



Comprehensive coastal vulnerability assessment and adaptation for Cherating-Pekan coast, Pahang, Malaysia

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ABSTRACT

Climate change is having a profound impact on most coastal regions around the world. Sea Level Rise (SLR) has exposed the coastal regions to various threats, such as inundation and erosion, which consequently influence the coastal environments. The main objective of this study is to assess the coastal vulnerability index (CVI) of the Pahang coast. This CVI comprises six variables, i.e. coastal geomorphology, coastal slope, rate of erosion and accretion, mean significant wave height, mean tidal range and rate of sea level rise. The vulnerability levels for 18 management units along the Cherating-Pekan coast are classified into five vulnerability rankings: very low, low, moderate, high and very high, based on the rating values of the above mentioned parameters. The findings indicated that two areas, namely Tjg Payang - Sg Balok and Cheruk Paloh - Kuala Pahang were categorized as high vulnerability level with 97.22% and 91.67% respectively. Meanwhile, 5.56% and 22.22% of the 87 km Cherating-Pekan coastline has low and very low vulnerability. Furthermore, the CVI values of 33.33% and 27.78% represent the high and moderate vulnerability category, respectively. Finally, the outcome of this study provides a comprehensive framework which can be used by researchers, decision makers and relevant authorities to formulate and implement mitigation and adaptation measures in an effort to address the impacts of climate change on coastal regions.

1. Introduction

Coastal areas are one of the major systems that ensure global sustainability. Apart from being highly productive ecosystems, these areas typically have a high population density and serve as important industrial and tourism centres which are supported by transportation infrastructure and waste disposal systems (Mani Murali et al., 2013; Camacho and Rivera, 2014; Fakhrudin and Rahman, 2014; Masria et al., 2014). In 1990, 23% of the world population (1.2 billion people)

lived within 100m of the coast, and the population densities in these areas are about three times higher than the global mean population density (Nicholls et al., 2007). Hence, in this regard the coastal areas and their inhabitants are exposed to higher risk and are more vulnerable to the storm events and flooding caused by a significant rise in sea levels (Hayrol et al., 2015; Hamzah et al., 2017).

Studies conducted by Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) in 2014 shows that sea levels are expected to rise from 18 to 66 cm in the 21st century

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(Boak and Turner, 2005; Karymbalis et al., 2012). Thus, the coastal erosion and flooding caused by the sea level rise will have an impact on millions of people living in the coastal areas. The damage to existing coastal infrastructure, all of which has an effect on the socio-economic factors and livelihood of coastal communities (Fakhrudin and Rahman, 2014; Masria et al., 2014; Vousdoukas et al., 2016a,b; Giardino et al., 2018; Tragaki et al., 2018). Vousdoukas et al. (2016a,b) added that in extreme conditions, most hydrodynamic and morphodynamic processes are accelerated, with the most dramatic impact being the fact that the water level can exceed the height of natural features or structural protection.

Additionally, the largest structural changes in hydrodynamic conditions and sediment supply are generally due to anthropogenic interventions such as human activities along the shoreline. Luijendijk et al. (2018) mentioned that coastal zones have generally attracted humans and human activities due to the abundant facilities, aesthetic value and various ecosystem services provided by them. Since Malaysia is a maritime country, in 2010, the National Hydraulic Research Institute of Malaysia (NAHRIM) conducted a study to project the SLR along the coast of Malaysia. Peninsular Malaysia is projected to experience a sea level rise of between 0.25 and 0.52 m by the year 2100 (Vousdoukas et al., 2016a,b).

Younus and Harvey (2013) explained that methods and tools for evaluating risks and vulnerability to climate change impacts on coastal systems are in the developmental stages. Thus, a comprehensive risk and vulnerability assessment is essential to ensure that the right adaptation response is taken for effective integration into development plans (Rygel et al., 2006; Younus and Sharna, 2014). Harvey and Nicholls (2008) described how adaptation at the coast plays an important role in the assessment of vulnerability for making policy decisions. Adaptation is able to assist society in avoiding the impacts of climate change and manage impacts that are unescapable. Therefore, coastal vulnerability assessment must incorporate the complex interaction of physical environmental factors at the coast area which affect these coastal processes and, hence, coastal vulnerability to SLR (Bryan et al., 2001).

In 1990, Gornitz was the first person to formulate the concept of CVI, focusing on the effects of SLR using six parameters (Sudha et al., 2015). During the last few years, there has been an important increase in the number of vulnerability indices for a specific coastal area (Abuodha and Woodroffe, 2010; Karymbalis et al., 2012; Kaymbalis et al., 2014). Most of the vulnerability assessments were done by adapting Gornitz's (1991) formula. The CVI assessment was later advanced by modifying the parameters depending upon the availability and geographical area. In this approach the ranges, which were used for vulnerability ranking of the involved variables, are those proposed by (Mohamad et al., 2014; F. A. Mohd et al., 2018a,b) for the east coastal of Peninsular Malaysia. The objectives of the present study is to assess the vulnerability of the Cherating-Pekan coast to SLR by using six CVI approach. Therefore, proper planning and protection strategies for the Pahang coast must be taken by coastal management and policy makers to sustain the coastal ecosystem and livelihood.

2. Description of the study area

The study area stretches almost 87 km along the Cherating-Pekan coast of Pahang, which is the largest state and is located at the east coast of Peninsular Malaysia. The coastal region is located between $3^{\circ} 28' 15.39''$ to $4^{\circ} 10' 6.8''$ latitude and $103^{\circ} 15' 48.79''$ to $103^{\circ} 40' 3.61''$ longitude and faces the South China Sea. The study area was divided into 18 Management Units (MU) along the Cherating-Pekan coasts, as shown in Table 1 and Fig. 1. The area is almost entirely exposed to wave attacks from the South China Sea. It experiences the southwest monsoon from May to September and northeast monsoon from November to March, with two shorter periods of inter-monsoon seasons, and receives an annual rainfall of between 1488 and 3071 mm per year

Table 1

Management units of the Cherating-Pekan coast.

No	Management Unit	Section
1	C1M1a	Tjg. Cherating - Sg. Cherating
2	C1M1b	Sg. Cherating - Sg. Ular
3	C1M1c	Sg. Ular - JetiGebeng
4	C2M2a	JetiGebeng - PelabuhanKuantan
5	C2M2b	PelabuhanKuantan -Tjg. Payang
6	C2M2c	Tjg. Payang - Sg. Balok
7	C2M2d	Sg. Balok - Sg. Karang
8	C2M2e	Sg. Karang - BatuHitam
9	C2M2f	BatuHitam - Kg. Beserah
10	C2M2g	Kg. Beserah - Tjg. Pelindung
11	C2M2h	Tjg. Pelindung - Tjg. Tembeling
12	C2M2i	Tjg. Tembeling - Sg. Kuantan
13	C3M3a	Sg. Kuantan - Tjg. Lumpur
14	C3M3b	Tjg. Lumpur - Kg. Kempadang
15	C3M3c	Kg. Kempadang - Sg. Dua
16	C3M3d	Sg. Dua - Sg. Penur
17	C3M3e	Sg. Penur - CherukPaloh
18	C3M3f	CherukPaloh - Kuala Pahang

(Ariffin et al., 2016; Azid et al., 2015; Wong, 1990; Teh and Voon, 1992). The study area is influenced by semidiurnal and mixed tides, with two high tides and two low tides within a lunar day (Hammar Klose and Thielier, 2010). The prevailing wind during the southwest monsoon season is light and south westerly, and is usually less than 15 knots, while the prevailing wind during the northeast monsoon is north-easterly or easterly and ranges from 10 to 20 knots, and can occasionally reach 30 knots or higher during periods of strong surges of cold air from the north (cold surges) (Azid et al., 2015). The wind during the two inter monsoon seasons is light and variable (Wong, 1990).

Regarding Nugraheni et al. (2018) in her study, the morphology type of the study area has major concentration of bauxite deposit. The coverage area of low land and swamp areas in Kuantan is about 40%. Meanwhile, the low relief and swamps conquer about 40% of the northeast study area. Besides that, Metcalfe (2013) and Nugraheni et al. (2018) explained that most of lowland morphology occupies the area around river, swamps and valley, with altitude of 10m–25m and slope of < 15%. Therefore, morphology in Kuantan area is closely similar to West Kalimantan, where this area is flat to undulating.

3. Materials and methods

The methodology adopted in the present study is in accordance with the procedure set by the United States Geological Survey (USGS) (Hammar Klose and Thielier, 2010). Seven variables were selected to calculate the CVI, and each variable represents a specific characteristic of coastal vulnerability. Most of the variables are dynamic in nature along the coastal region and vast amounts of data and information have to be gathered from different sources, then processed and analysed. A schematic representation flowchart for the development of the coastal vulnerability assessment and adaptation for Pahang coast is outlined in Fig. 2.

Table 2 shows the data used in the vulnerability analysis and their sources. These variables include both the quantitative and qualitative information about the coast.

3.1. Determination of coastal vulnerability parameters

The main of vulnerability parameters for the Pahang coast are comprises three main variables, namely geological (geomorphology, shoreline changes and coastal slope) and physical (SLR, mean significant wave height and mean tidal range).

