologic and physical process variables. The geologic variables are geomorphology, shoreline change rate, coastal slope and rock type. These variables influence erosion activity. While the physical process variables included maximum wave height, mean tidal range and sea level change, all of which contribute to the inundation hazards.
Geomorphology or landform is the scientific study of landforms and the processes that shape them. The geomorphology variable that are of concern is the relative erodibility of the different landform types.
Coastal erosion is due to natural causes as a result of shoreline response to natural shoreline conditions driven by meteorological ocean conditions of wind, waves, tides and currents. The shoreline change rate along the Malaysia coastline was monitored by Department of Irrigation and Drainage since last few decades. The data of this study also provided by [11]. This data was carried out in 1985 from National Coastal Erosion Malaysia Study (NCES). They mentioned that about 29% of shoreline are eroding. They identified three categories of erosion: category I (critical), category II (significant)and category III (acceptable). Natural causes of coastal erosion are tides and currents, storm waves and sea level rise.
The slope of the immediate hinterland is one of the most important factors to be considered in estimating the impact of sea level rise on a given coast [2]. Steep slopes experience less flooding compared to gentle to moderately sloping coasts where any rise in sea level will inundate larger extents of land [3]. The coastal slope is the main factor of area inundation. Sloping areas flood faster than the steep areas. The coastal slope data was provided by [12] which covers slope along the East Coast of Peninsular Malaysia.
Maximum wave height is used as a proxy for wave energy which drives coastal sediment transport. Wave energy is directly related to the square of wave height [13]. Wave data are obtaining from the Malaysian Meteorological Department for 12 months along the East Coast of Peninsular Malaysia.
The data used for tide in the calculation of physical vulnerability index (PVI) is obtained from the Mike C Map software. Mike C Map is an efficient tool for extracting depth data and predicted tidal elevation from the world wide Electronic Chart Database CM-93 Edition 3.0, named C-Map professional +, manufactured by Jeppesen Marine AS, Norway. Mean tidal range is linked to both permanent and episodic inundation hazards.
Sea level rise is the changes in sea level datum calculated on average 15 years. For the purpose of this study data for sea level rise change is adopted from [4]. The author based on their findings from analysis of 12 tidal gauges from the coastline of Peninsular Malaysia. This tidal network was operational since 1984. Sea level rise change variable is derived from the change in annual mean water elevation over time as measured at tide gauge stations along the coast such as Tanjung Sedili, Pulau Tioman, Tanjung Gelang, Chendering and Geting.

Lithology variable represents the bedrock occurring at, or underlying the shoreline [3]. There are many factors affecting the separation of settleable solids from water. The common types of factors to consider are particle size, water temperature and currents. Beaches in Malaysia constituted of easily erodible material. The east coast shoreline consists of sand along 860km whereas west coast consists of silt and clay along the 110 km length.

After identified variables for physical parameter, an index for each variable were calculated. The seven variables as explained previously has its own rankings and categories. The data for each variable will be used for the calculation of the physical vulnerability index (PVI). Each variable has been assigned a rank from 1 to 5 with 5 representing the most vulnerable class. Table 1 shows the ranking for physical variables. After the variables were ranked, they are calculated using the physical vulnerability index equation created by [14] to assess the risk of rising sea levels on the east coast of Peninsular Malaysia.

Table 1. Ranking of coastal risk classes for physical variables. Source: [13].

Variable	Rank				
	Very Low 1	Low 2	Moderate 3	High 4	Very High 5
1. Slope	≥30.1	20.1 – 30.0	10.1 - 20.0	5.1 – 10.0	0 – 5.0
2. Rock Type (Lithology)	High medium grade metamorphics	-Low grade metamor -Sandstone and conglomerate	Most sedimentary rocks	-Coarse and/or poorly-sorted -Unconsolidated sediments	Fine-unconsolidated sediment
3. Geomorphology / Landform	-Rocky, cliffed -Coasts -Fiords -Fiards	-Medium cliffs -Indented coasts	-Low cliffs -Glacial drift -Salt marsh -Coral reef -Mangrove	-Beaches -Estuary -Lagoon -Alluvial plains	-Barrier beaches -Beaches (sand) -Mudflats -Deltas
4. Sea Level Rise Change (vertical movement)	≤-1.1 Land rising	-1.0 – 0.99 Land rising	1.0 – 2.0 Within range of eustatic rise	2.1 – 4.0 Land sinking	≥4.1 Land sinking
5. Shoreline Change Rate (erosion @accretion)	≥2.1 Accretion	1.0 – 2.0 Accretion	-1.0 - +1.0 Stable	-1.1 - -2.0 Erosion	≤-2.0 Erosion
6. Tidal Range (Mean)	≤0.99 Microtidal	1.0 – 1.9 Microtidal	2.0 – 4.0 Mesotidal	4.1 – 6.0 Macrotidal	≥6.1 Macrotidal
7. Wave Height (Max)	0 – 2.9	3.0 – 4.9	5.0 – 5.9	6.0 – 6.9	≥7.0

According to [13] the physical vulnerability index (PVI) is calculated as the square root of the product of the ranked variables divided by the total number of variables;

$$\mathrm{PVI} = \sqrt{\frac{(a*b*c*d*e*f*g)}{7}} \quad (1)$$

Where *a* = geomorphology, *b* = shoreline change rate, *c* = coastal slope, *d* = max wave height, *e* = mean tidal range, *f* = sea level rise change and *g* = rock type.

