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TOWARDS THE IMPLEMENTATION OF CONTINUOUS COASTAL VULNERABILITY INDEX IN MALAYSIA: A REVIEW

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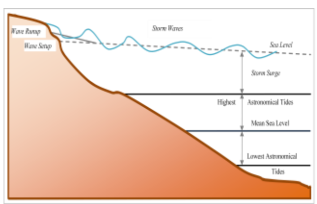
Graphical abstract



Abstract

Climate change has brought about many threats to the ecosystem by inducing natural hazards, particularly sea level rise. Coastal areas then are subjected to many adverse effects of sea level rise, hence posing a risk to the safety of the coastal population, resources and assets. As part of the mitigation and adaptation measures against these effects, the Coastal Vulnerability Index (CVI) was implemented by many coastal regions. The CVI is an index-based tool to map the risks related to coastal changes. In Malaysia, the practice of CVI is still in its initial stages. Whereby, the Department of Irrigation and Drainage (DID) Malaysia had earlier carried out two pilot projects on CVI. The first is located at Tanjung Piai and the second at the west coast of Pulau Langkawi. This paper reviews the definition and concept of CVI. An alternative implementation approach of CVI in Malaysia is also discussed.

Keywords: Climate Change; Sea Level Rise; Coastal Vulnerability Index

Abstrak

Perubahan iklim telah membawa banyak ancaman kepada ekosistem dengan mendorong bencana alam, terutamanya kenaikan aras laut. Kawasan pantai yang terdedah kepada banyak kesan buruk akibat kenaikan aras laut, akan menimbulkan risiko kepada keselamatan penduduk pantai, sumber alam dan aset. Sebagai langkah-langkah pencegahan dan adaptasi terhadap kesan-kesan ini, Coastal Vulnerability Index (CVI) telah dilaksanakan di kebanyakan kawasan pantai. CVI adalah alat berasaskan indeks untuk mengambarkan risiko yang berkaitan dengan perubahan pantai. Di Malaysia, amalan CVI masih di peringkat awal. Di mana, Jabatan Pengairan dan Saliran (JPS) Malaysia sebelum ini telah menjalankan dua projek perintis CVI. Yang pertama adalah di Tanjung Piai dan kedua di pantai barat Pulau Langkawi. Kajian ini mengkaji definisi dan konsep CVI. Pendekatan pelaksanaan alternatif CVI di Malaysia juga dibincangkan.

*Kata kunci:*Perubahan Iklim; Kenaikan Aras Laut; Coastal Vulnerability Index

1.0 INTRODUCTION

The rise in sea level has become a great concern to civilisation as a part of the global predicament of climate change. Scientific research has produced concrete evidence pertaining to the trend of sea level rise globally, such as that by Masters et. al.[1] who stated the global mean sea level rose at an average rate of ~3.2 mm/yr from 1992-2011 using satellite altimeter data (refer figure 1). Compared to the geophysical phenomena such as earthquakes and volcanic eruptions, the long-term effect of sea level rise seems benign. However, as 60% of the world's population is living near coasts,[2] the issue of sea level rise, especially in the sense of hazard safety and mitigation, has definitely developed into a critical matter.

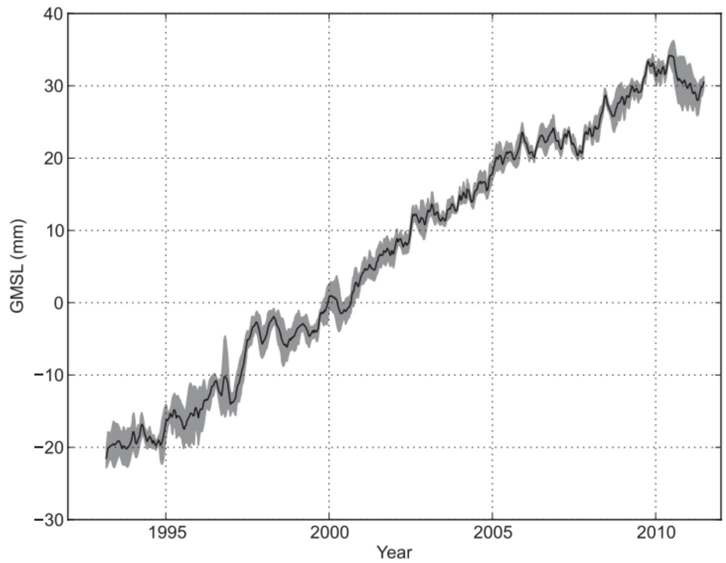


Figure 1 The mean of five independently computed GMSL time series. Shaded area represents 95% confidence interval about the mean[1]

The threats or consequences related to sea level rise include coastal flooding, shoreline erosion, and storm damages, of which each will impose a substantial burden on local coastal regions, especially economically and habitability. Therefore, much effective mitigation and adaptation responses have been implemented around the world as a prevention and compensation step against the impacts of sea level rise.[3]

Nonetheless, implementation of these steps is costly, thus an adequate coastal zone management system needs to be realized in order to specifically only select areas that are most vulnerable to the impact of sea level rise. According to the Intergovernmental Panel on Climate Change (IPCC),[4] vulnerability is defined as “the extent to which climate change may damage or harm a system; it depends not only on system sensitivity but also the ability to adapt to new climatic conditions.” This system then must be able to indicate the degree to which a climatic condition changes.[5] The present system adopted by many countries is the Coastal Vulnerability Index (CVI).