3.1.1. Geological parameters

3.1.1.1. *Geomorphology.* Geomorphological variables play an

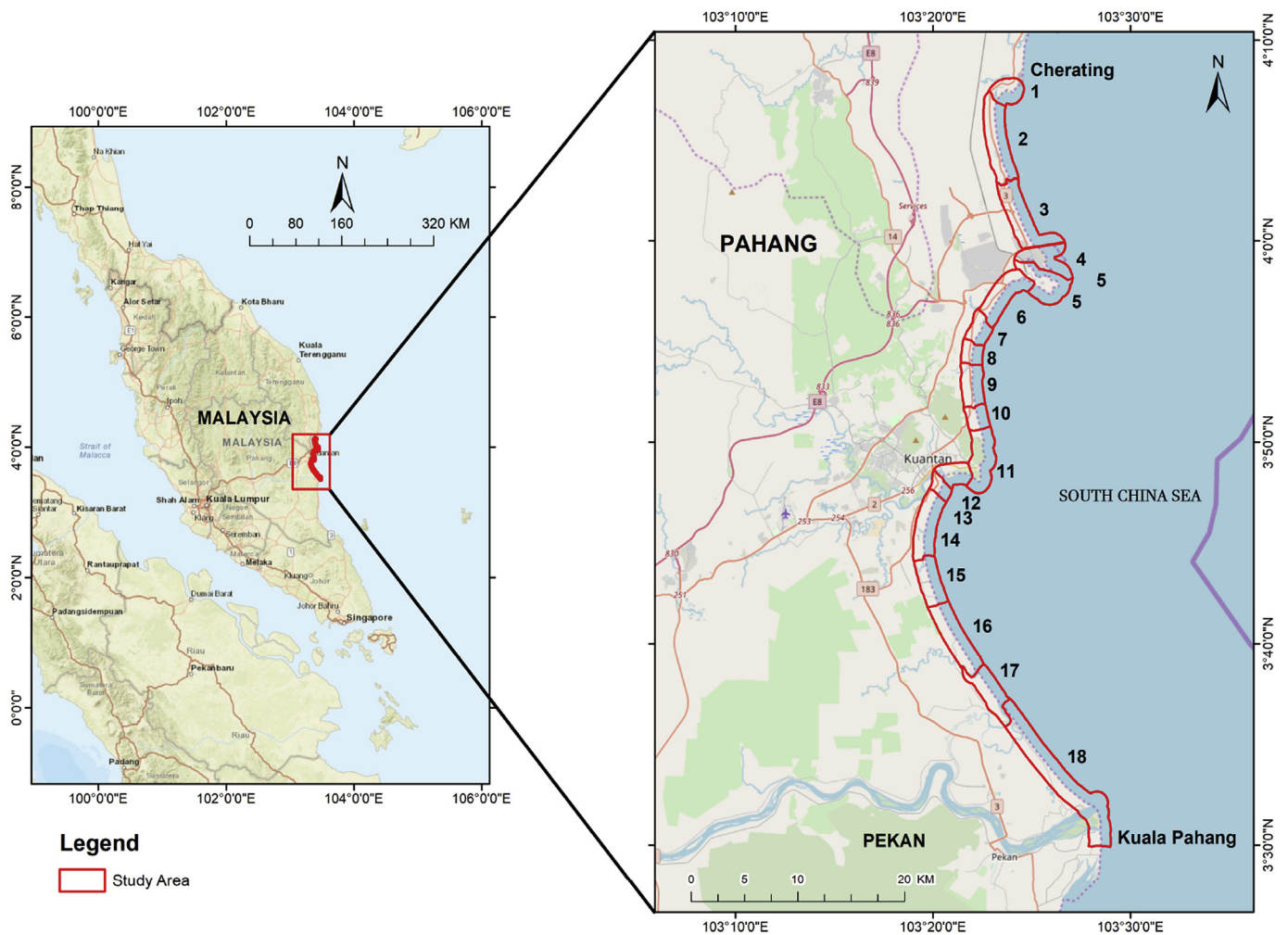


Fig. 1. Map of the study area, from Cherating to Pekan (Kuala Pahang), Pahang.

important role in a vulnerability study and there is a need to monitor them continuously in detail. Geomorphology is defined as the study of landforms and landscapes, including the description, classification, origin, development and history of environmental surfaces (Kumar et al., 2010; Sankari et al., 2015). In accordance with Gill et al. (2014), the coastal vulnerability assessment defines coastal areas as those areas that are in many cases already vulnerable to coastal hazards under present day conditions and are likely to become more vulnerable in the future as a result of climate change and SLR. For this study, geomorphologic parameters has been conducted using in-situ observation along Cherating to Pekan within 1 km zone of shorelines. Thus, the rank of vulnerability for geomorphological variables is also dependent on the varying landforms, since the materials in each landform respond differently to the natural hazards which occur along the shoreline.

3.1.1.2. Coastal slope. Coastal slope is an important parameter which must be taken into account in estimating the effect of SLR on the study area. Slope is used to describe the measurement of the gradient of a straight line (Kumar et al., 2010; Sankari et al., 2015). Coastal area, which is characterized by the steepness or flatness of coastal slope, is related to inundation caused by flooding, tsunamis and storm surges (Thieler and Hammar-Klose, 1997; Kumar et al., 2010). The coastal slope of the Cherating-Pekan coastal area was surveyed from the beach profile measurement using Total Station and GPS during low tide. The profile started in the dunes (vegetation) at a temporary benchmark and ended at the waterline by using the tachometry method. These

elevation points of MUs along the shoreline were converted into shapefile format then interpolated using the interpolation method (Inverse Distance Weightage, IDW) in order to get the coastal slope respectively. The result was verified using IFSAR data and Google Earth. Coastal areas with gentle slope are considered as highly vulnerable areas while coastal areas with steeper slopes are classified as areas of low vulnerability.

3.1.1.3. Coastal shoreline change. Shoreline is the boundary between sea and land and is continuously changing due to accretion, erosion, tidal processes, and changes in topography and sea level (Pramanik et al., 2016; Kumar and Kunte, 2012; Ashrafu Islam et al., 2016; IPCC, 2001). The changes in shorelines could occur as a result of anthropogenic and natural processes. The coastlines for the years 2006 and 2014 were digitized with a 2.5m resolution by using SPOT 5 satellite image. The images were processed using the ERDAS Imagine software, which includes geo-referencing and band extraction, while the ArcGIS software was used to vectorize the shoreline. These digitized vector files were used to calculate the rate of shoreline change and their trend in comparison to the reference baseline. Consequently the shoreline change was observed to understand land accretion and erosion processes. From the coastal vulnerability view, coasts subject to accretion are considered as less vulnerable areas, while those experiencing coastal erosion are considered to be more vulnerable due to the loss of private and public properties and important natural habitats such as beaches, dunes and marshes (Kumar et al., 2010).

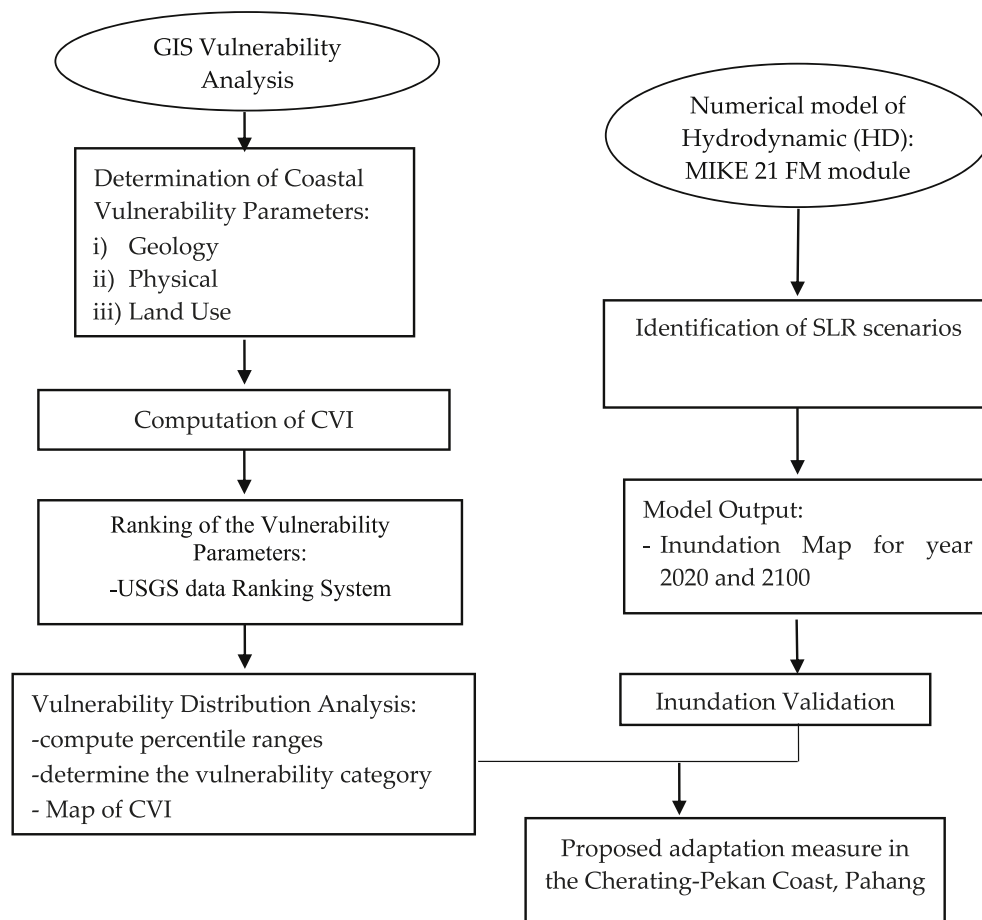


Fig. 2. A schematic flowchart of coastal vulnerability assessment and adaptation in Pahang coast.

