Penerbit Akademia Baru

Journal of Advanced Research Design

Journal homepage:
https://akademiabaru.com/submit/index.php/ard
ISSN: 2289-7984

Assessing Coastal Erosion Risks: A Comparative Study of Coastal Vulnerability Index and Coastal Erosion Risk Assessment Methods

Azreen Shafiqa Nabilla Azlan[1], Suhaila Sahat[2,*], Mohd Effendi Daud[1], Masiri Kaamin[2], Zaid Kassim Sultan[3]

1 Department of Civil Engineering, Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, Pagoh, 86400 Batu Pahat, Johor, Malaysia
2 Department of Civil Engineering, Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia, Pagoh, 84600 Batu Pahat, Johor, Malaysia
3 Department of Naval Architecture, Ocean and Marine Engineering, University of Strathclyde, Glasgow G1 1XQ, United Kingdom

ARTICLE INFO

Article history:
Received 13 January 2025
Received in revised form 14 February 2025
Accepted 2 May 2025
Available online 23 May 2025

Keywords:
Coastal erosion; CERA; CVI; risk; vulnerability

ABSTRACT

Coastal erosion poses significant environmental and socio-economic challenges, necessitating robust assessment methodologies for effective management. This study provides a comparative analysis of two widely used coastal risk assessment approaches: the Coastal Vulnerability Index (CVI) and the Coastal Erosion Risk Assessment (CERA). CVI evaluates broad-scale vulnerability based on physical and environmental indicators such as sea-level rise, shoreline erosion rates and geomorphology, making it suitable for large-scale coastal planning. In contrast, CERA integrates additional socio-economic and infrastructural factors to offer a more localized, high-resolution risk assessment, making it particularly useful for site-specific management and mitigation strategies. The study highlights key differences in spatial scope, data requirements and applicability, demonstrating that CVI is optimal for regional-scale vulnerability mapping, while CERA provides detailed risk classification essential for immediate intervention. The findings suggest that integrating both methodologies could enhance coastal risk assessments by combining CVI's large-scale vulnerability insights with CERA's detailed, site-specific risk evaluations. This hybrid approach would support more informed decision-making and adaptive strategies to mitigate coastal erosion impacts effectively.

1. Introduction

The coastal zone refers to the transitional area that serves as a connection between land and marine habitats. The coastal zone encompasses areas that are within a designated boundary of 1 kilometre from the shoreline at high tide, as well as additional areas that extend up to a depth of 200 metres seaward [7]. Coastal erosion refers to the gradual degradation of land, beaches and cliffs situated along coasts, mostly attributable to the effects of natural phenomena such as waves, tides, currents and wind. This natural process has the potential to be worsened by anthropogenic actions [11].

* *Corresponding author*
E-mail address: suhailasa@uthm.edu.my

https://doi.org/10.37934/ard.132.1.91102

The geographical boundary between land and sea, marked by the shoreline or coastline, is in a constant state of flux due to dynamic environmental changes. Numerous development projects in coastal areas have placed significant pressure on coastlines, leading to various hazards, including soil erosion, seawater intrusion, coral bleaching and shoreline change [5,6,21]. In regions such as Batu Pahat, soil stability varies across different shoreline zones, with certain areas exhibiting weak shear strength, making them more susceptible to erosion and land loss [10]. Addressing coastal erosion is a global issue that affects nearly every country in the world with a coastline.

Thus, risk assessment provides a comprehensive understanding of the hazards and vulnerabilities associated with coastal erosion, allowing for informed decision-making and the development of effective management strategies [23]. By evaluating factors such as coastal evolution, socioeconomic variables, ecological factors and cultural assets, risk assessment provides a basis for identifying high-risk areas and implementing appropriate measures to mitigate erosion impacts. In areas with soft marine clay soils, such as parts of Batu Pahat, weak soil conditions further increase erosion vulnerability, highlighting the need for targeted conservation efforts [10]. Risk assessment serves as a crucial tool for spatial planning, land use management and resource allocation for coastal protection [3].

There are various distinct methods and approaches available to assess the risks associated with coastal erosion [23]. However, this study has been designed to focus exclusively on comparing two distinct methodologies: the Coastal Vulnerability Index and the Coastal Erosion Risk Assessment. These methodologies enable decision-makers to effectively manage and allocate funds for coastal protection with prioritized orders based on identified risks and vulnerabilities. Overall, these methods provide important tools for understanding and addressing coastal erosion risks [9].

2. GIS Application

Geographic Information Systems (GIS) are powerful instruments that integrate geography, technology and data to facilitate the visualization, analysis and comprehension of the world within a geographical framework. Fundamentally, GIS is purposefully developed to collect, retain, alter, analyse and display data that are geographically or location oriented. This framework offers a means for investigating and analysing the relationships, structures and dynamics present in the natural world [24].

One of the most effective methods for assessing coastal vulnerability and risks is through the application of Geographic Information System technology. A GIS-based approach allows for the integration of various data sets and spatial analysis techniques, making it easier to identify vulnerable areas and understand the factors contributing to coastal erosion [27]. Additionally, GIS enables the analysis and visualization of complex spatial data, allowing for a more comprehensive understanding of coastal vulnerability.