2.2. Socioeconomic Parameter

Socioeconomic parameters are associated with the physical vulnerability. Socioeconomic parameters are divided into three categories such as the aggregated quality of life, economic value and aggregated infrastructure.

Most of the major cities located in the estuarine and coastal area. During the sea level rise, the major urban areas are most at risk of flooding. The city is also the most populous area. The data for aggregated quality of life are available from a number of government sectors such as statistical department and Economic Planning Unit (EPU). Aggregated quality of life covered fifteen variables such as population, living quarters, households, number of male, number of female, natural increases, stillbirth, livebirth, number of death, age less than 14, age 15-64, age more than 65, number of Malays, number of Chinese and number of Indians for each district.

Economic value including water plant production, agriculture area, livestock and fish landed. The source of these data is from Department of Agriculture, Department of Veterinary Services, Department of Water and Department of Fisheries. Water plant production means the amount of water production in litre. This data come from the Department of Water for each state. Agricultural area in hectare including several crop plants such as paddy, rubber, palm oil, cocoa, tobacco, vegetables and fruits. Department of Veterinary Services contributes the number of livestock data such as buffalo, cow, goat, sheep, chicken and duck. While the fish landed data consist of the amount of fish landed in metric tonne. It includes the fish landed in deep sea, water front and ponds/cages.

Infrastructure along the east coast of Peninsular Malaysia included number of schools, mosques, police stations, hospitals, industrial areas, train stations, petrol stations, recreational areas and critical infrastructure (airport, army base, marine park and power plant). The data source is the Institute of Oceanography and Environment, Department of Statistic and Economic Planning Unit.

Socioeconomic vulnerability index was calculated using SPSS software but the sample size (variables) were less than 100 and not suitable for this analysis. The other method for socioeconomic vulnerability index (SeVI) is calculated using Hazard Assessment Procedure by [15]. The equation is:

Step 1
Calculate X
X= Value in district / Value in state

Step 2
Calculate index by dividing X by Maximum X
Index = X / maximum X (2)

After getting an index for each parameter, the index will be mapped using ArcGIS software. ArcGIS software is used to make it easier to identify the level of destruction as each index will be placed in a different ranking of 1 to 5.

2.3.Coastal Vulnerability Index (CVI)

After obtaining the index for each parameter, coastal vulnerability index (CVI) is then calculated to determine the overall vulnerability for the coastal area. The overall index will be formed from weighted average of the sub-indices [16].

Combining both parameterswill derive the Coastal Vulnerability Index which are calculated using weighted average.

$$\text{CVI} = \frac{(N1\ X\ n1) + (N2\ X\ n2) + (N3\ X\ n3) + (N4\ X\ n4)}{n1+n2+n3+n4} \quad (3)$$

Where $N1$ = Physical vulnerability index, $N2$ = SeVI (Aggregated quality of life), $N3$ = Sevi (Aggregated economic value), $N4$ = Sevi (Aggregated infrastructures), $n1$ = number of variable (PVI), $n2$ = number of variable (Aggregated quality of life), $n3$ = number of variable (Aggregated economic value) and $n4$ = number of variable (Aggregated infrastructures). The number of variable for $n1$ (physical vulnerability index) = 7, $n2$ (aggregated quality of life) = 15, $n3$ (aggregated economic value) = 4 and $n4$ (aggregated infrastructures) = 2.

2.4.Mapping using GIS Software

ArcGIS software is used for creating maps, compiling geographic data, and analyzing mapped information. After getting an index for each parameter, the index will be mapped using ArcGIS software. In this study, ArcGIS version 10 is used. Once calculated the index within the GIS, they are now ready to be displayed. ArcGIS software is used to make it easier to identify the level of destruction as each index will be placed in a different ranking of 1 to 5. Very high ranking means the area is most vulnerable and very low vulnerability means least vulnerable, to sea level rise. The combinations of physical and socioeconomic vulnerability create a picture of the coastal present overall vulnerability. Combination of the two parameters indicate the overall destruction along the coast and mapping using ArcGIS software will clarify the areas that faces destruction.