3.1.2. Physical parameters

3.1.2.1. Rate of sea level rise. SLR is an important consequence of climate change, both for societies and the environment. The changes in mean sea level are measured by coastal tide gauges and known as relative sea-level change (Kumar et al., 2010). In the context of coastal vulnerability, areas with the highest rates of sea level change are considered as highly vulnerable coastal areas and vice versa. In this study, the rate of sea level rise for years 2020 until 2100 was measured using tide gauges and satellite altimetry. It is able to provide much better coverage and resolution of an area. The official record of mean SLR at the nearest station was used together with the sea level data gathered at the Tanjung Gelang tidal station which faces the South China Sea (Jeofry and Rozainah, 2013; Tiong and Yap, 2003, 2011). The rate of SLR obtained in this study poses a risk to low-lying coastal

areas which are also affected by inundation; these consequently increase the vulnerability of the coastal region.

3.1.2.2. Mean significant wave height. Mean significant wave height is the average height of the one-third highest waves during a 12-h period (Kumar et al., 2010; Jana and Hegde, 2016). Wave heights are generally taken into account to determine the degree of vulnerability along the coast. Vulnerability studies based on wave height are carried out since they are an important step in the hazards warning and management system [36]. Wave energy may increase as wave height gradually increases, and this could cause a loss inland area due to erosion and inundation along the shoreline (Mani Murali et al., 2013; Dwarakish et al., 2009; Mohamad et al., 2014; Murali et al., 2013). The visual observation data, namely SSMO wave data, were used to determine the

Table 2

The details of parameters used in the construction of the CVI.

No	Types of Data	Period/Year	Description
1	Wave Height	23rd May 2014 to 4 th June 2014	Data recorded using ADCP device at 3 locations covered for Northern, Centre and Southern part. This data used for numerical modelling.
2	Wave Direction	23rd May 2014 to 4 th June 2014	Data recorded using ADCP device at 3 locations covered for Northern, Centre and Southern. This data used for numerical modelling.
3	Satellite Image (SPOT 5) Spatial resolution 2.5m, 4 bands (Red, Green, Blue & Infrared)	2006 & 2014	To identify the shoreline changes and impacted area.
4	Tidal	1993 to 2016	Tidal data for Northern and Southern part from Department of Survey and Mapping Malaysia (JUPEM). Used to calculate the mean tidal range and numerical modelling.
5	Coastal Slope	5th to 8th August 2016 & February 2016	In-situ measurement of Beach Profile using Total Station and GPS. Validation method using DEM data generated by IFSAR data.
6	Geomorphology	2002, 2016 & 2017	In-situ observation and DID Report.
7	Rate of SLR	(Projected SLR at Pekan, Pahang in 2020–2100)	The SLR value obtained by the Inverse Distance Weightage (IDW) method using Altimeter and Tide gauge data.

offshore and nearshore wave characteristics in the area. The data were obtained by shipboard observations over a 41 year period from 1949 to 1989 in the South China Sea. These data are available in the wave database of the DID, Malaysia (Far et al., 2018). The estimation for mean significant wave height for the Cherating-Pekan area was extracted from the wave modelling data using MIKE 21 Spectral Wave module. During the Northeast Monsoon, the South China Sea recorded 1.5 m up to 2.7 m, with a greater wave height compared to the other seas (F. A. Mohd et al., 2018a,b). Therefore, coastal areas exposed to high wave heights are considered more vulnerable, while those exposed to low wave heights are considered less vulnerable.

3.1.2.3. Mean tidal range. Mean tidal range is defined as the vertical difference between the highest high tide and the lowest low tide (Gornitz et al., 1991; Doukakis, 2005; Kumar and Kunte, 2012; Pramanik et al., 2016). The tidal range is connected to both inundation and erosion hazards. Although a large tidal range dissipates wave energy, it is also susceptible to cases of permanent inundation. Thus, the strong tidal currents might influence coastal behaviour due to the large tidal range. In Peninsular Malaysia, the tides are mixed on the east coast, with mean tidal ranges less than 2 m. The highest astronomical tide recorded at the Tanjung Gelang is 1.8 m above mean sea level (Fazly et al., 2018). In this research, the predicted tide data was obtained from the Department of Survey and Mapping Malaysia (JUPEM) for the year 2014 and vulnerability ranks are assigned based on these data. In terms of vulnerability, coastal areas exposed to a high tidal range are classified as highly vulnerable while the areas exposed to a low tidal range are classified as the least vulnerable (Boruff et al., 2005; Dwarakish et al., 2009). For the recent study, coastal areas with a high tidal range are considered to have a high vulnerability, and those with a low tidal range low vulnerability.

3.2. Computation of coastal vulnerability index (CVI)

The CVI parameters are based in accordance with the USGS procedure published by Voudoukas et al. (2016a,b), which outlines the specific characteristics of coastal vulnerability based on the coastal fishery conditions of the study area. The 18 management units (MU) within the Cherating-Pekan coast were assigned a risk rating for each variable, and the CVI was then calculated as the square root of the results of the ranked variables divided by the total number of variables (Pendleton et al., 2010, 2004) as shown in Formula 1:

$$CVI = \sqrt{\frac{a \times b \times c \times d \times e \times f}{6}} \quad (1)$$

Where a = geomorphology, b = coastal slope, c = rate of shoreline change, d = rate of SLR, e = Mean Significant wave height and f = mean tidal range. The composite index of the selected Cherating-Pekan coast was calculated by their weighted averages by combining the individual parameters (Boruff et al., 2005). In the present vulnerability analysis, equal weight is assigned to each variable, an approach that is the commonly used in the literature (Boak and Turner, 2005; Pramanik et al., 2016; Dwarakish et al., 2009; Dora et al., 2011; Mohd Zaini et al., 2015).

3.3. Ranking of vulnerability parameters

Table 3 presents the vulnerability variables and their rankings, which are used to calculate the CVI. By referring the USGS methodology, the 18 MUs in the Cherating-Pekan area were assigned the vulnerability rankings of each parameter, which were used to gather comprehensive information regarding the vulnerability of the coastal areas. The selected parameters were divided and ranked into five categories based on the level of risk, namely very low, low, moderate, high and very high risks using natural break classification technique

which indicates that class boundaries tends to place large numbers of similar values in the same class. The values indicate the relative risk of the coastal land due to future SLR and related physical changes.

3.4. Vulnerability distribution analysis

The CVI ranks for the Cherating-Pekan area were calculated using the percentile values from a statistical formula which are divided into quartile ranges for the five vulnerability categories, as shown in Formula 2 and Table 4:

$$\text{Percentile \%} = \frac{L + (0.5 \times S)}{N} \quad (2)$$

Where, L = number below the rank, S = number of the same rank, and N = Total number of observation.

The approach composite coastal vulnerability index based on the relative risk rating of those parameters, each of the 18 MUs of Pahang coastal was highlighted according to their vulnerability category on the map.

3.5. Numerical hydrodynamic modelling

Numerical modelling simulations for Pahang coast were carried out based on the projected SLR for the years 2020–2100 using the MIKE 21 software, which is consist of Hydrodynamic FM module. Hydrodynamic modelling results produced some simulation parameters such as height of the water level, waves and current speeds. The findings of the numerical modelling is the inundation maps for year 2020 and 2100. Integration of satellite imagery, numerical simulations, Malaysian annual flood report and field observations was used for the validation assessment. The final output able to be used effectively by coastal management authorities and decision makers to manage better coastal zone as well as to ensure efficient adaptation measures to minimize the losses due to potential impact of predicted sea level rise through which appropriate measures to protect life, property and environment can be timely planned.

4. Results and discussion

4.1. Coastal geomorphology

The results of the analysis show that the morphology of the Pahang coast is quite varied. Tiong and Yap (2011) has shown that the coastal area of Tanjung Cherating has rocky beaches and sandy coastlines, except at the river mouth where there is a formation of a sandbank. A recent study conducted by Saad et al. (2009) supported the findings of Gill et al. (2014) that Teluk Cempedak and Tanjung Tembeling have rocky shores, Tanjung Lumpur is muddy and the shores of Kuala Pahang are sandy. Saad et al. (2009) also mentioned that the shores of the middle part of the Cherating-Pekan area have muddy fine sand where the minimum size is around 5–6 phi; this is especially apparent in Tanjung Lumpur. The shores of the southern part of the Cherating-Pekan area are characterized by larger sand size, especially in Kuala Pahang, which is located near the estuary of Sungai Kuala Pahang.

According to Church and White (2006), sandy coastal areas have a broad and gentle slope compared to rocky and composite sandy beaches with a relatively steep gradient toward the sea. Only four areas in the southern part of the Kuantan district are highly susceptible while two areas, i.e. the Gebeng Jetty in the port area of Kuantan and the area from Tanjung Pelindung to Tanjung Tembeling, have low vulnerability. The remaining eleven areas and one of the MUs in the study area have moderate and low levels of vulnerability.

4.2. Coastal slope

The Cherating-Pekan area is characterized by three ranks of coastal

Table 3
Vulnerability ranking of CVI variables.

Variable used	Ranking of Vulnerability				
	Very Low	Low	Moderate	High	Very High
Geomorphology	Rocky Cliff	Composite of sand and rocks	Sand	Composite of clay and sand	Muddy flat area
Slope Coastal (%)	> 4.8	4.7–3.6	3.5–2.4	2.3–1.2	< 1.1
Rate of Erosion and Accretion (m/year)	> 2.0 (Accretion)	1.9–1.0 (Accretion)	0.9 to –0.9 (Stable)	–1.0 to –1.9 (Erosion)	< –2.0 (Erosion)
Rate of SLR (m/year)	< 0.24	0.25–0.30	0.31–0.40	0.41–0.50	> 0.51
Mean Significant wave height (m)	< 0.8	0.9–1.3	1.4–1.8	1.9–2.3	> 2.4
Mean Tidal range (m)	< 0.5	0.5–1.0	1.0–1.5	1.5–2.0	> 2.0

Table 4
Quartile range and category.