By incorporating data on tidal and wave heights, shoreline characteristics, land use, infrastructure and socioeconomic factors, the GIS model can generate a coastal vulnerability and risks map that quantifies the vulnerability of different coastal areas. This index is based on the combined analysis of physical and human-induced vulnerability factors, providing a comprehensive assessment of coastal vulnerability to erosion [9].

3. Methodology overview

3.1 Coastal Vulnerability Index (CVI)

Developed by various researchers, the CVI considers key physical parameters such as coastal geomorphology, rate of sea-level rise, past shoreline evolution, coastal slope, mean tidal range and mean wave height. The CVI assigns relative rankings to different coastal areas based on their vulnerability, allowing for targeted interventions and resource allocation [1,4]. The CVI evaluates both physical and social indicators to assess coastal vulnerability, providing a more comprehensive understanding of the risks associated with erosion and flooding [22].

It is one of the predictive approaches to coastal classification by incorporating various coastal variables. This approach is favoured in the coastal investigation as it simplifies a number of complex parameters [10,16]. By incorporating variables such as geomorphology, shoreline change rate and sea level rise, the CVI considers both natural processes and human activities that can impact the coastline. This allows for a more holistic understanding of the vulnerability of the coastline and helps in identifying areas that require priority attention for mitigation and management measures [19].

3.1.1 Index ranking and calculation

Coastal classification from indices approach generally is based upon on the relative contributions of three groups which are socioeconomic, coastal characteristics and coastal forcing variables as described in Figure 1 [10]. These multidisciplinary variables, represented by diverse type of data literally complex in assembling for coastal vulnerability assessment. This index-based method simplifies a number of complex and interacting parameters is widely used to measure vulnerability of the coast globally [10,15].

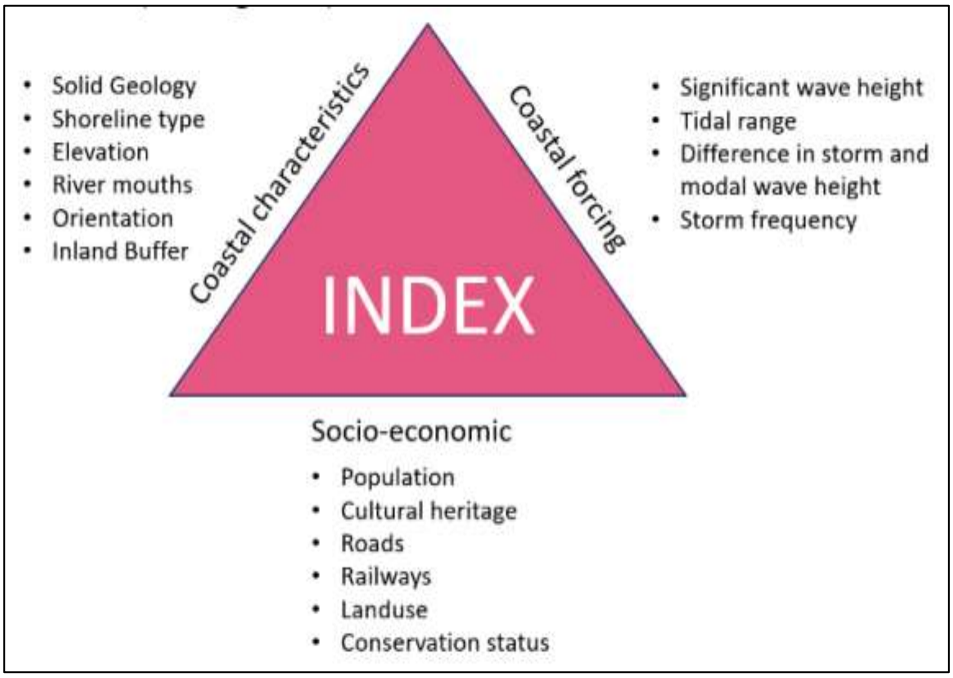

Fig. 1. Variable classification for indices [10]

Each variable is assigned to a rank to indicate its contribution to vulnerability. In other words, a value of 1 represents the lowest risk and 5 represents the highest risk. The database includes both quantitative and qualitative information. Thus, numerical variables are assigned a risk ranking based on data value ranges, while the non-numerical geomorphology variable is ranked according to the relative resistance of a given landform to erosion as shown in Table 1 [10,20].