The CVI is an index-based method used to measure the vulnerability of the coast by numerically ranking the impact of a few variables to coastal change.[6-7] Hence, the definition of CVI does not only include the impact of sea level rise, but also the impact of other variables that are associated to climatic and non-climatic changes. The reason being, in order to comprehensively assess the impact to coastal changes, other conditions must be integrated as well. Flather and Williams[8] studied that the changes in tide, storm surges and water levels are effects from change in sea level; while Nicholls and Tol[3] analysed the socio-economic impact of sea level rise. Therefore, these studies suggest that sea level rise should not be the only variable considered, as there are other variables that induce coastal changes.

The variables of CVI are divided into three groups: 1) Socio-economic variables, 2) Biological variables, and 3) Physical variables, as illustrated in figure 2. This paper will discuss the physical variables in particular.

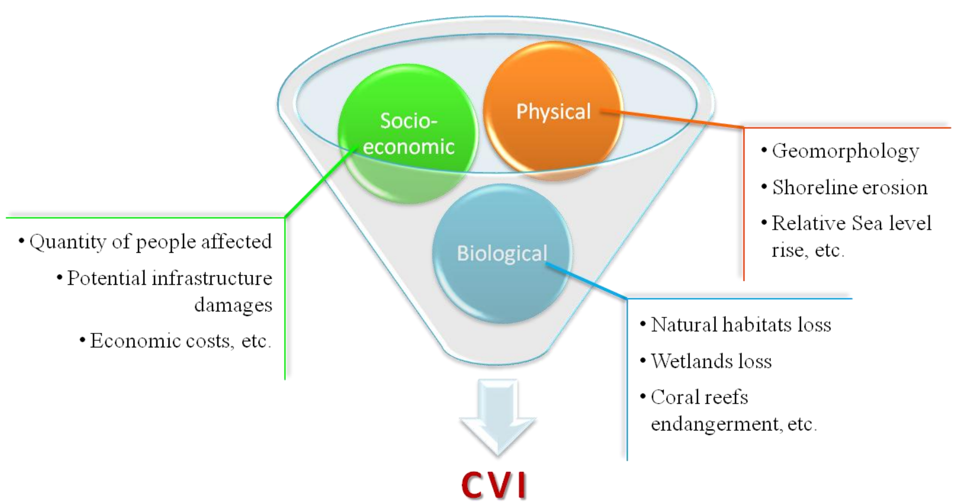


Figure 2 The variables associated with CVI

■2.0 THE PHYSICAL COASTAL VULNERABILITY INDEX (PCVI)

Before the development of CVI, a number of predictive approaches have been recommended, such as: 1) historical data extrapolation (e.g. paleo sea level rise), 2) static inundation modelling (e.g. topographic data), and 3) simple geometric models (e.g. the Bruun Rule).[6,9] However, each approach has their limitations in indicating the impact to coastal change. For example, the Bruun Rule is used for measuring shoreline recession relative to sea-level rise, is regarded obsolete due to wave energy is not included and it assumes that sea level rise causes solely coastline retreat, instead of coastline accretion as well.[10]

Human monopolization through coastal infrastructures, such as resorts and jetties, further complicate the assessment of coastal change. Hence, the CVI was implemented in order to evaluate coastal change by not only taking into account the natural aspects, but also the monopolized aspects of the coasts. The latter is mainly associated with the socio-economic variables but still affects the other variables. As the scope of the paper is within the physical variables of CVI, the term physical CVI, or PCVI, will be used.

The main purpose of the PCVI is to identify which areas along the coastline will undergo prominent coastal changes, thus allowing coastal managers and policy makers to prepare the most appropriate response for the area in advance.

The first step in formulating a PCVI is to identify the key variables that will contribute to coastal vulnerability.[7] There are six variables used by Gornitz et. al.[11] and Hammar-Klose and Thieler[12] of which are further classified into 2 groups: 1) Geologic variables, and 2) Physical variables.

The geologic variables are: a) geomorphology, b) shoreline erosion and c) coastal slope. The physical variables consist of: a) mean tidal range, b) mean significant wave height and c) relative sea level rate. These variables are usually locally defined, hence can be modified according to the coastal specifications, such as Dwarakish et. al.[13] who used the global sea level rise variables instead of local relative sea level rise.

The second step involves relating these six variables in a quantifiable manner.[12] This is carried out through an index-based approach by assigning each variable to numerical values ranging from 1 to 5, where 1 is the lowest risk of coastal vulnerability and 5 is the highest risk. Once each variable has been assigned a vulnerability value, the PCVI is calculated as the square root of the ranked variables divided by the total number of variables.[11]

$$PCVI = \sqrt{\frac{a \times b \times c \times d \times e \times f}{6}}$$

Where, a = geomorphology, b = shoreline erosion rate (m/yr), c = coastal slope (%), d = mean significant wave height (m), e = mean tidal range (m), and f = relative sea level rate (mm/yr).

2.1 Geomorphology

Geomorphology is the study of landforms and its erosive risk in a coastal area.[2,13] It encompasses the type of sediments at beaches, type of cliffs, the seascape and oceanic water bodies, and the vegetation in the coastal area.

