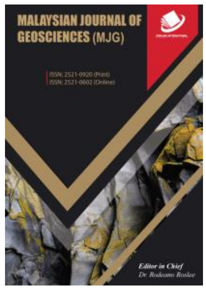
ZIBELINE INTERNATIONAL PUBLISHING

Malaysian Journal of Geosciences (MJG)

DOI: https://doi.org/10.26480/mjg.02.2018.33.38

Print ISSN : 2521-0920
Online ISSN : 2521-0602

CODEN: MJGAAN



PHYSICAL IMPACT OF SEA LEVEL RISE TO THE COASTAL ZONE ALONG THE EAST COAST OF PENINSULAR MALAYSIA

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ARTICLE DETAILS

Article History:

Received 26 June 2018
Accepted 2 July 2018
Available online 1 August 2018

ABSTRACT

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Sea level rise around the world caused by global warming since decade and effects on coastal especially country below mean sea level and country island. The prediction of sea level rise by 2100 is over 3m. Sea level rise increases caused by melting ice and thermal expansion. The impact of sea level rise concentrated along the coastal area. This paper studied the impact of sea level rise to physical parameters along the East Coast of Peninsular Malaysia. Seven physical variables such as geomorphology, shoreline change rate, coastal slope, lithology, maximum wave height, mean tidal range and sea level change were chosen to find an physical vulnerability index. The index also was mapped using ArcGIS software to picture the vulnerability. The worst area for physical vulnerability index is along the Pahang coastline especially Kuantan district. The prevention and adaptation from government and non-government agencies should be taken to reduce the effects of sea level rise.

KEYWORDS

Sea level rise, GIS, Physical Vulnerability Index, Simulation sea level rise.

1. INTRODUCTION

Sea level rise is the rising of sea level caused by several factors such as thermal expansion and melting ice. This sea level rise are recorded using geological data, tide gauge records and satellite altimeter [1-7]. There are two types of a sea level rise: eustatic and isostatic. Eustatic refers to the rise in global sea levels due to global warming. It changes as a result in an alteration to the global sea levels, such as changes in the volume of water in the world oceans or changes in the volume of an ocean basin. While an isostatic level rise refers to the increase in the water level of local reference areas only.

Over 140,000 years ago, sea levels were changing at an average rate of about 10 mm per year (1 m per century) during the end of the last ice age. Sea level stabilized in a few thousand years and there was little change between 1AD and 1800AD. Sea level rose much more slowly over the past 7,000 years. In the 19th century, sea level rose again and rose more rapidly in the 20th century. IPCC (2007) report that "The average rate was 1.7±0.5 mm/year for the 20th century, 1.8±0.5 mm/year for 1961-2003, and 3.1±0.7 mm/year for 1993-2003" clearly showing the increase of global mean of sea level rise between mid-19th and 20th century".

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.

For this study, the physical impact of sea level rise was concentrated. Physical impacts of sea level rise is vulnerability towards impact on the coastal in terms of the physical aspects. Physical vulnerability concerns the ultimate impacts of a hazard event, and is often viewed in terms of the amount of damage experienced by a system as a result of an encounter with a hazard [8].

To determine the impact of rising water levels, the physical vulnerability index should be calculated. There are various terms used to designate physical vulnerability index such as CVI, CSI [9-16]. The variables can effectively measure the both erosion and inundation risk factors [17,18]. The erosion risk could be determined based on the factors related to geology, geomorphology, tidal ranges and wave heights whereas the inundation risk could be estimated by sea-level and elevation data.

2. METHODOLOGY

East Coast of Peninsular Malaysia extends over 675 km facing the South China Sea and is shared by four coastal states i.e. Kelantan, Terengganu, Pahang and Johor. These states cover fifteen districts along the coastline starting from Tumpat in Kelantan to Kota Tinggi in Johor. The study sites do not include the islands along the East Coast because of the lack of physical data.

The coastline along the East Coast of Peninsular Malaysia is well known for its sandy beach, aquaculture ponds, agriculture area, recreational area, and major and minor industries. Environmental Sensitivity Index reported that there is not much coastal development along the coastal areas of the east coast of Peninsular Malaysia [19]. Meanwhile major town for each state located near the coastal area such as Kota Bharu, Kuala Terengganu and Kuantan.

For this study, seven variables were considered to be included in the development of physical vulnerability index. They are geomorphology, shoreline change rate, coastal slope, lithology, maximum wave height, mean tidal range and sea level change.

2.1 Geomorphology/Landform

Geomorphology is the scientific study of landforms and the processes that shape them. The geomorphology variable that are of concern the relative erodibility of the different landform types. A summary of the landforms is presented in Table 1 below.

Table 1: Geomorphology of each district along the East Coast of Peninsular Malaysia [19].