Table 1
Ranges for vulnerability ranking of variables [10]

Variables	Very low 1	Low 2	Moderate 3	High 4	Very high 5
Geomorphology	Rocky, coasts	Composite of sand and rocks	Sand	Composite of clay and rock or sand	Mud flats
Maximum current speed (m/s)	0 – 0.2	0.2 > 0.4	0.4 – 0.6	0.6 – 0.8	0.8 – 1
Shoreline sea-level change (mm/yr)	< 1.8	1.8 – 2.5	2.5 – 3.0	3.0 – 3.4	> 3.4
Shoreline erosion rate (m/yr)	> +8	+3 to +7	-1 to +3	-5 to -1	< -5
Mean tide range (m)	> 3.5	3 – 3.5	2.5 – 3	2 – 2.5	0
Significant wave height (m)	< 0.5	0.7 – 1.4	1.4 – 2.1	2.1 – 2.8	> 5

The index allows the six (6) physical variables to be related in a quantifiable manner. Once each section of coastline is assigned a risk value based on each specific data variable, the coastal vulnerability index is calculated as the square root of the geometric mean or the square root of the product of the ranked variables divided by the total number of variables as described in Eq. (1),

$$\mathrm{CVI} = \sqrt{\left(\frac{\mathrm{a}\times\mathrm{b}\times\mathrm{c}\times\mathrm{d}\times\mathrm{e}\times\mathrm{f}}{6}\right)} \tag{1}$$

where, a = geomorphology, b = coastal slope, c = relative sea level rise rate, d = shoreline erosion/accretion rate, e = mean tide range and f = mean wave height.

3.2 Coastal Erosion Risk Assessment (CERA)

Globally, the CERA method has also been widely adopted in various coastal regions. It has proven instrumental in identifying vulnerable areas, quantifying erosion rates and evaluating the effectiveness of erosion control measures. By integrating scientific data, socio-economic factors and environmental considerations, CERA offers a holistic approach to coastal erosion management [18].

The approach known as the CERA aims to evaluate the potential risk of coastal erosion. The evaluation is conducted by assessing vulnerability and potential consequences, use a system of rankings ranging from 1 to 5. By integrating these two evaluations, the erosion risk of the coast area may be determined [8].

3.2.1 Index ranking and framework

For the goal of evaluating the risk of coastal erosion, a comprehensive understanding of the risk concept and its assessment is vital [9]. Risk is best understood as the anticipated effects of an event, according to its basic definition. In contrast, the event is referred to as a hazard in coastal risk assessment, which is defined by UNISDR [25], as a dangerous phenomenon that may result in a loss of life, injury or other health effects, property damage, the loss of livelihoods and services, social and economic disruption or environmental damage. The likelihood, seriousness and repercussions of the risk, as well as the event's result, all go into the risk assessment [9,18].

The risk evaluation is split into two sections by the CERA method. First, a vulnerability assessment evaluates the coastline zone's qualitative susceptibility to erosion. The geophysical properties of the coastal zone and the potential for erosive agents are the main concerns of this assessment. The second section evaluates the consequences of the hazardous event while considering the social, environmental, cultural and economic factors of the surrounding area [19]. Figure 2 describes the framework for the coastal erosion risk assessment that combines all modules into one that allows the execution of all processes in a single run.