Geomorphology is mainly towards identification rather than measurement, either through site visits, topography maps or remote sensing images. The geomorphology variable is ranked based on the type of landform at the coastline. Tougher and more stable landforms such as rocky cliffs represent low risk of coastal vulnerability as they form a better coastal defence mechanism compared to vegetation such as coral reefs and mangroves.

2.2 Shoreline Erosion

According to Shalowitz,[14] as cited in Pujatomo,[15] shoreline is defined as "the line of contact between land and water body. On Coast and Geodetic Survey nautical charts and surveys the shoreline approximates the mean high water line." Recent studies have based their shoreline definition following Shalowitz. Therefore, the definition of shoreline is with respect to the mean high water line (MHW) derived from the mean high tide. Mean high water is used to indicate the highest possible water level that will cause land submergence, hence shoreline erosion.

The shoreline is constantly dynamic, as it experiences erosion and accretion, as a result of the action of natural processes such as sea level rise, wave energy and sedimentation. This causes coastal areas to gain land mass due to accretion and lose land mass due to erosion, thus changing the shoreline position. However, shoreline accretion is a very low vulnerability effect. Therefore, studying shoreline erosion is more significant as it causes a gateway for inundation and storm surges to bring forth natural disasters such as flooding.

A criterion for measuring shoreline erosion is to identify the shoreline area limit for hazard mitigation. The shoreline area limit is the area that includes all the important coastal resources and coastal processes. In Malaysia, shoreline area limit is from the shoreline to 1 km landward and 3 km seaward.[16]

Conventionally, shoreline erosion was measured using aerial photogrammetry images and topographic maps. They were digitized to provide shoreline positions. Aerial photogrammetry had to be carried out during the desired tidal datum, i.e. mean high tide.[17] This method was carried epoch to epoch to measure shoreline erosion. However, these methods were labour intensive, costly and time consuming.

With the advent of space remote sensing technology, the measurement of shoreline erosion is now a simpler task. By projecting tide levels from tide gauges onto a DEM derived from Interferometry Synthetic Aperture Radar (InSAR), a shoreline positions can be determined based on the elevation contour. The DEM then will be superimposed onto base maps to calculate the area of accretion or erosion and their maximum rate can be estimated based on the beach width values.[13]

Potential shoreline erosion can also be accurately determined from high resolution Digital Elevation Model (DEM) acquired by airborne (e.g. Light Detection and Ranging (LiDAR), IfSAR) techniques.[18] However, airborne remote sensing techniques are also tide-controlled; they are carried out during mean low tide to observe the highest, intermediate and lowest shoreline positions. Hence, with remote sensing technologies, shoreline erosion measurements are made much simpler in addition to high accuracy.

2.3 Coastal Slope

Coastal slope highlights the most affected areas in terms of the potentiality of inundation and rapidity of shoreline retreat as steeper coastal regions retreat slower than low-sloping coastal regions due to shallow water is exposed to high wave energy (high wave height).

Coastal slope is basically measured perpendicular to the shoreline to a certain distance seaside and a certain distance landside.

$$coastal\ slope(\%) = \frac{coastal\ slope\ rise(m)}{distance\ from\ slope\ origin(m)} x\ 100\%$$

Previously, bathymetry survey was used to measure ocean depth through depth sounding. From bathymetry survey the seabed contour profile can be created, then merged with a digitized topography map. This will provide a map with coastal slope information. However, this method is costly and time consuming as well.

Satellite altimeter (SALT) is able to derive bathymetry data as well. It can recover seabed topography from measurements of ocean surface slope.[19] Nevertheless, mapping the coastal region using SALT is a very complicated method and subjected to many errors.

Therefore, global topographic models such as the Denmark Technical University 10 (DTU10) Bathymetry can be used to determine bathymetry of a coastal slope. DTU10 Bathymetry is an improvement of GEBCO global bathymetry model with the use of DTU10 gravity derived from satellite altimetry.[20] It is mapped with a resolution of 1 minute by 1 minute corresponding to 2 minute by 2 minute resolution at Equator.[21]

Other techniques include LiDAR bathymetry for seabed topography mapping (see Guenther[22]) and DEM generation derived from remote sensing techniques such as InSAR (see Papanastassiou et. al.[23])), or even derived from global topography models. The DEM from InSAR can also be inserted into Google Earth to generate coastal slope values such as depicted in the thesis by Davies[24] as shown in figure 3.