No	Percentile No	Category
1	≤ 20th percentile	Very Low
2	20th percentile ≤ CVI ≤ 40th percentile	Low
3	40th percentile ≤ CVI ≤ 60th percentile	Moderate
4	60th percentile ≤ CVI ≤ 80th percentile	High
5	≥ 80th percentile	Very High

vulnerability: medium, high and very high. The measurement of the coastal profile show that three areas can be ranked as highly vulnerable, namely Tanjung Cherating-Sungai Cherating, Tanjung Payang-Sungai Balok and Sg. Penur-Cheruk Paloh, which have a coastal reading of 1.1% and 1.9%, respectively. Additionally, the slope along the Cherating-Pekan coast varies from 2.4% to 3.5%, which indicates moderate vulnerability in the remaining 14 areas. Wong (1990) added that a positive relationship exists between the grain size and beach gradient of the east coast beaches, for example steep beaches ($> 8^\circ$) occur mostly along the barrier coast and the material is coarse, and gentle beaches ($< 4^\circ$) occur where the sand is fine and are generally related to a wide low-tide area.

4.3. Rate of shoreline change

The trend of coastal changes shows in Fig. 3 that erosion and accretion occur at 16 of the MUs. Three areas, namely Sg Cherating-Sg Ular (C1M1b), Pelabuhan Kuantan-Tanjung Payang (C1M2b) and Cheruk Paloh-Kuala Pahang (C3M3f), show significant changes of more than 1m per year. The coastal areas of Tg. Tembeling-Sg. Kuantan (C2M1i), Tanjung Lumpur-Kampung Kempadang (C3M3b), Kampung

Kempadang-Sg. Dua (C3M3c), Sungai Dua-Sungai Penur (C3M3d) and Cheruk Paloh-Kuala Pahang (C3M3f) experience higher rates of accretion between 1 and 4 m per year. The other two MUs have a relatively stable shoreline with variations of less than 1m per year.

The results for the study area Tjg. Payang-Sg. Balok and Cheruk Paloh-Kuala Pahang are classified as having very high vulnerability while Tjg. Tembeling-Sg. Kuantan and Kg. Kempadang-Sg. Dua are defined as having low vulnerability respectively. The Sg Cherating-Sg Ular coast is classified as highly vulnerable, ten MUs are classified as moderately vulnerable and four MUs are classified as having very a low level of vulnerability.

4.4. Rate of relative sea level rise

Mean sea level refers to the height of sea with respect to the local benchmark of the coast for a year or a month averaged over a certain period of time. The relative SLR is a change in average sea level as measured by the tide gauge stations (Ami Hassan, 2012). Based on the SLR calculation using the satellite altimeter and the record at the Tidal Gauge station, the SLR at Tanjung Gelang for the year 2100 is projected to be 0.31 m. This is congruous with the results of the studies made by Jabatan Perancangan Bandar Dan Desa (2016) and Jeofry and Rozainah (2013) which show that the SLR at Tanjung Gelang is 0.32 m and 0.31 m, respectively. Therefore, the variation along the Cherating-Pekan coast is minimal, and the rate of the SLR is lower than the value provided by the IPCC. This is not surprising, since the study area is relatively small and the entire 87 km shoreline can be classified in the medium risk category.

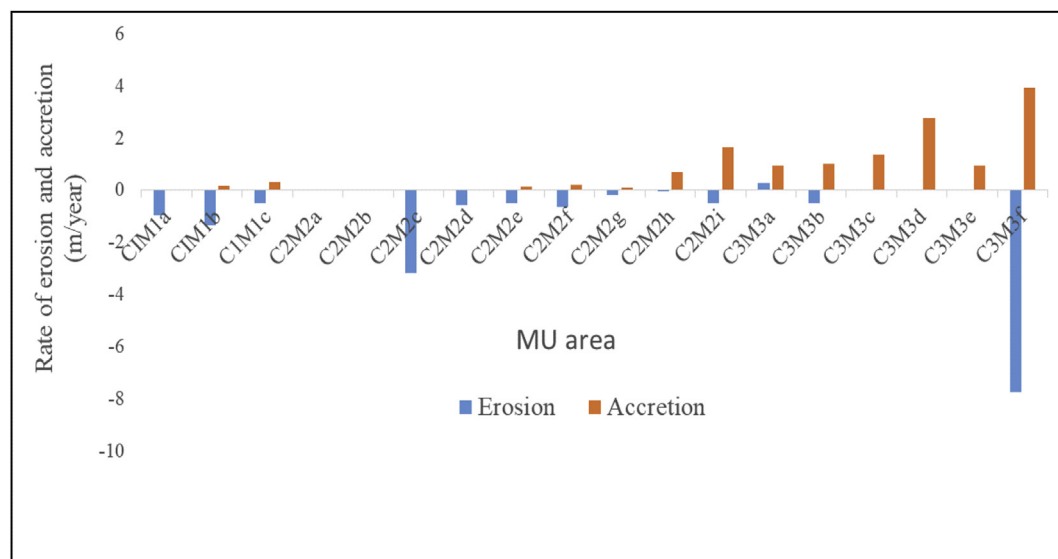


Fig. 3. Rate of erosion and accretion in the MUs.

Table 5
Tide levels at Tanjung Gelang and Kuala Pahang.

Tidal level	Tanjung Gelang	Kuala Pahang
Lowest Astronomical Tides (LAT)	0.00	0.00
Mean Lowest Water Spring (MLWS)	0.50	0.41
Mean Lowest Water Neap (MLWN)	1.57	1.49
Mean Sea Level (MSL)	1.92	1.76
Mean Highest Water Neap (MHWN)	2.28	2.02
Mean Highest Water Spring (MHWS)	3.34	3.11
Highest Astronomical Tides (HAT)	3.84	3.69

4.5. Mean significant wave height

In this study, the mean significant wave height was obtained from the Index of Wave Analysis for coastal areas produced through hydrodynamic modelling of visual ship observation data (SSMO) obtained from the DID. The overall results of the mean significant wave height show the mean significant wave height ranges from 1.1 m to 1.8 m. This indicates the moderate vulnerability of all MUs. A study conducted by Wong (1990) shows that the mean wave height in the Pahang coastal area ranges from 1.77 m to 1.80 m. A recent study by Mohamad et al. (2014) proved that the East coast of Peninsular Malaysia is exposed to large waves in comparison to the West coast of Peninsular Malaysia, where wave height in the study area ranges from 1.4 to over 4.0 m, including during the Northeast monsoon.

4.6. Mean tidal range

Table 5 presents the details of the tidal level for Tanjung Gelang and Kuala Pahang. Based on the tidal range in the study area, the difference in the tidal range between both tidal gauge stations is due to the calculations of the spring and neap tide.

The mean tidal range along the Cherating-Pekan coast is 1.7 m. The minimum tidal range along the coast of Malaysia is categorized as high. In the context of coastal vulnerability, Azid et al. (2015) contended that coastal areas with larger tidal ranges are categorized as highly vulnerable. Reviews by Azid et al. (2015) and Kumar and Kunte (2012) demonstrate that the coastal areas characterized by low tidal ranges are classified as having the highest vulnerability level. Similarly, a recent study conducted by Kumar and Kunte (2012) reported that areas with a tidal range greater than 3.5 m are classified as having a low vulnerability. All MUs within the Cherating-Pekan area are classified as being highly vulnerable.

4.7. Coastal vulnerability of the Cherating-Pekan area

The vulnerability classification of coastal areas is based on the elements of sensitivity and the exposure of the coastal areas to six parameters, including geological and physical parameters. Table 6 illustrates the ranks of coastal vulnerability for the 18 management units (MU) along the Cherating-Pekan coast. Table 7 show the ranking and percentile for six vulnerability parameters.

The value of CVI for the Cherating-Pekan area ranges from 4.24 to 18.97 while the percentiles of the calculated CVI range from 2.78% to 97.22% as shown as on Fig. 4. Hence, the MUs along the Cherating-Pekan coastline can be considered as having moderate vulnerability due to the presence of sand and clay in the area, with the exception of the Tjg. Tembeling-Sg Kuantan, Tjg. Lumpur-Kg. Kempadang and Sg. Dua-Sg. Penur areas. The geomorphology of these areas consists of a mixture of clay and sand close to the river mouth. This finding is supported by Hashim and Noor (2013), they have shown that wave dominated beaches form an accreting coastline which receives sand from the river mouths in the north and south of Pahang coast. Hence, the sand in these areas is moderately sorted.

The studied coastal area also displays a moderate CVI rank with

regard to the rate of SLR. Interestingly, this is contrary to the findings made by Jeofry and Rozainah (2013), they asserted that the tidal station at Tanjung Gelang recorded the highest SLR compared to other stations. This demonstrates that the middle region of Peninsular Malaysia is exposed to the highest SLR, whereas the northern part of Peninsular Malaysia experiences the lowest SLR. The coastal areas of Tanjung Payang-Sungai Balok and Cheruk Paloh-Kuala Pahang have CVI values of 18.97 and 16.43 respectively. These regions are in the high vulnerability category with regard to mean tidal range and slope coastal, but are moderately vulnerable with regard to mean significant wave height and rate of SLR.