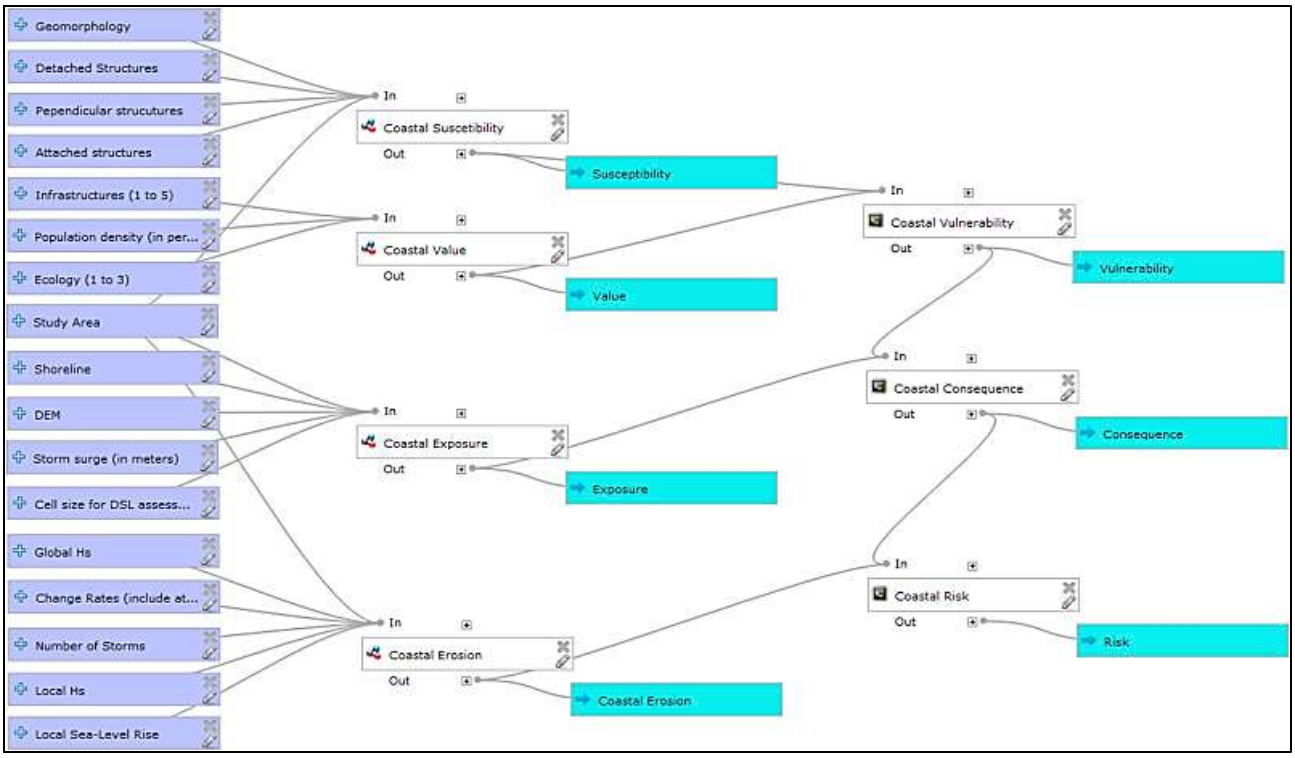

Fig. 2. Framework for the coastal erosion risk assessment, CERA [19]

The process follows the Source-Pathway-Receptor-Consequence (SPRC) conceptual model and evaluates risk propagation through four modules: susceptibility, value, exposure and hazard. Twelve indicators are considered, including geomorphology, coastal defences, population density, infrastructures and wave climate [19]. The methodology is designed to be easily applicable without the need for highly detailed data, making it suitable for entities with limited resources and time constraints [18]. Table 2 describes the detail of each module, including the description of the considered indicators, how the recommended criteria were developed and the suggested approach and index to perform the assessment.

Table 2
Classification criteria of coastal erosion risk assessment, CERA [19]

Parameter	Very low 1	Low 2	Moderate 3	High 4	Very high 5
Geomorphology	Rock coast	Cliffed coast	Salt marsh	Pebble beach	Exposed beach
Coastal defences	Perpendicular coastal defence, Longitudinal detached coastal defence	Longitudinal attached coastal defence	-	-	-
Ecology	Moderate ecologic relevance	High ecologic relevance	-	-	-
Infrastructure	No structures	Rural agglomeration, municipal roads	Urban agglomeration	City centres, heritage landmarks, main highways	Critical infrastructures
Population density (hab/km^2)	[0; 500]	[500; 1000]	[1000; 2000]	[2000; 4000]	[4000; +∞]
Significant wave height (m)	[0; 0.4]	[0.4; 0.8]	[0.8; 1.6]	[1.6; 2.0]	[2; +∞]
No. of storms per year	0	[1; 5]	[6; 10]	[11; 15]	[16; +∞]
Shoreline change rates (m/yr)	[+0.5; +∞]	[-0.5; +0.5]	[-1.5; -0.5]	[-2.5; -1.5]	[-∞; -2.5]
Sea level-trend (mm/yr)	[-∞; 0.0]	[0.0; 1.8]	[1.8; 3.2]	[3.2; 4.8]	[4.8; +∞]
Distance to shoreline (m)	[350; +∞]	[225; 350]	[125; 225]	[50; 125]	[0; 50]
Topography + storm surge (m)	[30+Ss; +∞]	[20+Ss; 30+Ss]	[10+Ss; 20+Ss]	[5+Ss; 10+Ss]	[-∞; 5+Ss]

4. Case studies

4.1 Case Studies on Coastal Vulnerability Index (CVI) Method

The CVI has emerged as a widely used tool to assess and classify coastal regions based on their susceptibility to erosion, flooding and other coastal hazards. By integrating multiple physical and environmental parameters, CVI enables policymakers, researchers and coastal managers to identify high-risk zones and implement appropriate mitigation measures. This section explores global and regional applications of CVI, with a focus on Malaysia, particularly Peninsular Malaysia and Johor, where coastal vulnerability assessments have been instrumental in guiding coastal management strategies.

4.1.1 Global application of the CVI

The CVI has been widely applied in various coastal regions worldwide to assess the susceptibility of shorelines to erosion, sea level rise and other coastal hazards. For instance, a study conducted along the Limassol coastline in Cyprus utilized CVI to evaluate coastal risk based on factors such as land cover, coastal slope, shoreline erosion rates, tidal range, wave height and sea level rise. The findings highlighted the Kouris River estuary as a highly vulnerable area, emphasizing the need for targeted coastal management strategies [12]. Similar studies have been conducted in Europe and India, where the CVI methodology has helped identify high-risk zones and guide mitigation strategies.

4.1.2 CVI in Malaysia

Malaysia, with its extensive coastline, is highly susceptible to coastal hazards, making CVI a crucial tool in coastal risk assessment. Various studies have applied CVI to analyse vulnerability levels across different regions, particularly focusing on the impacts of climate change, sea level rise and anthropogenic activities. These studies highlight the significant variations in coastal vulnerability across the country and provide recommendations for coastal management [13,14,17].