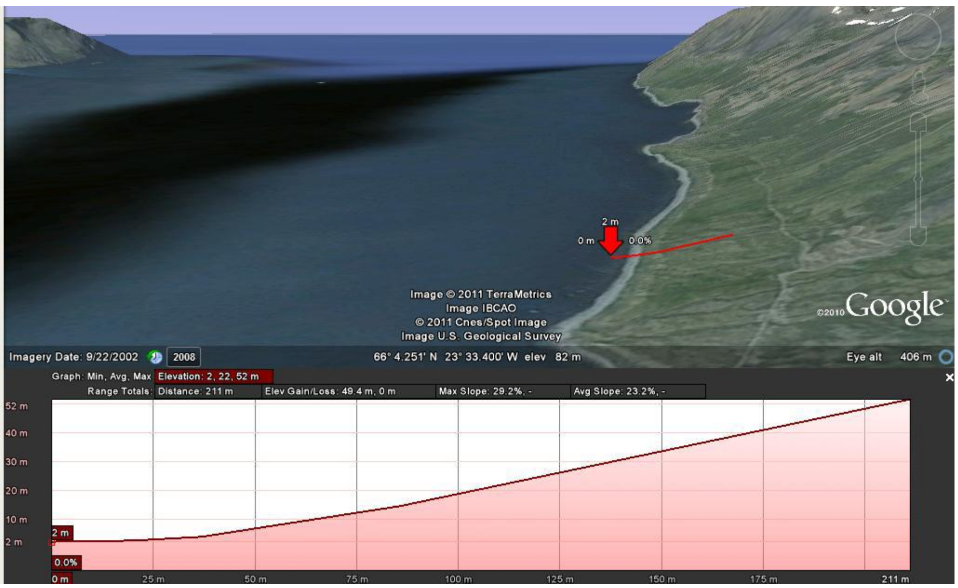


Figure 3 Coastal slope measurement using Google Earth[24]

2.4 Mean Significant Wave Height

Wave is basically formed by wind travels on the sea surface. The significant wave height (SWH) can be defined as the average height of the highest one-third waves in a wave spectrum.[25-26]

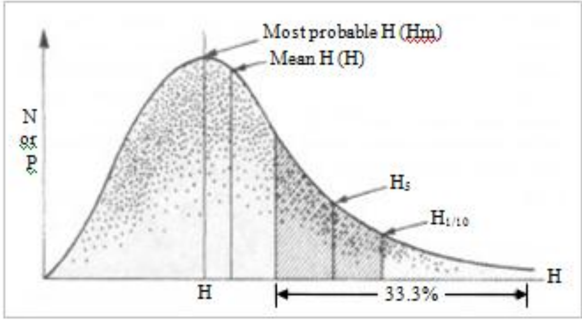


Figure 4 Statistical distribution of weight height[27]

Figure 4 shows how significant wave height is determined. Each dot on the graph represents a wave with their respective heights. The graph shows small waves and large waves to the left side and right side of the graph respectively. The greatest frequency of wave height is indicated by Hm. The highest one-third (33.3%) number of waves in this spectrum is shaded on the graph; therefore the average height of waves in this shaded group is the significant wave height, Hs.[27]

In the 1970s, wave heights data collection was limited to coastal buoys and ship reports.[28] However, presently it is possible to monitor significant wave height with the use of satellite altimetry. Data from satellite altimeter observations gives a better SWH estimation in the open ocean; unfortunately, it is unable to give comparable accuracy for coastal areas (30 – 70 km from the coast) due to several factors such as signal backscatter.[29] One method of resolving this issue is by applying retracking techniques to reduce noise.

Coastal area changes continuously due to the presence of wave. Doukakis[2] stated that waves have the ability to physically and geologically transform the shore as it acts as the medium to transport sediments towards offshore and inshore, and change the shape of the coastlines. He added that the assessment of coastal susceptibility to the threat caused by wave height is based on the maximum SWH of a particular coastal area.

2.5 Mean Tidal Range

Tide is a phenomenon of which causes sea level to continuously change over time as the resultant from gravitational attractions from the sun and moon.[30] From tidal observations, a few water levels can be derived such as the mean sea level (MSL), mean high tide and mean low tide. Within these water levels there exist several more specific terms. For example there are a number of mean high tides such as Mean High Water Spring (MHWS) and Mean Higher High Water (MHHW) and a number of mean low tides, for instance the Mean Low Water Neap (MLWN) and Mean Lower Low Water (MLLW). Tidal range is the difference between any of these corresponding high tides and low tides. During full moon and new moon, the greatest tidal range occurs due to maximum difference between high tides and low tides.

Conventionally, tides are observed by using tide gauge. According to Hok,[30] due to its spatial location, tide gauge is able to provide accurate coastal tides data. He further stated that in terms of temporal sampling, tide gauge provides continuous tide data at 5 minutes interval. Presently SALT is unable to directly measure coastal regions without any modelling (e.g. retracking), hence providing less accurate tidal data. Moreover, the temporal sampling of SALT is one week due to its satellite orbit design (Exact Repeat Orbits).[30]

Tidal range is closely related to inundation of low-lying coastal areas. Due to sea level rise, an area with large tidal range is susceptible to permanent inundation associated with mean high tides thus causing floods.[2] According to Hammar-Klose and Thieler,[12] large tidal range (macrotidal) is larger than 4.0 m, while small tidal range (microtidal) is smaller than 2.0 m. Large tidal range is associated with high vulnerability rating while small tidal range to low vulnerability rating. This is due to the fact that large tidal range is associated with strong tidal currents that influence coastal behaviour.[31]

Contrary to Gornitz's[31] statement, Hammar-Klose and Thieler[12] stated that macrotidal is related to low vulnerability rating and the opposite for microtidal. Hammar-Klose and Thieler[12] further stated that if a storm strikes, the worst situation occurs when the high tide takes place. If the tidal range for that particular area is large, the worst situation caused by the storm occurs approximately with only a 50% chance (in a diurnal area). For a microtidal area, if a storm strikes, then that particular area will experience the same magnitude of storm impacts as there is only a small difference between high tide and low tide water levels. Hence, the magnitude is the same even in mean high tide or mean low tide; justifying that small tidal range results in higher vulnerable.