State	District	Geomorphology
Kelantan	Tumpat	Deltas, sandy beaches
	Kota Bharu	Sandy beaches
	Bachok	Sandy beaches
	Pasir Puteh	Sandy beaches
Terengganu	Besut	Sandy beaches
	Setiu	Mudflats, sandy beaches
	Kuala Terengganu	Barrier beaches, sandy beaches
	Marang	Barrier beaches, sandy beaches
	Dungun	Sandy beaches
	Kemaman	Mudflats, barrier beaches, sandy beaches
Pahang	Kuantan	Mudflats, sandy beaches
	Pekan	Sandy beaches
	Rompin	Sandy beaches
Johor	Mersing	Mudflats, sandy beaches
	Kota Tinggi	Estuary, beaches, lagoon

2.2 Shoreline Change Rate (Erosion and Accretion)

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. Coastal erosion is pronounced in morphological active areas and areas immediately adjacent to river mouths which are subject to considerable short-term morphological changes. Table 2 below shows shoreline change rate along the East Coast of Peninsular Malaysia.

Table 2: Shoreline change rate (erosion and accretion) along the East Coast of Peninsular Malaysia [20].

State	District	Shoreline Change Rate
Kelantan	Tumpat	Stable
	Kota Baharu	-5
	Bachok	-5
	Pasir Puteh	-4
Terengganu	Besut	Stable
	Setiu	-3
	Kuala Terengganu	-5
	Marang	-4
	Dungun	-10
	Kemaman	Stable
Pahang	Kuantan	Stable
	Pekan	Stable
	Rompin	Stable
Johor	Mersing	Stable
	Kota Tinggi	Stable

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 DID (1985). 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.

2.3 Coastal Slope

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 [12]. Steep slopes experience less flooding compared to gentle to moderately sloping coasts where any rise in sea level will inundate larger extents of land [16]. 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 ESI which covers slope along the East Coast of Peninsular Malaysia [19]. Table 3 below shows coastal slope along the East Coast of Peninsular Malaysia

Table 3: Coastal slope for each district along the East Coast of Peninsular Malaysia [19].

State	District	Coastal Slope
Kelantan	Tumpat	0.573 - 4.093
	Kota Bharu	1.05 - 4.17
	Bachok	1.9 - 4.5
	Pasir Puteh	1.99 - 4.36
Terengganu	Besut	3.74 - 8.19
	Setiu	2.7 - 10.7
	Kuala Terengganu	1.67 - 10.25
	Marang	5.62 - 12.82
	Dungun	4.3 - 10.89
	Kemaman	3.595 - 9.598
Pahang	Kuantan	0.91 - 7.52
	Pekan	1.38 - 7.64
	Rompin	1.53 - 8.14
Johor	Mersing	0.11 - 9.94
	Kota Tinggi	0.94 - 9.65

2.4 Wave Height

Maximum wave height is used as a proxy for wave energy which drives coastal sediment transport. Wave data are obtain from the Malaysian Meteorological Department. The data are derived from marine surface observations reported by ship that participated in the World Meteorological Organization (WMO) Voluntary Observing Ships Scheme, oilrigs/oil platforms and light houses that are located in the Malaysian waters [21]. Table 4 below shows maximum wave height for 12 months along the East Coast of Peninsular Malaysia

Table 4: Wave height along the East Coast of Peninsular Malaysia [21].

Month	State			
	Kelantan	Terengganu	Pahang	Johor
Jan	-	1	3	2
Feb	1	1.5	2	3
Mar	-	1	1	2.5
Apr	-	2	2	1
May	-	-	1	1
Jun	1.5	1.5	4.5	1
Jul	2.5	1.5	7	2
Aug	-	2	2	1.5
Sep	-	-	2	1.5
Oct	-	1	4	1
Nov	-	1.5	2	1.5
Dec	-	2.5	2.5	2.5

The wave height along the coastal area in range 1 to 7 m. All of districts for Kelantan and Terengganu in rank 1 (very low) while Johor in ranking 2 (low). Pahang have the highest ranking which is no 5 (very high).

2.5 Tidal Range

The tide is rising and lowering of sea levels caused by the combined effects of gravitational forces due to the Moon, Sun and Earth's rotation. Tides are not constant but vary depending on the position of the Moon and the Sun. Malaysia's coasts are influenced by diurnal, semi diurnal and mixed tides. 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. Mean tidal range below 1.9 is classified as low and very low, mean tidal range in between 2.0 to 4.0 is moderate and more than 4.1 is classified as high and very high vulnerability. Table 5 below shows tidal range along the East Coast of Peninsular Malaysia.

Table 5: Tidal range along the East Coast of Peninsular Malaysia.