3.Results and Discussions

3.1.Physical Vulnerability Index

The physical parameters are qualitative data and classified using the coastal risk classes used by [13] (Table 1). Then the value will be calculated to find an index. After giving rank to each variable, physical vulnerability index is calculated as the square root of the product of the ranked variables divided by the total number of variables. Table 2 shows the areas with the highest vulnerability value are Kuantan followed by Pekan and Rompin while the lowest values at Tumpat district.

The vulnerability indices are mapped according to the lowest (0) to possible maximum score. The possible maximum score for physical vulnerability index is 105.6. For this study, there are no district will very high and high category of the physical vulnerability index. The moderate ranks consist Kuantan, Pekan and Rompin, low ranks are at the districts of Besut, Setiu, Kuala Terengganu, Marang, Dungun, Kemaman, Mersing and Kota Tinggi while very low rank included the districts of Tumpat, Kota Bharu, Bachok, and Pasir Puteh (Figure 1a).

3.2. Socioeconomic Vulnerability Index

The data used for the socioeconomic parameter in 2010 were from various government agencies. Similar with the physical vulnerability index map, a map for socioeconomic also divided into five categories with different colors depends on the vulnerable area. The red color shows the most vulnerable followed by blue (high ranking), green (moderate), pink (low) and yellow (very low). Table 2 shows the socioeconomic vulnerability index for aggregated quality of life, aggregated economic value and aggregated infrastructure fifteen districts.

The district with highest vulnerability value is Kota Bharu with 13.32 while the lowest value is Setiu with 1.73. Using the minimum and maximum possibility maximum score, the result shows the areas with very high ranking are Kota Bharu and Kuantan district. Kuala Terengganu is in the high rank. There is no moderate ranking. While the low-ranking area are Tumpat, Bachok, Pasir Puteh, Besut, Dungun, Kemaman and Kota Tinggi while very low ranking is Setiu, Marang, Pekan, Rompin and Mersing. Figure 1(b) shows map of aggregated quality of life index along the coastal.

The highest vulnerable index for aggregated economic value is Kota Tinggi followed by Kuantan while the least vulnerable area is Tumpat. Refer to Figure 1(c), based on possible maximum score, there are no very high ranking. The high ranking is Kota Tinggi while in the moderate ranking are Kuala Terengganu, Kemaman and Kuantan district. The district of Kota Bharu, Pasir Puteh, Bachok, Dungun, Pekan, Rompin and Mersing are in the low ranking. Very low-ranking areas are Tumpat, Bachok, Setiu and Marang district.

Figure 1(d) shows map of aggregated infrastructures index along the coastal. The most vulnerable area is Kemaman and the lowest is Pasir Puteh. Based on possible maximum score index, the very high ranking for aggregated infrastructure is Kemaman and high ranking is Kuantan. Moderate ranking area are Bachok, Besut, Setiu, Kuala Terengganu, Dungun, Rompin, Mersing and Kota Tinggi. While the low vulnerability areas are Tumpat, Kota Bharu, Marang and Pekan. Very low vulnerability is Pasir Puteh.

Table 2. Coastal Vulnerability Index (CVI) based on the district along the coastal area.

State	District		Sevi			
		PVI	QOL	EV	INF	CVI
Kelantan	Tumpat	17.93	4.39	0.381	0.79	6.94
	Kota Bharu	20.7	13.32	0.862	0.70	12.49
	Bachok	20.7	3.21	0.467	1.04	7.04
	Pasir Puteh	20.7	3.41	0.957	0.20	7.15
Terengganu	Besut	22.68	3.94	1.068	0.85	8.00
	Setiu	26.19	1.73	0.528	0.88	7.61
	Kuala Terengganu	26.19	9.53	1.749	1.17	11.99
	Marang	26.19	2.78	0.634	0.47	8.16
	Dungun	26.19	4.08	1.005	0.96	8.94
	Kemaman	22.68	4.72	1.696	1.77	8.57
Pahang	Kuantan	56.69	12.70	2.009	1.58	21.38
	Pekan	50.71	2.86	1.188	0.57	14.42
	Rompin	50.71	2.89	1.471	1.02	14.51
Johor	Mersing	27.77	1.89	1.490	1.19	8.25
	Kota Tinggi	21.51	4.99	2.570	0.82	8.48

3.3. Coastal Vulnerability Index (CVI)

CVI shows the whole vulnerability index. In the case of coastal vulnerability index for districts along the coastal area, the highest value is the Kuantan district and the lowest value is Tumpat district (Table 2).

Based on the map using possible maximum score, the index categorized into five categories. High ranking area is Kuantan district, moderate ranking is Pekan and Rompin, very low ranking is Tumpat and the other districts in low ranking. 1(e) shows map of coastal vulnerability index based on the district along the coast.