2.6 Relative Sea Level Rate

Sea level, or referred as the Mean Sea Level, is the average height of the surface of the ocean. As the average height increases, it causes major implications to coastal vulnerability, especially in the sense of seizing land area. Based on figure 1, global sea level has been rising, mainly due to ocean thermal expansion and mass changes (e.g. melting of ice sheets). However, sea level variation differs between global and regional measurements, as there are some regions where sea level seems to be falling due to land uplift, such as the Gulf of Alaska.[32] Therefore, to measure sea level variations regionally, both sea level and vertical land motions need to be considered.

There are two types of measurements for sea level; the first is relative sea level, and the second is absolute sea level. Relative sea level (RSL) measures sea level rate with the inclusion of vertical land motion. It is measured via tide gauges over a coastline. Hence, the apparent sea level rate at the coast of a region can be derived. Absolute sea level (ASL) measures only the sea level rate without any external effects. Conventionally, this was measured using an integration of GPS (provides land motion rate) and tide gauges (provides both land motion and sea level rates). By comparing the two techniques, the ASL could be derived. Since 1992, ASL could also be measured from sea level anomaly via satellite altimetry (SALT), such as TOPEX/Poseidon and Jason satellites. It is able to provide much better coverage and resolution of an area. Whereas, in order to extend the RSL values for an area using tide gauges, extrapolation techniques need to be used, as tide gauges are point-based. Nonetheless, RSL seems to be the better approach for measuring sea level rate for CVI. This is due to the fact that land motion is taken into account, thus need not to measure land motion exclusively.

The effects of sea level rise, on the other hand, have a vital relationship with four variables of CVI, which are coastal slope, shoreline erosion, tidal range, and mean significant wave height. The effects of sea level rise are exhibited in shoreline erosion which will be large on low sloping coastal regions.[13] If the coastal area has a large tidal range, it will cause frequent or even permanent inundation resulting from sea level rise.[2,31] Due to this devastating relationship, it is important that the CVI incorporates these four variables together with sea level rise.

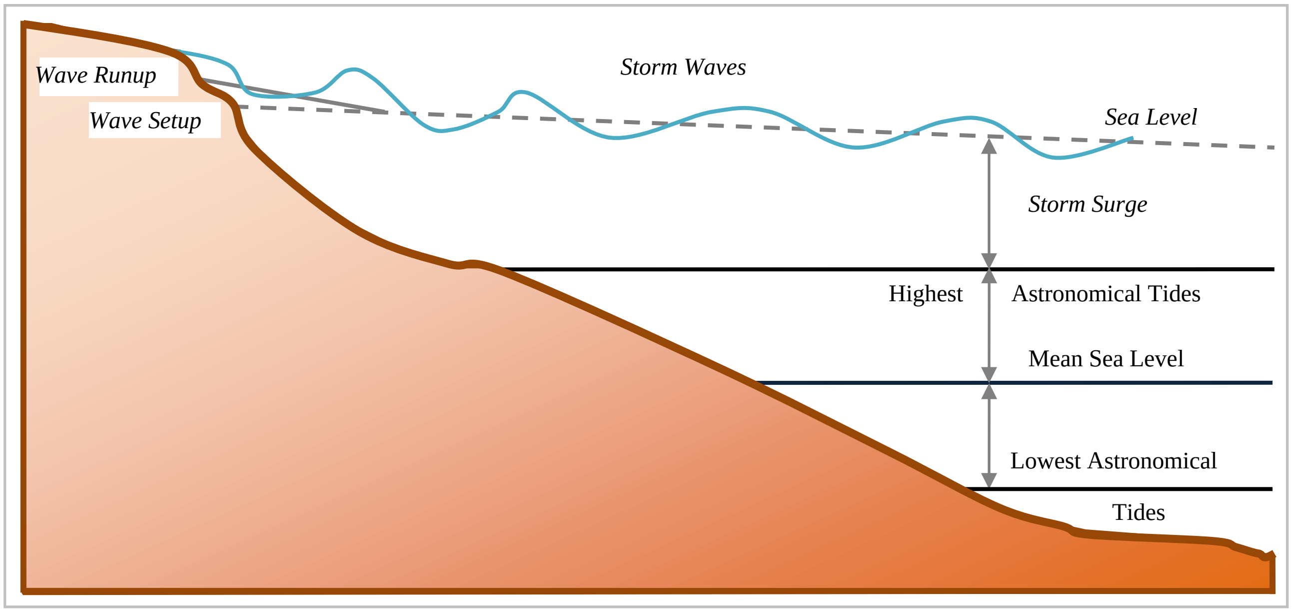


Figure 5 Relationship of sea level with tidal range and mean significant wave height[33]

3.0 DATA RANKING

Based on table 1, all variables are ranked on a linear scale from 1 to 5, ordered by increasing vulnerability towards a coastal area. The database includes numerical and non-numerical information, where the numerical information is assigned data value ranges and the non-numerical information (geomorphology) is assigned based on the vulnerability of the coastal area to erosity of landform.[12]

The numerical information is obtained by measurement over many years. Then, by obtaining the variables variations values, especially the maximum and minimum values, the values can be ranked according to vulnerability.). The values in table 1 are mainly used in the United States. However, it can be adopted in other regions as well, such as Malaysia, who used these values in their CVI pilot studies.[34]

Relationships can be formed by comparing the values of different variables, for example as sea level rises (> 3.16), the higher the coastal erosion (< -2.0), or the lower the coastal slope (< 0.25), the higher the mean wave height (> 1.25). Hence, with CVI, these relationships can be formed in a quantifiable manner making it intelligible to assess vulnerability.