State	District	Tidal Range
Kelantan	Tumpat	1.788
	Kota Bharu	1.788
	Bachok	1.788
	Pasir Puteh	1.788
Terengganu	Besut	2.21
	Setiu	2.114
	Kuala Terengganu	2.118
	Marang	2.582
	Dungun	2.605
	Kemaman	2.394
Pahang	Kuantan	3.03
	Pekan	2.999
	Rompin	2.783
Johor	Mersing	2.845
	Kota Tinggi	2.563

2.6 Sea Level Rise Change

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 a study [7]. 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. Table 6 shows the sea level rise change along the East Coast of Peninsular Malaysia.

Table 6: Sea level rise change along the East Coast of Peninsular Malaysia.

State	District	Sea level rise change (mm/year)
Kelantan	Tumpat Kota Bharu Bachok Pasir Puteh	1.73
Terengganu	Besut Setiu Kuala Terengganu Marang Dungun Kemaman	3.2
Pahang	Kuantan Pekan Rompin	2.64
Johor	Mersing Kota Tinggi	1.83

2.7 Lithology (Rock Type)

Rock type variable represents the bedrock occurring at, or underlying the shoreline [16]. According to Dictionary of Environmental Science (2003), "sediment is defined as the organic and inorganic materials or solid fragments derived from the weathering processes of sand, pebbles, silt, mud and loess (fine-grained soil). These are then carried by wind, ice or other naturally occurring agents. Sediments can also be defined as the material deposited at the bottom of rivers, which are silt and deposits".

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. Lithology is categorized into five ranking; 1) very low, low, medium, high and very high. Very low rank is high medium, grade and metamorphic, low rank is low grade and metamor, medium is sedimentary rock, high is coarse and/or poorly sorted and unconsolidated sediment and very high ranking is fine, and unconsolidated sediment.

Beaches in Malaysia constituted of easily erodible. The east coast shoreline consists of sand along 860km whereas west coast consist of silt and clay along the 110 km length. Table 7 below shows lithology along the East Coast of Peninsular Malaysia.

Table 7: Rock type along the East Coast of Peninsular Malaysia.

State	District	Lithology
Kelantan	Tumpat	Fine- unconsolidated sediment
	Kota Bharu	Coarse and/or poorly sorted, Unconsolidated sediment
	Bachok	Coarse and/or poorly sorted, Unconsolidated sediment
	Pasir Puteh	Coarse and/or poorly sorted, Unconsolidated sediment
Terengganu	Besut	Coarse and/or poorly sorted, Unconsolidated sediment
	Setiu	Coarse and/or poorly sorted, Unconsolidated sediment
	Kuala Terengganu	Coarse and/or poorly sorted, Unconsolidated sediment
	Marang	Coarse and/or poorly sorted, Unconsolidated sediment
	Dungun	Coarse and/or poorly sorted, Unconsolidated sediment
	Kemaman	Coarse and/or poorly sorted, Unconsolidated sediment
Pahang	Kuantan	Fine- unconsolidated sediment
	Pekan	Coarse and/or poorly sorted, Unconsolidated sediment
	Rompin	Coarse and/or poorly sorted, Unconsolidated sediment
Johor	Mersing	Coarse and/or poorly sorted, Unconsolidated sediment
	Kota Tinggi	Most sedimentary rock

After identified the physical variables, then the variables were ranked into 5 ranking (Table 8). Rank 5 means very high risk and rank 1 means very low risk. Then variables are calculated using the physical vulnerability index equation created by Gornitz to assess the risk of rising sea levels on the east coast of Peninsular Malaysia [17].

Table 8: Ranking of coastal risk classes for physical variables [17].

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

After identified variables for physical parameter, an index for each variable were calculated. According to some study, 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 [9, 22-24];

$$\text{PVI} = \sqrt{(a * b * c * d * e * f * g)/7}$$

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.

The variables of physical vulnerability index then were mapped using ArcGIS software. The map has five ranks from very high, high, moderate, low to very low. Very high ranking means the area is most vulnerable and very low vulnerability means least vulnerable, to sea level rise.

3. RESULTS AND DISCUSSION

Seven variables were selected for the physical parameters along the East Coast of Peninsular Malaysia. These variables are qualitative data and classified using the coastal risk classes used (Refer Table 8) [9]. Then the value will be calculated to find an index. Table 9 below shows the physical risk classes for each district along the east coast of Peninsular Malaysia.

Table 9: Physical risk classes for each variable.