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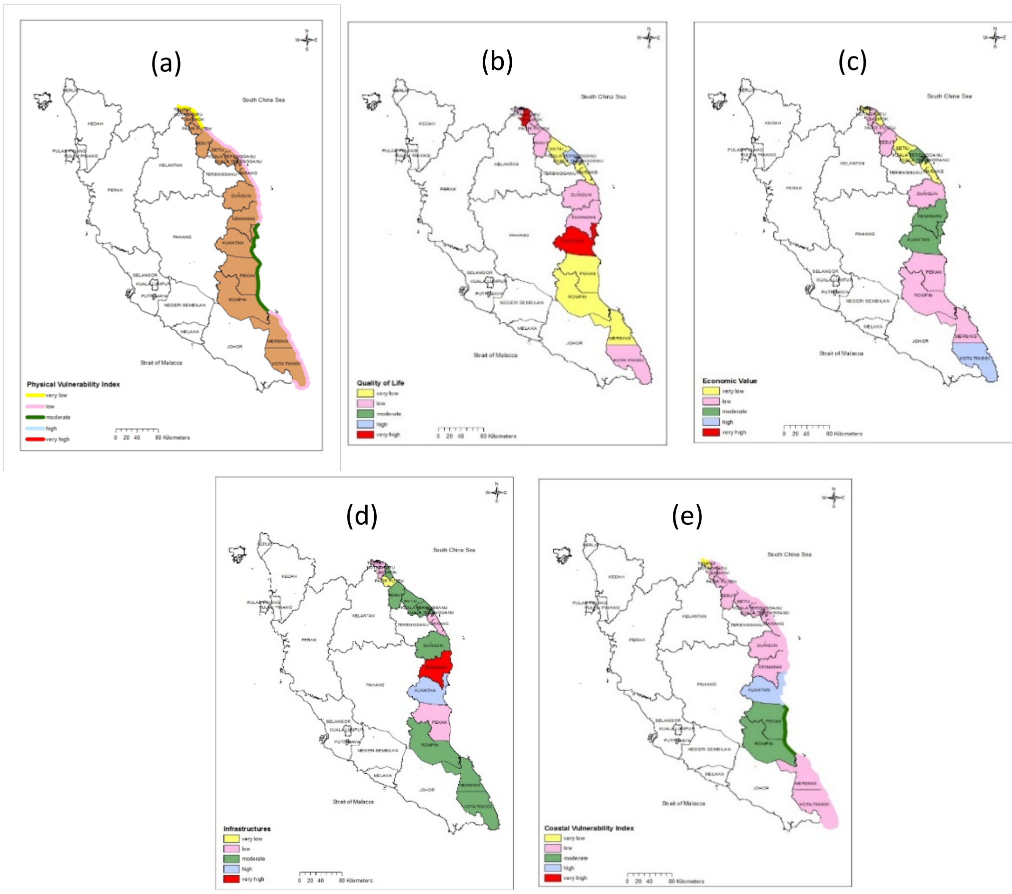

Figure 1 (a) Map of Physical Vulnerability Index; (b) Map of Aggregated Quality of Life; (c) Map of Aggregated Economic Value (d); Map of Aggregated Infrastructures and (e) Map of Coastal Vulnerability Index

4.Conclusion

The risky area is at low land and areas close to the river. The worst physical vulnerable district along the east coast of Peninsular Malaysia is Kuantan, Pekan and Rompin while the least vulnerable area is Tumpat. The worst physical vulnerability indices are interconnected with each other, which consists of the geomorphology area of sandy beaches, mudflats and deltas, most of this beach area is exposed to erosion with sloping coastal slope which <5.0, rock types are fine unconsolidated sediment, while sea level rise change ≥ 2.1. Tidal range along the coast is between 2.0 – 4.0 m which mesotidal type and wave height is between 7 m and are ranked in category 5.

For socioeconomic vulnerability index along the coastal area, the aggregated quality of life with highest vulnerability value is Kota Bharu while the lowest value is Setiu. While the highest vulnerable index for aggregated economic value is Kota Tinggi followed by Kuantan while the least vulnerable area is Tumpat. The most vulnerable area is Kemaman and the lowest is Pasir Puteh for aggregated infrastructures.

After deriving an index for these two parameters, the total of vulnerable index value was calculated using a weighted average and named as Coastal Vulnerability Index. Overall, the highest value is Kuantan district and the lowest value is Tumpat district. As expected, the CVI reveals that major towns along the coastline of the East Coast of

Peninsula Malaysia is more at risk compared to other areas. It can also be concluded that, in general, the coastline of the East Coast of Peninsula Malaysia would not be facing serious consequence of risk either to property or quality of life in the next few hundred years due to the small yearly rate of rise reported for the Malaysian waters. Nevertheless, it is prudent for policy makers to develop policies to lessen the risk of sea level rise especially to sensitive areas and shift new development and infrastructure to areas less prone to sea level rise.

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