The Tg. Tembeling-Sg. Kuantan, Tanjung Payang-Sg. Balok, Sungai Penur-Cheruk Paloh and Cheruk Paloh-Kuala Pahang coasts are classified as highly vulnerable due to the almost flat, low-lying surface with sand and mudflats characteristics of coastal areas. Furthermore, the coastline along the Cherating-Pekan area experiences a higher rate of erosion, especially in the Sg Cherating-Sg Ular which was classified a rank of 4; meanwhile, the Tanjung Payang-Sg Balok, and Cheruk Paloh-Kuala Pahang areas were classified as having vulnerability ranks of 5. This is supported by the data provided by Rahman et al. (2005) in an NCES 1985 study which shows that approximately 46.3%, or 125.4 km, of the entire Pahang shoreline has experienced erosion. Tiong and Yap (2011) added that most of these low-lying coastal plains are composed of a coast ridge plain which is vulnerable to storm surge and bore the brunt of the impacts of the extreme event which occurred in December 1999 when sands and tidal water reached up to about 100 m inland.

Rahman et al. (2005) contended that the Pahang delta on the East coast of Peninsular Malaysia is impacted by waves. Thus, differences in the degree of wave and tidal influence are the main factors influencing the morphology of the delta and the sediment dispersal trend along the Kuala Pahang coast (S. S. H. Mohd et al., 2018c). The physical variables of the CVI, such as mean significant wave height and SLR, were given the same vulnerability value in the study area, which is unlike the results of the geological variables. Moreover, the vulnerability of three coastal areas, i.e. Jeti Gebeng-Pelabuhan Kuantan, Pelabuhan Kuantan-Tanjung Payang and Sungai Dua-Sungai Penur, are considered to be very low due to the lower erosion and accretion rates and steep coastal slope along the shorelines of these areas. The slopes in these areas are moderately steep due to the presence of exposed rocky cliffs.

The report of National Coastal Erosion Study published by the Unit Perancang Ekonomi (1985) stated that the three coastal areas have in place erosion mitigation measures, namely breakwater and rock revetment at Kuantan Port, labuan blocks at Taman Gelora and rock revetment at Cheruk Paloh. These protective structures are very suitable for mitigating coastal erosion problems in Malaysia. Hashim and Noor (2005) contended that the main function of breakwater, revetment and geo-tube is to provide protection, hence reducing coastal erosion problems and wave action behind the structure (Fitri et al., 2019). Breakwaters are commonly constructed in areas where jetties and harbours are present. The existing adaptation done by local community or tourism operators are groyne protection structure near to the Cherating beach.

Tiong and Yap (2011) reported that the waves in these area are typically generated by monsoon winds by virtue of their directional circulation, which is similar to offshore winds. The study of shoreline are more exposed to dominant bigger waves during the northeast monsoon, with values exceeding 2.0 m. The findings show that the shorelines of Jeti Gebeng-Pelabuhan Kuantan, Pelabuhan Kuantan-Tanjung Payang, Tanjung Pelindung-Tanjung Tembeling and Sg. Dua-Sg. Penur are less vulnerable than those of Tjg. Cherating-Sg. Cherating, Tjg. Payang-Sg. Balok and Cheruk Paloh-Kuala Pahang.

4.8. Validation method

Validation methods are only often conducted in vulnerability assessments. Ge et al. (2013) in their first study emphasized vulnerability

Table 6
Vulnerability ranking of 18 MUs in the Cherating-Pekan area.

MU	Location	Geomorphology	Mean Tidal range	Rate of SLR	Rate of erosion and accretion	Mean Wave Height	Coastal Slope
C1M1a	Tjg. Cherating - Sg. Cherating	3	4	3	3	3	4
C1M1b	Sg. Cherating - Sg. Ular	3	4	3	4	3	3
C1M1c	Sg. Ular - JetiGebeng	3	4	3	3	3	3
C2M2a	JetiGebeng - PelabuhanKuantan	1	4	3	1	3	3
C2M2b	PelabuhanKuantan -Tjg. Payang	2	4	3	1	3	3
C2M2c	Tjg. Payang - Sg. Balok	3	4	3	5	3	4
C2M2d	Sg. Balok - Sg. Karang	3	4	3	3	3	3
C2M2e	Sg. Karang - BatuHitam	3	4	3	3	3	3
C2M2f	BatuHitam - Kg. Beserah	3	4	3	3	3	3
C2M2g	Kg. Beserah - Tjg. Pelindung	3	4	3	3	3	3
C2M2h	Tjg. Pelindung - Tjg. Tembeling	1	4	3	3	3	3
C2M2i	Tjg. Tembeling - Sg. Kuantan	4	4	3	3	3	3
C3M3a	Sg. Kuantan - Tjg. Lumpur	4	4	3	3	3	3
C3M3b	Tjg. Lumpur - Kg. Kempadang	4	4	3	3	3	3
C3M3c	Kg. Kempadang - Sg. Dua	3	4	3	2	3	3
C3M3d	Sg. Dua - Sg. Penur	4	4	3	1	3	3
C3M3e	Sg. Penur - CherukPaloh	3	4	3	3	3	4
C3M3f	CherukPaloh - Kuala Pahang	3	4	3	5	3	3

assessment in order to validate the results. The simulation of SLR prediction for 2020 and 2100 was conducted using the numerical model by MIKE 21. Hydrodynamic simulation is the basic model of the MIKE 21 software package for free surface flows based on flexible mesh method. The inundation area was rely on the numerical solution of the 2D shallow water equations using Depth integrated Reynolds averaged Navier Stokes (DIRANS) equations. Fig. 5 show the result of inundation area from simulation modelling for year 2017 (baseline measurement) and 2100 (long term assessment). The collection of marine data such as the tide level, bathymetry, current velocity and direction were used as input, calibration and analysis of hydraulic scenarios around Pahang coast via MIKE21 numerical model simulation. The output of SLR prediction simulation was displayed automized using the MIKE to Google Earth tool. The inundation area maps is possible to display the values from dfsu data files in 2D and saved in KML file format. The overlay tool in ArcGIS software able the surface elevation of SLR projected on 2017 and 2020 to 2100 in KML format overlayed with shoreline and satellite imagery data, in order to identify areas that will be inundated.

As a baseline condition, the findings show 13 locations were impacted with coastal inundation. Most of the locations are located near to the river and low-lying area especially at C1M1a, C1M1c, C2M2i, C3M3D and C3M3f as shown on Table 8. The Malaysia Annual Flood report for year 2016 and 2017 indicates that all the 13 locations expressly facing flooding problems caused by high tides phenomenon (The Department of Irrigation and Drainage, 2017). The largest of inundation area in year 2017 indicate C3M3d area with 12.11 ha. Within the period of 2017–2100, the changes of inundation area increasing dramatically almost 1.35 ha–12.11 ha into 9.47 ha–292.38 ha respectively.

Furthermore, the results illustrate that about 17%–22% of the Cherating to Pekan shoreline is at risk of being inundated in 2020 and 2100. The simulation modelling shows that four main MUs - Sg. Cherating - Sg. Ular (C1M1b), Batu Hitam - Kg. Beserah (C2M2f), Tjg. Tembeling - Sg. Kuantan (C2M2i) and Cheruk Paloh - Kuala Pahang (C3M3f) are predicted to experience the highest SLR in 2020 and 2100. A hydrodynamic modelling incorporating the CVI result has shown the potential negative impacts around the study area especially Tjg.

Table 7
CVI values for 18 MUs in the Cherating-Pekan area.

No	Location	CVI Value	Percentile of CVI (%)	Level
1	Tjg. Cherating - Sg. Cherating	14.70	72.22	High
2	Sg. Cherating - Sg. Ular	14.70	72.22	High
3	Sg. Ular – Jeti Gebeng	12.73	41.67	Moderate
4	Jeti Gebeng – Pelabuhan Kuantan	4.24	2.78	Very Low
5	Pelabuhan Kuantan -Tjg. Payang	6.00	8.33	Very Low
6	Tjg. Payang - Sg. Balok	18.97	97.22	Very High
7	Sg. Balok - Sg. Karang	12.73	41.67	Moderate
8	Sg. Karang – Batu Hitam	12.73	41.67	Moderate
9	Batu Hitam - Kg. Beserah	12.73	41.67	Moderate
10	Kg. Beserah - Tjg. Pelindung	12.73	41.67	Moderate
11	Tjg. Pelindung - Tjg. Tembeling	7.35	13.89	Very Low
12	Tjg. Tembeling - Sg. Kuantan	14.70	72.22	High
13	Sg. Kuantan - Tjg. Lumpur	14.70	72.22	High
14	Tjg. Lumpur - Kg. Kempadang	14.70	72.22	High
15	Kg. Kempadang - Sg. Dua	10.39	25.00	Low
16	Sg. Dua - Sg. Penur	8.49	19.44	Very Low
17	Sg. Penur – Cheruk Paloh	14.70	72.22	High
18	Cheruk Paloh - Kuala Pahang	16.43	91.67	Very High