A study conducted along the Terengganu coastline applied CVI to assess the impact of coastal erosion at multiple sites, including Pantai Rusila, Pantai Chendering, Pantai Batu Buruk, Pantai Seberang Takir and Pantai Menggabang Telipot. The study utilized the National Coastal Erosion Study (NCES) as a guideline, incorporating shoreline changes observed from 2013 to 2021. Results indicated significant erosion in several locations, leading to severe socioeconomic and environmental consequences. The analysis showed that erosion in these areas was primarily driven by seasonal monsoonal waves, with the northeast monsoon contributing significantly to shoreline retreat. The study also highlighted the need for adaptive management approaches, including both structural (e.g., seawalls, groynes) and non-structural (e.g., mangrove restoration, zoning regulations) measures [13,15].

Research on Selangor's coastline employed a geospatial approach to assess coastal vulnerability using six key variables: geomorphology, coastal slope, erosion/accretion rates, wave height, tidal range and sea level rise. The study found that the Pantai Jeram and Bagan Sungai Janggut areas exhibited the highest vulnerability levels, necessitating immediate intervention measures to mitigate further coastal degradation. The study also pointed out that human activities, such as land reclamation and unregulated coastal development, have exacerbated erosion in these areas. Findings emphasized that future coastal management strategies must integrate environmental impact assessments to prevent further degradation [17].

A study focusing on the East Coast of Peninsular Malaysia, covering areas from Kelantan to Johor, assessed coastal vulnerability by integrating physical and socioeconomic indices. Key factors considered included shoreline change rate, wave height, tidal range and sea level rise. The findings identified Kuantan as the most vulnerable area, with Kota Tinggi in Johor also displaying high susceptibility due to its direct exposure to monsoonal waves from the South China Sea. The study also noted that coastal communities in these areas were at higher risk due to limited adaptive capacity and inadequate infrastructure to withstand coastal hazards. The research recommended that coastal zone planning policies should prioritize nature-based solutions such as beach nourishment and mangrove rehabilitation alongside engineered protective structures [14].

4.1.3 Limitations of CVI studies

Despite its effectiveness, the CVI method has certain limitations. One of the key challenges is the variability in parameter selection, as different studies employ different factors and weightage, making cross-comparisons difficult. Additionally, CVI primarily focuses on physical vulnerability and may not fully incorporate socioeconomic or ecological aspects, which are essential in understanding the full scope of coastal risks. Another limitation is the reliance on historical shoreline data, which may not fully capture dynamic changes caused by extreme weather events and climate change. Moreover, the accuracy of CVI assessments depends on data availability and resolution, which can impact the reliability of vulnerability classifications. Some studies have suggested integrating CVI with other assessment tools, such as remote sensing and machine learning models, to enhance predictive accuracy [12,17].

4.2 Case Studies on Coastal Erosion Risk Assessment (CERA) Method

The CERA method has been applied globally to assess coastal vulnerability and risk. Despite its widespread use in regions such as Portugal, Mozambique, China and Mexico, Malaysia has seen limited adoption of this method. To date, only one study has utilized CERA in Malaysia, specifically in Batu Pahat, Johor. This section highlights global applications of the CERA framework, followed by its application in Malaysia.

4.2.1 Global applications of CERA

Pedro Narra *et al.,* [18] developed and applied the CERA tool to assess coastal erosion risk in various regions, including Aveiro, Portugal, Macaneta, Mozambique and Hainan Island, China. These studies classified coastal risks into five categories based on vulnerability and consequence assessments. Findings showed that high-risk areas were characterized by shoreline exposure, wave activity and geomorphological characteristics. Socioeconomic factors, such as urban development and critical infrastructure, further influenced the overall risk levels.

In Aveiro, Portugal, CERA identified high-risk zones due to extensive urbanization along the coast. Macaneta, Mozambique, exhibited similar vulnerabilities but had a lower consequence classification due to lower socioeconomic exposure. The study also highlighted the strengths of CERA as a tool that requires minimal data input compared to other models, making it accessible for different regions. However, the accuracy of assessments depended on the availability of geospatial data, which varied between locations.

In Hainan Island, China, Su *et al.,* [26] applied CERA alongside Monte Carlo simulations to validate the method, finding that the eastern coastline, particularly Wulong Port, Yalin Bay and Yalong Bay, faced very high erosion risks. The study identified shoreline change rates, population density and storm events as key contributing factors. One of the primary limitations was the exclusion of long-term sea level rise effects and sediment grain size in the model. The research suggested integrating additional parameters, such as sediment transport and climate change projections, to enhance the predictive accuracy of CERA for long-term coastal management.

4.2.2 CERA in Malaysia: Batu Pahat, Johor

The only documented use of CERA in Malaysia was in Batu Pahat, Johor. This study assessed vulnerability in Pantai Perpat, Pantai Punggur and Pantai Parit Hailam using five parameters: geomorphology, coastal defences, population density, infrastructure and ecology. The results indicated that Pantai Perpat had the highest vulnerability due to weak natural defences, high wave energy exposure and proximity to critical infrastructure, making it the most at-risk location. Meanwhile, Pantai Punggur and Pantai Parit Hailam exhibited moderate risks, primarily influenced by localized geomorphological conditions and existing coastal defence measures.