Table 1 The ranking of CVI variables based on values from Hammar-Klose and Thieler[12]

	Ranking of coastal vulnerability index				
	Very low	Low	Moderate	High	Very high
Variable	1	2	3	4	5
Geomorphology	Rocky cliffed coasts, Fiords, Fiards	Medium cliffs, Indented coasts	Low cliffs, Glacial drift, Alluvial plains	Cobble beaches, Estuary, Lagoon	Barrier beaches, Sand beaches, Salt marsh, Mud flats, Deltas, Mangrove, Coral reefs
Coastal Slope (%)	> 0.2	0.2 – 0.07	0.07 – 0.04	0.04 – 0.025	< 0.025
Relative sea-level change (mm/yr)	< 1.8	1.8 – 2.5	2.5 – 2.95	2.95 – 3.16	> 3.16
Shoreline erosion/ accretion (m/yr)	> 2.0 Accretion	1.0 – 2.0	-1.0 – +1.0 Stable	-1.1 – -2.0	< -2.0 Erosion
Mean tide range (m)	> 6.0	4.1 – 6.0	2.0 – 4.0	1.0 – 1.9	< 1.0
Mean wave height (m)	< 0.55	0.55 – 0.85	0.85 – 1.05	1.05 – 1.25	> 1.25

4.0 THE IMPLEMENTATION OF CVI IN MALAYSIA

In 2007, Department of Irrigation and Drainage (DID) Malaysia had conducted two pilot studies on CVI to determine the potential impacts of climatic drivers, especially the impacts of sea level rise that may cause inundation of coastal areas, shoreline erosion and destruction of ecosystems. The study on CVI was a follow up project from the National Coastal Erosion Study from 1984 to 1986 which found that 29% out of 4,809km of the country's coastline was undergoing erosion.[16] Therefore, the Government had implemented an assessment study in order to identify the coastal zones that were highly susceptible to further erosion by sea level rise. The study was called the National Coastal Vulnerability Index (NCVI) Study. The NCVI had adopted the USGS methodology to compute CVI for the six physical variables. The techniques used are of conventional practices.

The two pilot sites were at coastal stretches from Tanjung Piai to Sungai Pulai Estuary, and the West Coast of Pulau Langkawi from Tanjung Belikit to Tanjung Malai. 20-year tidal records at both pilot sites were analyzed. From the results, it indicated that the rate of relative sea level rise at Tanjung Piai is 1.3mm/yr and at West Coast of Pulau Langkawi is 1.0mm/yr.[34] The results shows that Malaysia may not be vulnerable to sea level rise, however necessary steps must be planned in order to face the phenomena of sea level rise in the future.

Analysis of the Total Composite Vulnerability Index (TCVI) for each site is tabulated below.

Table 2 TCVI for both pilot studies[34]

Tanjung Piai		
Coastline covered (%)	CVI Rank	Areas affected
37.5%	1	BetweenTanjung Piai and Tanjung Bin
25%	3	Along the souther banks of Tanjung Pelepas Port
20.8%	5	Tanjung Pelepas Port, Tanjung Bin, and southern tip of Tanjung Piai.

West Coast of Pulau Langkawi		
Coastline covered (%)	CVI Rank	Areas affected
25%	1	North Tanjung Belikit and south Tanjung Malai
8.3%,	2	South Kampung Teriang
33.3%	3	along the stretches to the south and north of Pantai Chenang and the airport.
8.3%	4	Kampung Teriang
25%	5	along Pantai Chenang, Pantai Kuala Chenang, and souther part of Pantai Chenang

Adaptive measures proposed by DID consisted of: 1) Coastal defense, 2) Mangrove regeneration, 3) Retreat, 4) Reclaiming land from the sea, AND 5) Implementation of integrated coastal zone management.

DID then developed an Integrated Shoreline Management Plan (ISMP) to address the major issues and problems facing the Malaysian shorelines. The objectives of ISMP are as follows: 1) Appraisal and selection of coastal development management strategies, 2) Appraisal and selection of defense options for the coastline, and 3) Formulation of Specific Guidelines and Policies for Development Activities/ Proposals in the coastal area.[16]

The status of ISMP implementation is completed for Pahang, Melaka, Negeri Sembilan, Pulau Pinang, Labuan and Miri.[16] The ISMP is planned to be completed for the entire country by 2020.

In 2010, another study was conducted based on CVI by the Forest Research Institute of Malaysia (FRIM). This study focused on the prediction of coastal erosion and sea level rise impacts towards the mangrove forest in Kuala Langat, Selangor.[35]

The techniques used in this study were more modern, using satellite imagery data from Landsat TM and SPOT-5 XS. This study also followed the USGS methodology to compute CVI for the six physical variables. The results showed that 42.57km of the total length 48.73km of Kuala Langat covered by mangroves was experiencing coastal erosion.[35] The vulnerability ranks are mapped in figure 6.