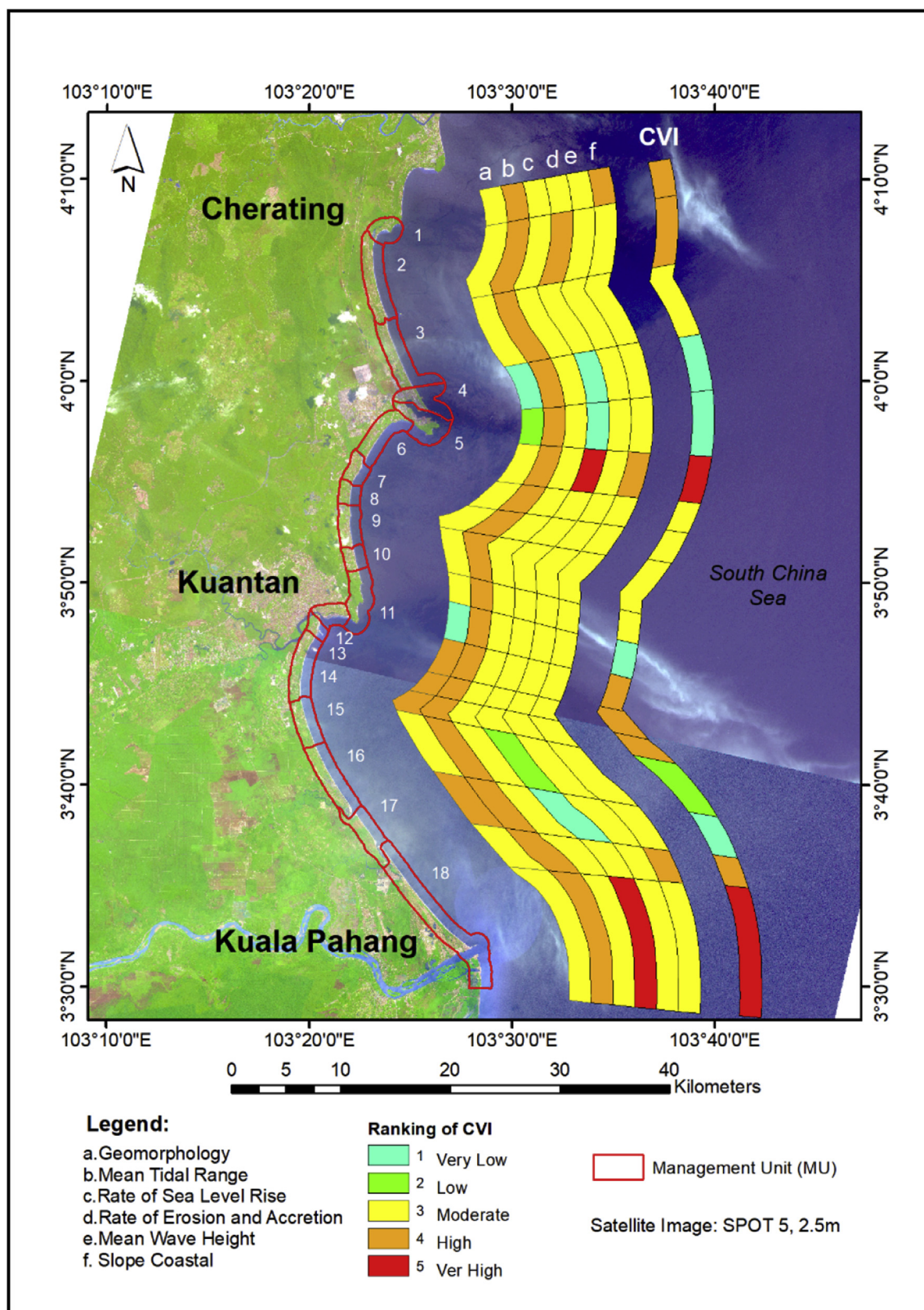


Fig. 4. Map of CVI for the Cherating-Pekan area.

Cherating - Sg. Cherating (CIM1a), Tjg. Payang - Sg. Balok (C2M2c) and Cherok Paloh - Kuala Pahang (C3M3f). Furthermore, from total 87 km shoreline that being studied, 16.7% of the MUs along the shoreline is classified as being very highly risky due to future SLR. The coastal vulnerability index (CVI) and simulation of SLR prediction modelling

provides insight into the relative potential of coastal damage especially for four MUs namely Sg. Balok - Sg. Karang (C2M2d) to Kg. Beserah - Tjg. Pelindung (C2M2g) due to future SLR. Fig. 6 indicates that infrastructural features within the 1 km buffer zone from shoreline might be affected due to inundation from SLR.

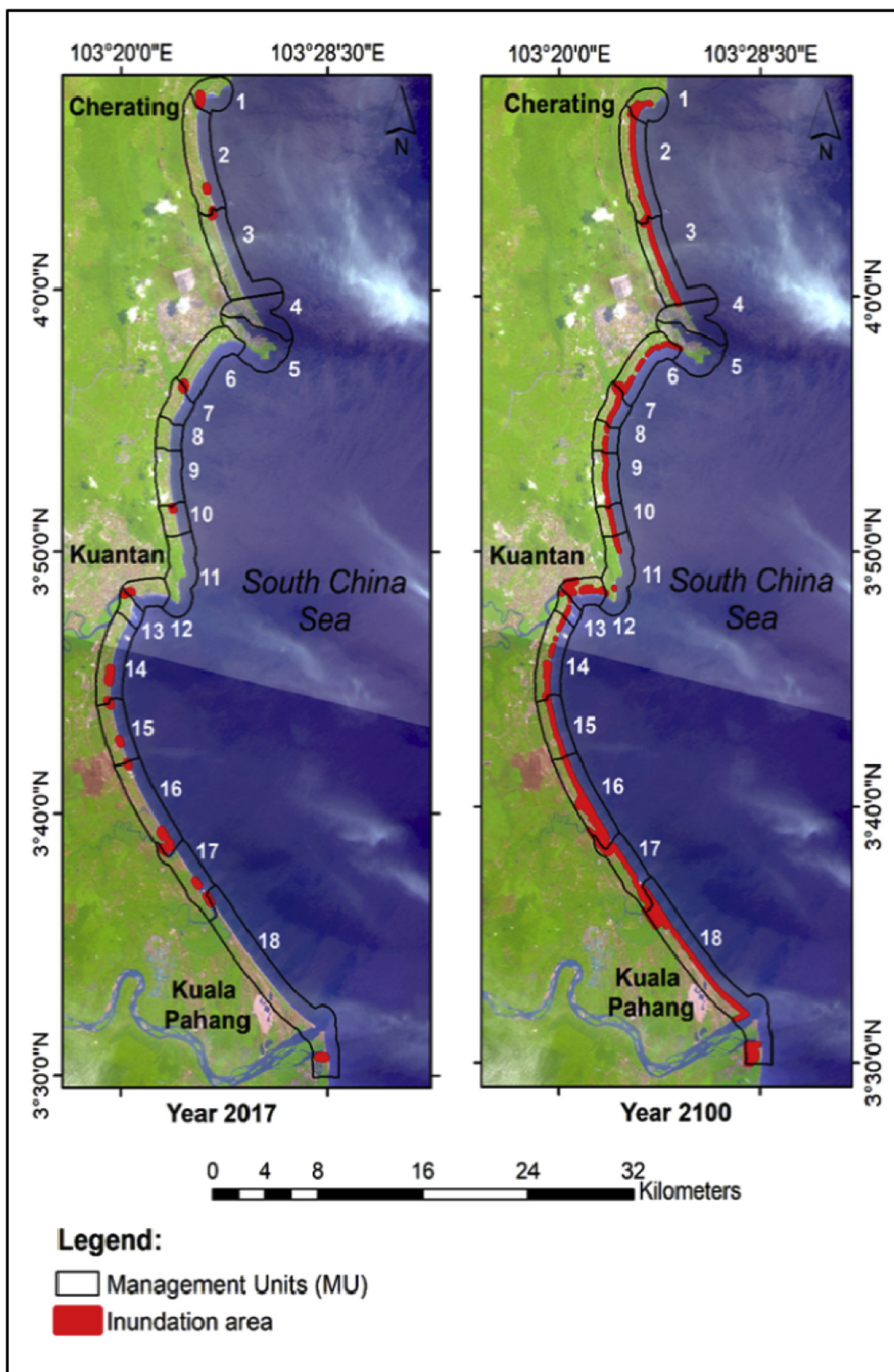


Fig. 5. Inundation area in years 2017 and 2100.

Table 8
Location of inundation area based on MUs in 2017 and 2100 and level of CVI categories.

No	(MU)	Length of MU coastline (km)	Inundation area in 2017 (ha)	Inundation area in 2100 (ha)	Changes of Area (ha)	Percentage changes of inundation area (%)	Level of CVI
1	CIM1a	3.4	6.74	32.41	25.67	47.96	High
2	CIM1b	7.2	1.35	77.35	76.00	142.00	High
3	C1M1c	6.3	2.63	59.31	56.58	105.90	Moderate
4	C2M2a	2.4	0	0	0	0	Very Low
5	C2M2b	6.1	0	0	0	0	Very Low
6	C2M2c	5.8	2.45	32.65	30.2	56.43	Very High
7	C2M2d	2.2	1.59	35.53	33.94	63.42	Moderate
8	C2M2e	1.8	0	10.79	10.79	20.16	Moderate
9	C2M2f	3.8	0	26.90	26.90	50.26	Moderate
10	C2M2g	2.2	1.19	13.28	12.09	22.59	Moderate
11	C2M2h	6.0	0	11.73	11.73	21.92	Very Low
12	C2M2i	2.8	6.24	82.90	76.66	143.24	High
13	C3M3a	1.3	0	9.47	9.47	17.69	High
14	C3M3b	5.7	8.86	51.39	42.53	79.47	High
15	C3M3c	4.5	2.57	40.69	38.12	71.23	Low
16	C3M3d	7.1	12.11	194.08	181.97	340.00	Very Low
17	C3M3e	3.9	4.60	70.14	65.54	122.46	High
18	C3M3f	14.5	3.19	292.38	289.19	540.34	Very High
TOTAL		87.0	53.52	1041.00			

4.9. Adaptation to sea level rise in the pahang coastal area

The shorelines of Pahang have immense social, environmental and economic value, especially for the population living in the area (Azid et al., 2015). The economic development in these areas, however, has been adversely affected by erosion events. Hence, adaptation measures need to be implemented to reduce the adverse impacts of SLR and to protect the resources and livelihood of the communities in the coastal region (Wong, 2003). Observation and measurement of coastal erosion needs to be carried out in order to prevent this problem from worsening in the long term.