The study emphasized the importance of integrating both natural and artificial coastal defences to mitigate erosion risks. It also underscored the role of Geographic Information Systems (GIS) in improving coastal risk assessments by providing spatial analysis and visualization of high-risk areas. However, one limitation noted was the lack of high-resolution geospatial data, which affected classification accuracy. The study recommended further refinement of the CERA model, incorporating additional factors such as tidal influence, sediment transport dynamics and more granular socio-economic data for a better understanding of regional erosion patterns [2].

4.2.3 Limitations of CERA

These case studies demonstrate that CERA is a valuable tool for coastal erosion risk assessment across diverse geographic locations. It has been successfully used in regions with varying coastal characteristics, from high-energy wave environments in Portugal to sediment-rich shorelines in China and Malaysia. However, several limitations exist, including data availability, reliance on general classification frameworks that may not fully capture site-specific characteristics and the exclusion of long-term climate change impacts in some assessments.

Another critical observation is the adaptability of CERA. While its simplified methodology allows for easier application compared to more complex coastal risk models, its effectiveness is heavily dependent on the quality and comprehensiveness of input data. In cases where detailed geospatial and environmental data are available, CERA produces more refined and accurate assessments. However, in regions where data gaps exist, results may be skewed, necessitating supplementary methodologies or expert validation.

5. Comparative Analysis

This section provides an in-depth comparison of the CVI and CERA methodologies in assessing coastal hazards. While both methods aim to quantify coastal risk and vulnerability, their focus, spatial coverage, data requirements and applications differ significantly. This comparative analysis highlights their strengths, limitations and potential for integration in coastal management strategies.

5.1 Commonalities

5.1.1 Indicators

Both CVI and CERA incorporate fundamental coastal indicators, including shoreline erosion rates, which measure the extent of land loss over time, wave height and tidal range, which assess the hydrodynamic forces impacting the coast and sea-level rise trends, which identify long-term vulnerabilities. Additionally, geomorphology is considered to evaluate the coastal composition and its resistance to erosion. These indicators enable both methodologies to assess coastal susceptibility effectively and contribute to the development of informed risk mitigation strategies.

5.1.2 Vulnerability assessment

Both methodologies aim to classify coastal zones based on vulnerability levels. By analysing environmental factors, each method assigns relative rankings to different coastal sections, allowing for prioritization in coastal protection and management efforts.

5.1.3 Data requirements

Both CVI and CERA utilise GIS for data processing, visualization and spatial analysis. GIS tools enable researchers to integrate multiple datasets, enhancing the accuracy of vulnerability assessments and risk predictions.

5.2 Key Differences

Although CVI and CERA share similarities, they differ in methodology, spatial scope and application has been describe in Table 3.

Table 3
Key differences of CVI and CERA method

Feature	Coastal Vulnerability Index (CVI)	Coastal Erosion Risk Assessment (CERA)
Primary focus	Broad vulnerability assessment due to sea-level rise and coastal changes	Erosion-specific risk assessment incorporating socio-economic impacts
Spatial scope	Limited to the shoreline	Extends inland up to 2 km, including built infrastructure
Data complexity	Uses six key environmental indicators	Uses nine or more indicators, including socio-economic and infrastructure-related parameters
Output detail	Generalised ranking of vulnerability along the coast	High-resolution risk mapping with localized impact analysis
Applicability	Suitable for large-scale national and regional studies	Best applied to regional and local coastal management efforts

5.2.1 Area representation

CVI primarily focuses on coastal zones directly exposed to oceanic influences, making it an effective tool for large-scale vulnerability mapping. In contrast, CERA provides a more comprehensive spatial representation, incorporating inland factors such as infrastructure, population density and land use changes. This difference makes CERA more effective in evaluating localized risks beyond the immediate shoreline.

5.2.2 Focus and objectives

CVI is designed to evaluate overall coastal vulnerability, with an emphasis on physical and environmental factors contributing to susceptibility. It provides a broad assessment useful for long-term planning and policy development. Meanwhile, CERA is specifically tailored to assess erosion risk, integrating both environmental and socio-economic considerations. Its results offer detailed insights into short-term and site-specific risk management strategies.

5.2.3 Scale and applicability

CVI is suitable for first-order national to regional-scale assessments, making it suitable for large areas. It can provide a relative assessment and easily identify hotspots along coastlines. CERA, on the other hand, is more appropriate for coastal stretches at a regional scale (50-70 km) where high-resolution data is available and coastal management can be supported at a municipal scale.

5.2.4 Data requirements and processing

CERA requires a larger dataset due to its inclusion of socio-economic and infrastructural variables. This makes it more complex but also more precise in identifying high-risk areas. CVI, by contrast, is less data-intensive, making it easier to implement in data-limited regions while still providing valuable insights.

5.3 Integration and Future Considerations

While CVI and CERA serve different purposes, integrating both methodologies could enhance coastal risk assessment and management. By combining the large-scale vulnerability mapping capabilities of CVI with the high-resolution, impact-focused approach of CERA, decision-makers can develop more effective coastal protection strategies. Future research should explore hybrid models that merge these methodologies to provide a holistic understanding of coastal erosion risks.