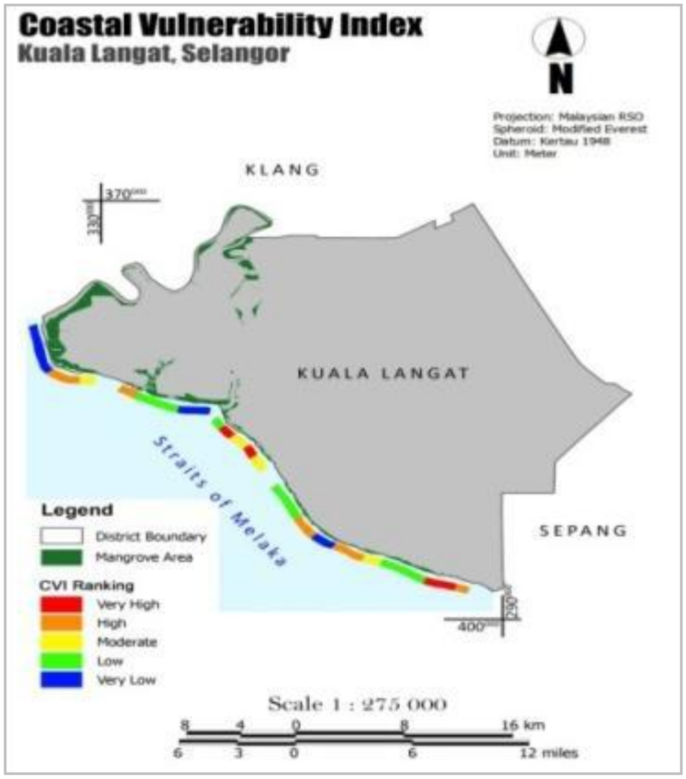


Figure 6 Coastal Vulnerability Index to future sea level rise for the coast of Kuala Langat[35]

4.1 Discussion

The discussion focuses mainly on the implementation of CVI by DID as they are the governmental body in charge of assessing the vulnerability throughout the coastlines in Malaysia. Both studies have been carried out using the USGS' CVI values, and the techniques employed have not yet fully utilized the capabilities of modern remote sensing technology. Further analysis has to be carried out on whether the USGS' CVI values are suitable to be adopted in Malaysia, as wrong CVI values will provide misleading interpretations, thus resulting in costly mitigation and adaptation measures against coastal vulnerability. In addition, it will cause ill-preparation for a catastrophic event such as Tsunami. Even though the two pilot studies regarding CVI have been successfully implemented in Malaysia, the reassurance on accuracy and reliability needs to be re-examined.

Since the completion of the two pilot projects, progress on the implementations of CVI had not been accessible to the public. This may be due to the fact that CVI is too costly to be implemented using conventional techniques such bathymetric survey and buoy observations. Therefore, the techniques employed should also be re-evaluated for better cost- and time-saving prospects. Satellite remote sensing techniques, such as SALT for sea and InSAR for land, are good alternatives in terms of cost over data coverage.

Moreover, two variables of the current implementation of CVI in Malaysia need to be re-examined: 1) The sea level change rate variable, and 2) The tidal range variable different conditions.

Harun[34] stated, "The result(s) from the CVI study indicate that Malaysia may not be vulnerable to sea-level rise." As mentioned previously, the rate of relative sea level rise at Tanjung Piai is 1.3mm/yr and at West Coast of Pulau Langkawi is 1.0mm/yr. This is relatively low and falls under rank 1 (very low risk) of the CVI.

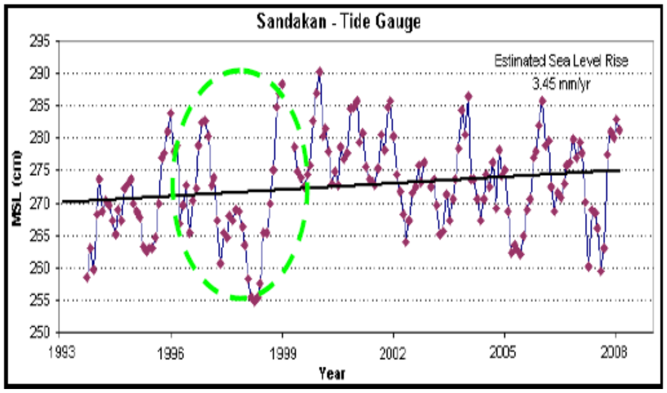
Based on the study by Din et. al.,[36] sea level has not been rising uniformly around Malaysia; it was recorded at a varying rate of 1.4 to 4.1 mm/yr using satellite altimeter data of 15 years (1993 to 2008). Furthermore, the study also adopted tide gauge data from all over Malaysia using data from 1993 to 2008. The sea level rise values from the study are tabulated in table 3.

Table 3 Summary of tide gauge and satellite altimeter sea level rise values[36]

Location	Tide Gauge (mm/yr)	Satellite Altimeter (mm/yr)
Kota Kinabalu (Sabah)	2.63	2.66
Tawau (Sabah)	2.77	2.84
Sandakan (Sabah)	3.45	3.34
Geting (Kelantan)	1.73	1.92
Pulau Tioman (Pahang)	2.36	2.39
Pulau Langkawi (Kedah)	1.21	1.54

Based on table 3, the results indicate that Sandakan has a very high risk (rank 5) of sea level rise, while Kota Kinabalu and Tawau has a moderate risk (rank 3), Pulau Tioman has a low risk (rank 2), and Geting and Pulau Langkawi have a very low risk (rank 1). Ranked sea level rise values are based on the USGS definition. The accuracy of ranked values is questionable in the sense of suitability with the Malaysian coastal regions. For instance, the sea level rise of 2.5mm/yr may essentially be considered high risk for most Malaysian coastal regions.