Approximately 46.3%, or 125.4 km, of the total Pahang shoreline has undergone erosion (Unit Perancang Ekonomi, 1985). Wong (1990) reported that monsoon changes are one of the primary causes for coastal erosion in Malaysia. Another reason is because the development and expansion of Kuantan ports along the coasts have also resulted in shifts in sediment transport patterns and contributed to the erosion. In Pahang, coastal adaptation measures such as structural and non-structural measure are practical alternatives for supporting coastal planning; this includes encouraging and giving responsibilities to relevant agencies to proactively mitigate various hazards along the coast that are caused by climate change. A suitable adaptation measure along a particular coastal area is dependent upon the related response. The adaptation proposed measures are implemented in the coastal zone along Cherating–Tanjung Agas, as shown in Table 9.

These findings show that the vulnerable shorelines in the north of Pahang; for example, Pantai Cherating, Jeti Gebeng, Taman Gelora and Kelab Golf di Raja Pahang, were protected from erosion to some extent due to the implementation of shoreline erosion protection measures. William et al. (2016) stated that protection structures constitute a high cost, however, mostly the price paid for hard and soft protection engineering usually balances out through time, while great variability can occur due to factors such as location, labour costs, current erosion rate and more. Among the protection measures that are suitable for protecting the shores of Pahang from coastal hazards are rock revetment, breakwater, sandbags, groyne and beach nourishment. Construction of

revetment should be limited only to certain settlements and ports that are exposed to high risk of inundation. All currently available protection measures should be strengthened and a higher protection standard must be implemented to deal with the current trend in SLR (Fitri et al., 2019).

The study found that the rate of erosion in three locations, namely Tjg, Cherating to Sg. Cherating, Sg. Cherating to Sg. Ular, and Pelabuhan Kuantan to Tjg. Payang, exceeded the rate of accretion. Essentially, the coastal erosion was caused by a huge wave during Northeast monsoon and human activities such as beach construction at Cherating and port construction activities (Azid et al., 2015). The Cherating coast is one of the most beautiful beaches, with fascinating landscape and scenery, and is suitable for recreational activities (Azid et al., 2015). The beach in Cherating is wide and sandy with a general gradient face of 4.8%. The area is also an important turtle-landing site and serves as a fishing base (Unit Perancang Ekonomi, 1985).

The wave pattern and water level along the Northern coast of Pahang is moderate compared to other MUs. The shoreline appears to be stable, with a configuration defined by the groyne to the east, as shown in Fig. 7. The short groynes cause a local depression in the littoral drift along the beach face, but allow the majority of the littoral drift to pass by uninterrupted. Several chalets and other structures have littered the length of this beach, with some of them located on the beach itself. Some of these chalets were built too close to the sea in an area which, in the past, was exposed to considerable shoreline movements, as evidenced by the loss of several patches of lands to the sea. The construction of too many chalets directly to the beach is not recommended due to the risk of flooding and storm damage.

The Gebeng Jetty MU is characterized by a new development comprising large industrial units, a new petrochemical storage facility and major coastal reclamation. The coastal reclamation done in the year 2000 has resulted in a significant alteration of the shoreline, which is fully protected by revetment. Interference by discharge in the industrial area north of the Gebeng Jetty could have some adverse effects on drainage, unless the discharge is properly regulated.

Taman Gelora is the largest recreation area near the north of

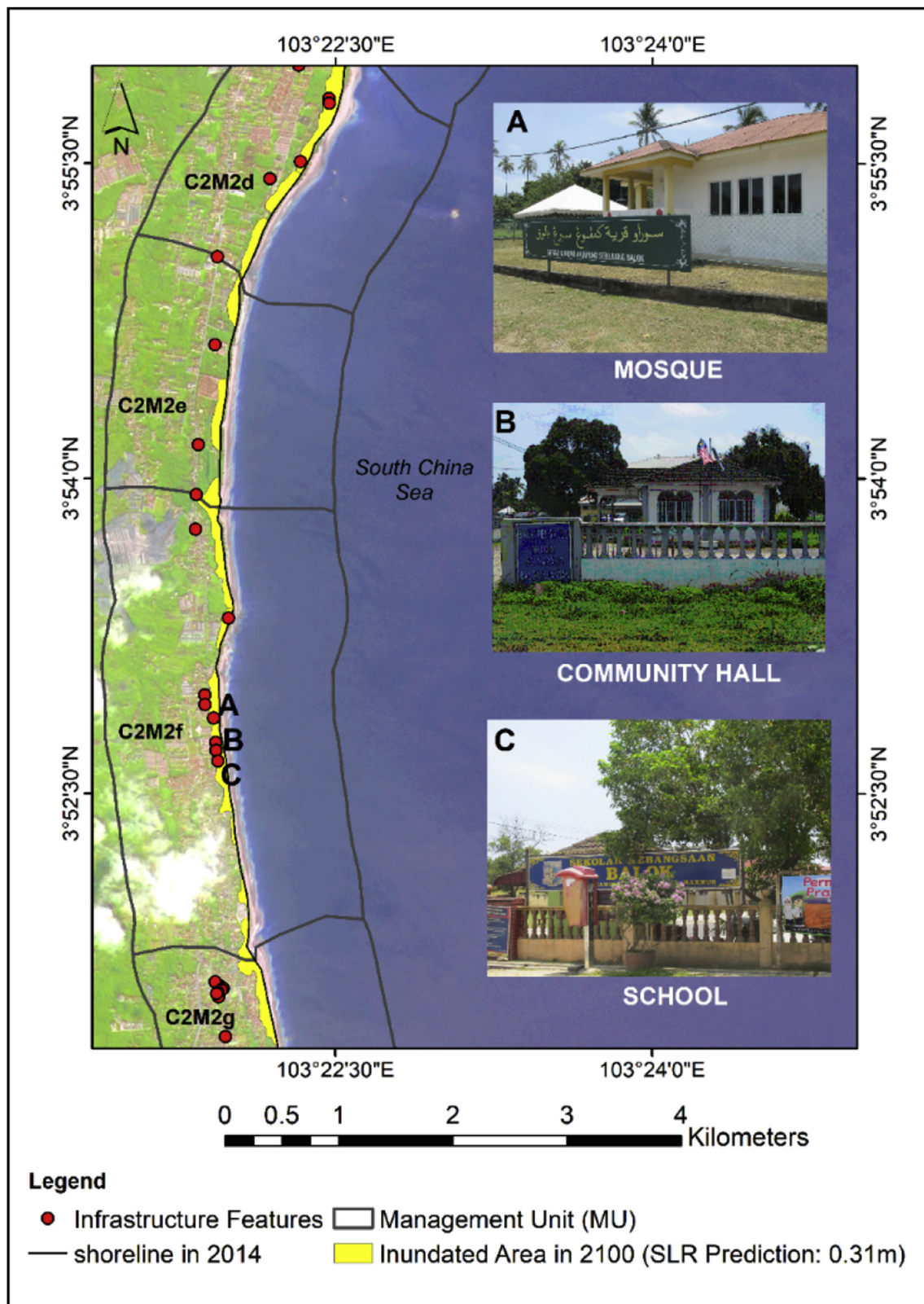


Fig. 6. Predicted inundation area at C2M2f in 2100.

Kuantan river mouth and is popular among Kuantan residents. This coastal area is undergoing severe erosion, as evidenced by the casuarina trees lining the shore not being in their normal equilibrium. In order to preserve the recreational area, there is a need to find a balance between constructing rock revetment to protect the coastline and ensuring

public access to the beach and a good beach width. The trees and revetments along the shoreline of Taman Gelora should be preserved, since they play a natural function as a coastal defence, as shown in Fig. 8.

The Royal Pahang Golf Club MU is characterized by a long stretch of

Table 9
Coastal adaptation measures along the Cherating-Tanjung Agas shoreline, Pahang.