6. Conclusion

The comparative analysis of CVI and CERA highlights their distinct roles in coastal risk assessment. CVI excels in broad-scale assessments, identifying overall vulnerability patterns, whereas CERA provides a more detailed and location-specific risk analysis. The choice of methodology should be guided by the assessment objectives, available data and the desired level of detail. Given the dynamic nature of coastal environments, a combined approach leveraging the strengths of both CVI and CERA can lead to more informed decision-making, improved mitigation efforts and enhanced coastal resilience.

Acknowledgement
This research was supported by Universiti Tun Hussein Onn Malaysia (UTHM) through Tier 1 (vot Q483).

References
[1] Akshaya, B. J. and Arkal Vittal Hegde. "Assessment of coastal vulnerability to combined effects of socio-economical factors and Erosion on Karnataka coast with the aid of integrated remote sensing and GIS techniques." *International Journal of Earth Sciences and Engineering* 10, no. 02 (2017): 313-320. https://doi.org/10.21276/ijee.2017.10.0224

[2] Azlan, Azreen Shafiqa Nabilla, Mokhtar, Mardiha, Daud, Mohd Effendi, Kaamin, Masiri, Sahat, Suhaila and Mohd Bukari, Saifullizan. "Coastal Erosion Vulnerabilities in Batu Pahat, Johor: An Analysis Using the CERA Method." *Journal of Tourism, Hospitality and Environment Management* 9 (38), (2024): 227–241. https://doi.org/10.35631/JTHEM.938016

[3] Barilla, Giuseppina Chiara, Giuseppe Barbaro, Giandomenico Foti, P. I. E. R. L. U. I. G. I. Mancuso, Vincenzo Fiamma, A. G. N. I. E. S. Z. K. A. Malesinska, Pierfabrizio Puntorieri and Maria Mandalari. "Coastal erosion hazard and vulnerability: Case study of Porticello, South Calabria, Italy." In *Proceedings of 11th International Conference on Sustainable Water Resources Management: Effective Approaches for River Basins and Urban Catchments, WRM*, pp. 181-193. 2021. https://doi.org/10.2495/WRM210161

[4] Bertoni, Duccio, Serena Giacomelli, Lorenzo Ciulli and Giovanni Sarti. "Litho-sedimentological and morphodynamic characterization of the Pisa Province coastal area (northern Tuscany, Italy)." *Journal of Maps* 16, no. 2 (2020): 108-116. https://doi.org/10.1080/17445647.2019.1700836

[5] Boumboulis, Vasileios, Dionysios Apostolopoulos, Nikolaos Depountis and Konstantinos Nikolakopoulos. "The importance of geotechnical evaluation and shoreline evolution in coastal vulnerability index calculations." *Journal of Marine Science and Engineering* 9, no. 4 (2021): 423. https://doi.org/10.3390/jmse9040423

[6] Bushra, Nazla, Rubayet Bin Mostafiz, Robert V. Rohli, Carol J. Friedland and Md Adilur Rahim. "Technical and social approaches to study shoreline change of Kuakata, Bangladesh." *Frontiers in marine science* 8 (2021): 730984. https://doi.org/10.3389/fmars.2021.730984

[7] Cabrera, Jonathan Salar and Han Soo Lee. "Coastal zone environment Integrity assessment for sustainable management: Part 1. Development of Adaptive Expert-Driven coastal zone Health index framework." *Journal of Marine Science and Engineering* 10, no. 9 (2022): 1183. https://doi.org/10.3390/jmse10091183

[8] Ferreira, A. M., C. Coelho and P. Narra. "Coastal erosion risk assessment to discuss mitigation strategies: Barra-Vagueira, Portugal." *Natural Hazards* 105, no. 1 (2021): 1069-1107. https://doi.org/10.1007/s11069-020-04349-2

[9] Ghiffari, Rizki Adriadi and Haryo Dwito Armono. "Coastal erosion risk assessment in the coastal area of Muara Asam Asam, Tanah Laut Regency." In *E3S Web of Conferences*, vol. 325, p. 01023. EDP Sciences, 2021. https://doi.org/10.1051/e3sconf/202132501023

[10] Hamid, Nor Baizura, Mardiha Mokhtar, Mohd Effendi Daud, Aslila Abd Kadir, Masiri Kaamin, Mohamad Azim Mohammad Azmi, Suhaila Sahat, Syamsul Azrin Kamaruddin, Muhamad Syamil Sabri and Azreen Shafiqa Nabilla Azlan. "Undrained Shear Strength from Field Vane Shear Test (VST) of Soil at Shoreline Area." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 33, no. 2 (2024): 76-84. https://doi.org/10.37934/araset.33.2.7684

[11] Oral, Hasan Volkan and Seyithan Alagöz. "Designing appropriate site determination criteria for installing constructed wetland treatment system based on multi-criteria decision-making analyses." *Environmental Monitoring and Assessment* 195, no. 6 (2023): 639. https://doi.org/10.1007/s10661-023-11240-7