The tide gauge results for Pulau Langkawi is close to the results from DID (1.0 mm/yr). However, it does not represent the whole of Malaysia, as other areas have a high risk of sea level rise such as Sabah. Therefore, vulnerability of sea level rise exists in Malaysia, even though Pulau Langkawi does not have a significant impact in terms of vulnerability.



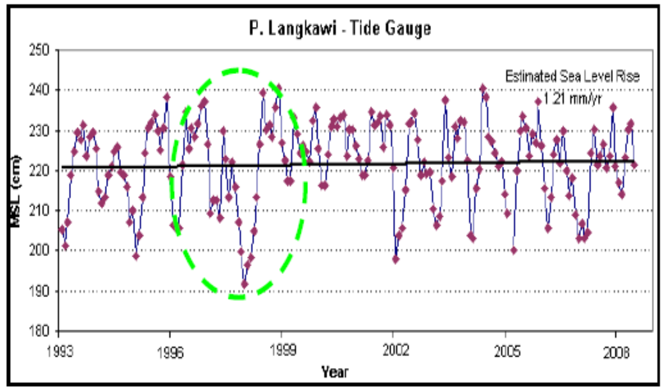


Figure 7 Positive linear trend of sea level rise at Sandakan and Pulau Langkawi tide gauge stations[36]

As mentioned in section 2.5, the smaller the tidal range, the higher the risk during storm surges as storm surges will be frequently be in contact with the mean high tide; hence causing storm waves to be able to penetrate deeper into the land area.[12] As for the mean low tide for small tidal ranges, the effect would be similar to a mean high tide for a small tidal range as well. Basically, the reason for a small tidal range to be considered vulnerable is due to the frequency of contact between a storm surge and mean high and low tide. If the storm surge makes contact with the mean high tide for a large tidal range, the consequences should be drastically more severe. Note that the coastal slope remains constant in both cases. However, the mean low tide will be much weaker for a large tidal range. The tidal range values proposed by Hammar-Klose and Thieler[12] are towards assessment of vulnerability to inundation and erosion from storm surges.

As for normal conditions (no storm surges), the larger the tidal range, the higher the risk to coastal vulnerability due to large tidal energy.[31] However, Gronitz's[31] theory was very general; it was not specific to storm surges. As storm surges induced high additional energy, even a small tidal range can have a large effect to costal vulnerability. In the case for normal conditions, the external energy is not much; hence it requires a larger tidal energy to cause inundation and erosion.

Therefore, further studies need to be conducted in order to adopt a relevant tidal range variable for the Malaysian coastal regions based on the two theories aforementioned. Suggestively, both theories could be adopted but separately used depending on seasonal implications.

The second part of the discussion aims to highlight the issues concerning measuring sea level rise from satellite altimeter. The sea level change rate from satellite altimeter provides absolute sea level changes, hence ignoring effects of vertical land motions. Unfortunately, absolute sea level change is inadequate to completely identify the sea level rise vulnerability of a regional coastline due to the presence of tectonic movements. Therefore, relative measurements are required to monitor both sea level changes and vertical land motions. Aforementioned, as relative sea level changes are measured using tide gauges, extrapolation needs to be carried out to obtain the sea level variations over an area; hence tide gauge stations have to be within close proximity.

In Malaysia, tide gauge stations are sparsely located causing degradation of accuracy in extrapolation. As a result, SALT techniques are employed to obtain a better coverage and resolution for measuring sea level changes. The issue arises when the vertical land motion is not considered. So far, there has not yet been a study converting absolute-derived to relative-derived data. Therefore, the most probable methods to solve these are by;

- Establishing GPS CORS stations at coastlines, or at tide gauges stations for correlation purposes, to measure the vertical land motions. This method then yields another variable to be included in the determination of CVI.
- Deriving a "k-factor" that will convert between absolute and relative data. This method needs a long time series observation of both tide gauges and SALT. However, the derivation requires the data from both sources to be near parallel. Accuracy achieved would depend on the correlation between SALT and tide gauge stations data.

■5.0 Summary

CVI is an index-based tool to quantify vulnerability in coastal regions. It is used by many regions as an assessment for their regional coastal vulnerability; hence number of variables and its values do differ between regions in order to fit the CVI with the specific conditions of each region.

Based on the study by Din et. al.,[36] sea level rise is increasing at a significant rate for certain regions in Malaysia, particularly Sabah. Hence, it is important to identify the areas, via CVI, that require the necessary mitigation and adaptation steps against sea level rise and its related hazards. However, further studies on the reliability of the USGS CVI variable values for the use in Malaysian coastal regions, i.e. vulnerability index for sea level rise, as well as the techniques employed for cost-saving measures are still required.

Prospects of the CVI for the entire coastlines of Malaysia could finally be implemented with the use of remote sensing techniques complimented by tide gauges, and evaluated from time to time for an extensive spatial and temporal coastal vulnerability assessment.

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