State	District	Variable						
		Coastal Slope	**Geomorphology**	**SLR Change**	**Shoreline Change Rate**	**Wave Height**	**Rock Type**	**Tidal Range**
Kelantan	Tumpat	5	5	3	3	1	5	2
	Kota Bharu	5	5	3	5	1	4	2
	Bachok	5	5	3	5	1	4	2
	Pasir Puteh	5	5	3	5	1	4	2
Terengganu	Besut	5	5	4	3	1	4	3
	Setiu	4	5	4	5	1	4	3
	Kuala Terengganu	4	5	4	5	1	4	3
	Marang	4	5	4	5	1	4	3
	Dungun	4	5	4	5	1	4	3
	Kemaman	5	5	4	3	1	4	3
Pahang	Kuantan	5	5	4	3	5	5	3
	Pekan	5	5	4	3	5	4	3
	Rompin	5	5	4	3	5	4	3
Johor	Mersing	5	5	3	3	2	4	3
	Kota Tinggi	5	4	3	3	2	3	3

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 10 below shows the physical vulnerability index for the districts.

Table 10: Physical vulnerability index along the East Coast of Peninsular Malaysia.

State	District	PVI	Characterization
Kelantan	Tumpat	17.93	Very low
	Kota Bharu	20.7	Very low
	Bachok	20.7	Very low
	Pasir Puteh	20.7	Very low
Terengganu	Besut	22.68	Low
	Setiu	26.19	Low
	Kuala Terengganu	26.19	Low
	Marang	26.19	Low
	Dungun	26.19	Low
	Kemaman	22.68	Low
Pahang	Kuantan	56.69	Moderate
	Pekan	50.71	Moderate
	Rompin	50.71	Moderate
Johor	Mersing	27.77	Low
	Kota Tinggi	21.51	Low

The areas with the highest vulnerability value are Kuantan followed by Pekan and Rompin while the lowest values at Tumpat district. Value of vulnerability is influenced by physical factors in the districts such as geomorphology, shoreline change rate, coastal slope, wave height, tidal range, sea level rise change and rock type.

The values of a vulnerable area were mapped using ArcGIS to get a picture of the vulnerability. The vulnerability level is ranked into five categories such as very low, low, moderate, high and very high. Very high category means the most vulnerable level. This study only focuses on the districts near the coast. As a recollect there are fifteen districts along the coast of the east coast of Peninsular Malaysia.

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 1).

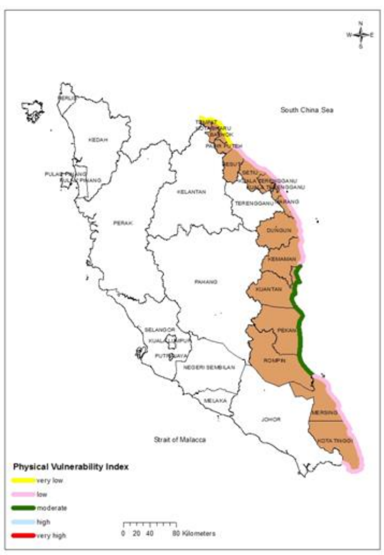

Figure 1: Physical Vulnerability Index map. The red color shows the most vulnerable followed by blue (high), green (moderate), pink (low) and yellow (very low). The districts along the coastal are colored by dark brown.

4. CONCLUSION

Global warming is very serious effect on the whole world and in Malaysia in particular. Global warming is caused by greenhouse gases resulting from human activity. As the Earth continues to warm, there is a growing risk that the climate will change in ways that will disrupt our lives. The impacts caused by global warming is climate change such as rising sea levels, droughts and wildfires, hurricanes, acid rain, warmer oceans, changes in plant life cycles and more extreme weather events. Among the gases that contribute to the greenhouse effect are carbon dioxide (CO_2), methane (CH_4), nitrogen dioxide (N_2O) and CFCs.

There are seven variables for physical parameters namely geomorphology, shoreline change rate, coastal slope, mean wave height, mean tidal range, sea level rise change and rock type. Each of the seven variables, relating to coastal inundation and erosion hazards, has been assigned a rank, from 1 to 5, based on the relative risk factor. These risk factors are then combined into an overall physical vulnerability index, PVI, here taken as the square root of the geometric mean of the risk classes. 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 main objective of finding the coastal indices is the classification coastal beaches in the units for displaying the properties or characteristics of the same.

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.

Physical vulnerability index was mapped using GIS software to picture of vulnerable areas. They are visualized in ArcGIS 10. The map will be classified into five categories such as very low, low, moderate, high and very high. Very high showed the most vulnerable and very low means least vulnerable. The most vulnerable is colored by red color while highly vulnerable is blue color, moderately vulnerable is green color, low vulnerable is pink color and very low vulnerable is yellow color.

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.

ACKNOWLEDGEMENT

This research was supported from MOSTI for the E-Science fund (Vot. Number 52061) and also MyBrain Scholarship (under MyPhD) for granting a scholarship for three years.

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