[12] Hammar-Klose, Erika S. and E. Robert Thieler. *Coastal vulnerability to sea-level rise: a preliminary database for the US Atlantic, Pacific and Gulf of Mexico coasts*. No. 68. US Geological Survey,, 2001. https://doi.org/10.3133/ds68

[13] Rahim, Haris Abdul, Fatin Irdina Isa, Nor Aizam Adnan and Fazly Amri Mohd. "The Coastal Vulnerability Index and Impact of Erosion Along Terengganu Coastline." *Journal of Advanced Geospatial Science & Technology* 3, no. 2 (2023): 1-24. https://doi.org/10.11113/jagst.v3n2.67

[14] Ismail, I., M. L. Husain, W. S. W. Abdullah and R. Zakaria. "Modelling of Coastal Vulnerability Index Along the East Coast of Peninsular Malaysia due to Sea Level Rise Impact." In *IOP Conference Series: Earth and Environmental Science*, vol. 1103, no. 1, p. 012011. IOP Publishing, 2022. https://doi.org/10.1088/1755-1315/1103/1/012011

[15] Mclaughlin, Suzanne and J. Andrew G. Cooper. "A multi-scale coastal vulnerability index: A tool for coastal managers?." *Environmental Hazards* 9, no. 3 (2010): 233-248. https://doi.org/10.3763/ehaz.2010.0052

[16] Mohamad, Mohd Fauzi, Lee Hin Lee and Mohd Kamarul Huda Samion. "Coastal vulnerability assessment towards sustainable management of Peninsular Malaysia coastline." *International Journal of Environmental Science and Development* 5, no. 6 (2014): 533-538. https://doi.org/10.7763/IJESD.2014.V5.540

[17] Mohd, F. A., A. A. A. Rahman, KN Abdul Maulud, M. K. Kamarudin, N. A. Majid and A. Rosli. "geospatial approach for coastal vulnerability assessment of Selangor Coast, Malaysia." In *IOP conference series: earth and environmental science*, vol. 767, no. 1, p. 012025. IOP Publishing, 2021. https://doi.org/10.1088/1755-1315/767/1/012025

[18] Narra, Pedro, Carlos Coelho, Francisco Sancho and Jaime Palalane. "CERA: An open-source tool for coastal erosion risk assessment." *Ocean & Coastal Management* 142 (2017): 1-14. https://doi.org/10.1016/j.ocecoaman.2017.03.013

[19] Narra, Pedro, Carlos Coelho and Francisco Sancho. "Multicriteria GIS-based estimation of coastal erosion risk: Implementation to Aveiro sandy coast, Portugal." *Ocean & Coastal Management* 178 (2019): 104845. https://doi.org/10.1016/j.ocecoaman.2019.104845

[20] Pendleton, Elizabeth A., J. A. Barras, S. J. Williams and D. C. Twichell. *Coastal vulnerability assessment of the Northern Gulf of Mexico to sea-level rise and coastal change*. No. 2010-1146. US Geological Survey, 2010. https://doi.org/10.3133/ofr20101146

[21] Prasad, Durusoju Hari and Nandyala Darga Kumar. "Coastal erosion studies—a review." *International Journal of Geosciences* 2014 (2014).

[22] Putra, I. Wayan Krisna Eka, I. Wayan Gede Astawa Karang, Abd Rahman As-Syakur and I. Wayan Arthana. "Socio-Physical Assessment of Coastal Vulnerability Index in a Tourism Island Bali Using Multisatellite Data." (2023). https://doi.org/10.4108/eai.28-10-2022.2326360

[23] Rangel-Buitrago, Nelson, William J. Neal and Victor N. de Jonge. "Risk assessment as tool for coastal erosion management." *Ocean & Coastal Management* 186 (2020): 105099. https://doi.org/10.1016/j.ocecoaman.2020.105099

[24] Selamat, Siti Norsakinah, KN Abdul Maulud, O. Jaafar and H. Ahmad. "Extraction of shoreline changes in Selangor coastal area using GIS and remote sensing techniques." In *Journal of Physics: Conference Series*, vol. 852, no. 1, p. 012031. IOP Publishing, 2017. https://doi.org/10.1088/1742-6596/852/1/012031

[25] United Nations (UN). "International Strategy for Disaster Reduction Secretariat." *UNISDR Terminology on Disaster Risk Reduction*. United Nations, New York, USA. (2009).

[26] Su, Qianxin, Zhiqiang Li, Gaocong Li, Daoheng Zhu, and Pengpeng Hu. "Coastal erosion risk assessment of Hainan Island, China." *Acta Oceanologica Sinica* 42, no. 7 (2023): 79-90. https://doi.org/10.1007/s13131-022-2122-1

[27] Paiman, Tuminah, and M. Zainora Asmawi. "Gis application in coastal management: The perspectives of government agencies in Selangor." *Planning Malaysia* 15 (2017). https://doi.org/10.21837/pmjournal.v15.i3.306