No (MU)	Description of the MU	Potential Impact as a Result of SLR	Adaptation proposed measures	Justification for the proposed adaptation
1 MU1	Flat slope, wide sandy area, with a Mean Significant wave height of 0.55 m. Fine, white sandy beach. Recreation area. Coastal and mangrove forest at river mouth.	Impact on chalet/hotel and road	Raising and maintenance of existing groyne along the beach	Due to the major contribution of beach tourism to the national economy, beaches must be well-preserved and protected against erosion.
2 MU2	Flat slope with a Mean Significant wave height of 0.56 m; wide sandy area; fine, white sandy beaches. Scattered residential area.	Impact on chalet/hotel	Construct beach nourishment	Refilling beaches with sand provides an alternative and often more successful physical approach to reducing risk of SLR. Sandy beaches are particularly vulnerable to erosion and retreat. The placement of sandy material along the shore to establish and maintain the desired beach width is effective for Malaysia.
3 MU3	Flat slope with a Mean Significant wave height of 0.59 m; wide sandy area; coarse, grey sandy beach. Gebeng Jetty and port area.	Impact on residential area and fishing jetty. Serious siltation problem.	Construct new rock revetment along the shoreline	Structural protection will protect residential area and other infrastructure from erosion and inundation.
4 MU4	Coarse, grey sandy beach. Mean Significant wave height of 0.62 m. Port area.		Rock revetment has been constructed	The structural of protection was built by State Authority (The Department of Irrigation and Drainage (DID) Malaysia.
5 MU5	Coarse, grey sandy beach. Mean Significant wave height of 0.57 m. Industrial area. Forest area along the shoreline.		Breakwater and rock revetment have been constructed	The structural of protection was built by State Authority (The Department of Irrigation and Drainage (DID) Malaysia.
6 MU6	Flat slope, with a Mean Significant wave height of 0.53 m. Coarse, grey sandy beach. High-density residential and industrial areas.	Impact on industrial building and road	Construct new rock revetment along the shoreline	Revetment will protect the properties such as residential and industrial building behind it against erosion. Along the protected area at both ends; erosion continues and, most likely, becomes more severe because of the effects of wave diffraction.
7 MU7	Flat slope with a Mean Significant wave height of 0.55 m; wide sandy area; Mixture of fine and coarse, grey sandy beaches. Recreation area. Coconut tree and forest at mouth of river.	Impact on residential area and infrastructure	Construct new rock revetment along the shoreline	Structural protection will protect residential area and other infrastructure from erosion and inundation.
8 MU8	Flat slope with a Mean Significant wave height of 0.57 m. Wave movement parallel to the beach. Coarse, grey sandy beach. Casuarina along shoreline. Hotel and recreation area.	–	–	–
9 MU9	Flat slope, with a Mean Significant wave height of 0.53 m. Coarse, muddy, grey sandy beach. Residential area and infrastructure along the shoreline.	Low-lying area could be inundated. Impact on infrastructure. Serious siltation problem.	Concrete wall has been constructed along shoreline	The concrete wall will maintain a balanced sediment i.e., the supply of sediment to this reach, from natural sources and mostly nourishment efforts, equals the loss of sediment directed away from this region.
10 MU10	Flat slope with a Mean Significant wave height of 0.53 m. Mixture of fine and coarse, white sandy beaches. Idle land and scattered residential area.	Low-lying area could be inundated.	Construct new rock revetment along the shoreline	Protect inland properties from the direct effects of waves and storm tides.
11 MU11	Steep slope with a Mean Significant wave height of 0.50 m. Fine, white sandy beach. Recreation area. Sparsely populated.	–	–	–
12 MU12	Steep slope with a Mean Significant wave height of 0.50 m. Fine, white sandy beach. Densely populated area with facilities. Recreation area.	–	Rock revetment has been constructed at Kuantan River	The structural of protection was built by State Authority (The Department of Irrigation and Drainage (DID) Malaysia.
13 MU13	Flat slope with a Mean Significant wave height of 0.51 m. Coarse, muddy, yellowish sandy beach. Residential area and fishing area along the shoreline. Good infrastructure facilities.	–	–	–
14 MU14	Flat slope with a Mean Significant wave height of 0.57 m. Fine, yellowish sandy beach. Scattered residential area and fishing area. Coastal forest along the shoreline. Low development.	–	–	–
15 MU15	Flat slope with a Mean Significant wave height of 0.63 m. Fine, yellowish sandy beach. Agricultural area, idle land and low development.	Low-lying area could be inundated.	Construct new rock revetment along the shoreline	Because of agricultural area, the implemented revetment on shoreline is found to be positively related to property value.
16 MU16	Flat slope with a Mean Significant wave height of 0.62 m. Wide sandy area. Muddy, grey sandy beach. Aquaculture activities. Shoreline is covered with mangroves forest.	Low-lying area could be inundated. Impact on mangrove and coastal vegetation.	Replant mangrove trees	The mangrove species that can be planted Rhizophora species that grows in muddy area around the mouth of the river. The mangrove planting can be done gradually, step by step, starting in the more protected areas.
17 MU17	Flat slope with a Mean Significant wave height of 0.63 m. Coarse, yellowish and brown sandy beaches. Coastal forest, casuarina trees, and agricultural area along the shoreline. Low development.	Low-lying area could be inundated. Impact on coastal forest along the shoreline.	Rock revetment has been constructed along the bank of the river mouth	The structural of protection was built by State Authority (The Department of Irrigation and Drainage (DID) Malaysia.
18 MU18				

(continued on next page)

Table 9 (continued)

No	(MU)	Description of the MU	Potential Impact as a Result of SLR	Adaptation proposed measures	Justification for the proposed adaptation
		Moderate slope, higher rate of erosion, Mean Significant wave height of 0.62 m. Coarse, yellowish and brown sandy beach. Aquaculture area in Tanjung Agas, residential area and fishing near river. Morphology of beach changes constantly due to wave action.	Impact on house, infrastructure, pond and fishing jetty.	Breakwater has been constructed, raise the width and height of existing rock revetment on both sides of the river mouth	The structural of protection was built by State Authority (The Department of Irrigation and Drainage (DID) Malaysia.



Fig. 7. Groyne protection structure on the Cherating beach.



Fig. 8. Rock revetment at Taman Gelora, Pahang.



Fig. 9. Protection structure near the Royal Pahang Golf Club area.

coastline with a highly varied morphology. The main club buildings are located on the eastern part of the club and the area is protected by revetment against active erosion, as shown in Fig. 9. The shoreline is characterized by deposits of riverine sediments which are reworked by wave action diffracted around Tg. Tembeling.

The beach in front of the eastern spit consists of fine white sands and gentle slope. All permanent defence structures are considered to be in good condition and effective in performing their general functions of protecting the shoreline. The coastal erosion along this section of the coast should be monitored, particularly the area around the club house, which is very close to the shore.

The results of site assessment indicate that some coastal sections are

less vulnerable, especially the southern areas of the Kuantan-Kuala Pahang coast, with the exception of the Cheruk Paloh-Kuala Pahang coast. This MU was classified as more vulnerable due to its exposure to higher rates of erosion, which exceed 6 m per year especially to MU 18 (Cheruk Paloh-Kuala Pahang); the steep coasts are deemed to be of medium value and are highly populated. The findings of Fazly et al. (2018) reveal that the cause of erosion might be due to the monsoon and tides, changes in sea level and various human activities. In addition, Lun et al. (2011) showed that every year during Northeast season (mostly November to December), extreme rainfall has caused the Kuala Pahang River to overflow, which has led to the inundation of the lowland and the erosion of nearby areas.

To reduce community vulnerability and to assist sustainable adaptation to these natural hazards, local agencies, Pahang government and the local community need to pay more attention to infrastructure development and future adaptation planning at the risk area. For instance, Kuantan and Cherating in particular have been very popular recreational spots among the locals rather than serving as a tourist destination. Most accommodation and facilities are located within 1 km from the sea with direct access to the beach, rather than being separated from the sea by major roads.

Another aspect of future adaptation planning for Pahang coastal is to establish a module and guidance for the restoration and conservation efforts of the mangroves area. Fatimah and Zhang (2017) described how the mangrove locations are commonly small along the east coast, which faces the South China Sea. The mangroves forest for Pahang especially only cover the river mouth and extend from 0.5 to 1 km inland, especially at Cherating, Kuantan and Penor river. In these areas, the local community and society groups play an important role in creating awareness among the local communities through activities such as talks, awareness exhibitions, planting trees and distributing flyers and kits about the significance of mangrove and other coastal forests along the shoreline. The involvement of the authorities and volunteers are significant to this approach because they are based on the focus area, so they are close and have better communication with local communities.

Therefore, the responsibility for implementing coastal adaptation measures must be shared by both the non-governmental organizations and the state government in order to ensure that good decisions are made in an effort to protect the coast from the hazard of climate change events.

5. Conclusion

In this study, a CVI was developed for the Cherating-Pekan coastal area by ranking six parameters, namely coastal slope, coastal geomorphology, rate of erosion and accretion, shoreline change, mean wave height, rate of SLR and mean tidal range to represent the risk level of the study coast. Calculated CVI values along shoreline of Cherating-Pekan vary between 4.24 and 18.97. Approximately 5.56% and 22.22% of the 87 km along coast is categorized as having low and very low vulnerability. Meanwhile, 33.33% and 27.78% are represented as the high and moderate vulnerability categories, respectively. Among the other four parameters, geomorphology, mean tidal range, rate of erosion and accretion, and coastal slope shows a big variation, while rate of sea level rise and mean wave height have the same values along the entire shoreline. This study has definitively proven the effectiveness of in-situ data measurement, numerical spectral wave and hydrodynamic modelling, and GIS analysis tools for coastal vulnerability studies. The integration of the different CVI parameters has allowed the present study to make a much more comprehensive vulnerability assessment along the coastal area. The study suggests that there is a need to strengthen the current adaptation or protection measures to reduce the adverse impacts of SLR and to protect the resources and livelihood of the coastal communities. Therefore, further research can be carried to investigate the solutions and effective adaptation measures including

structural and non-structural measures in order to reduce climate change impacts and coastal vulnerability in the Pahang coast of Malaysia. To reduce community vulnerability and to assist sustainable adaptation to these natural hazards, local agencies, Pahang government and the local community need to pay more attention to infrastructure development and future adaptation planning at the risk area. For instance, Kuantan and Cherating in particular have been very popular recreational spots among the locals rather than serving as a tourist destination. Most accommodation and facilities are located within 1 km from the sea with direct access to the beach, rather than being separated from the sea by major roads. Consequently, the output of coastal vulnerability provides reliable information to other researchers and relevant authorities responsible for making decisions and formulating policies, allowing them to mitigate and adapt to the impacts of climate change occurring in coastal regions.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ocecoaman.2019.104948>.

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