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COASTAL EROSION VULNERABILITIES IN BATU PAHAT, JOHOR: AN ANALYSIS USING THE CERA METHOD

Azreen Shafiqa Nabilla Azlan[1], Mardiha Mokhtar[2*], Mohd Effendi Daud[3], Masiri Kaamin[4], Suhaila Sahat[5], Saifullizan Mohd Bukari[6]

[1] Department of Civil Engineering, Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, 86400, Batu Pahat, Johor, Malaysia
Email: azreenshafiqa@gmail.com
[2] Department of Civil Engineering, Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia, 84600 Pagoh, Johor, Malaysia
Email: mardiha@uthm.edu.my
[3] Department of Civil Engineering, Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, 86400, Batu Pahat, Johor, Malaysia
Email: effendi@uthm.edu.my
[4] Department of Civil Engineering, Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia, 84600 Pagoh, Johor, Malaysia
Email: masiri@uthm.edu.my
[5] Department of Civil Engineering, Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia, 84600 Pagoh, Johor, Malaysia
Email: suhailasa@uthm.edu.my
[6] Department of Civil Engineering, Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, 86400, Batu Pahat, Johor, Malaysia
Email: saifulz@uthm.edu.my
[*] Corresponding Author

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Abstract:

The coastal zones of Batu Pahat, Malaysia, are highly vulnerable to erosion due to their exposed sand-mud geomorphology, intensified by human activities and climate change. The aim of this research is to assess vulnerability of coastal erosion in Pantai Perpat, Pantai Punggur, and Pantai Parit Hailam using the Coastal Erosion Risk Assessment (CERA) tool. This study evaluates five key parameters: geomorphology, coastal defences, population density, infrastructure, and ecology to understand the area susceptibility and overall

[*] *Corresponding author.*
E-mail address: *mardiha@uthm.edu.my*

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vulnerability. The CERA framework was applied to quantify erosion risks through a vulnerability assessment, using data from satellite imagery, statistical reports, and literature. A Monte Carlo sensitivity analysis was performed to evaluate model accuracy, with the Root Mean Square Error (RMSE) calculated to validate the assessment. Results indicate that Pantai Perpat is the most vulnerable site, mainly due to its weak natural defences and nearest distance to infrastructure, while Pantai Punggur and Pantai Parit Hailam exhibit moderate risks. Geomorphology and coastal defences were identified as the most influential factors in determining vulnerability, highlighting the need for improved coastal protection measures. In conclusion, the research underscores the importance of strengthening both natural and artificial defences to mitigate erosion risks. Further studies are recommended to refine the CERA model, aiming for greater precision in coastal management strategies to protect vulnerable regions from future erosion.

Keywords:

Coastal Erosion, Coastal Erosion Risk Assessment (CERA), Geographic Information Systems (GIS), Vulnerability Assessment, Batu Pahat

Introduction

The coastal zone is where land meets the ocean, creating a dynamic environment shaped by land, sea, and air interactions. This area supports ecosystems like coral reefs, mangroves, and seagrass beds, offering significant natural resources and economic benefits such as tourism, fishing, and transportation (Cabrera *et al.*, 2022; Moser *et al.*, 2014; Ahmad, 2019). However, rapid population growth and human activity, including habitat destruction and pollution, have placed coastal zones under pressure, particularly from coastal erosion (Bushra *et al.*, 2021). Natural processes such as waves, currents, and tides are the main drivers of erosion (Islam & Ryan, 2016), but human interventions like land reclamation and construction worsen the situation (Ahmad, 2019). Climate change and rising sea levels also intensify erosion by increasing storm surges and wave action (Nelson *et al.*, 2020). This can lead to habitat loss, biodiversity decline, and infrastructure damage, even displacing communities (Dong *et al.*, 2024).

To address these challenges, Geographic Information Systems (GIS) have become crucial for analysing and managing coastal changes. GIS enables visualization and analysis of data on shoreline changes, erosion rates, and environmental factors like tidal movements and wave patterns (Ranju, 2021). Its ability to monitor changes over time allows for informed decision-making in coastal management (Parthasarathy & Deka, 2019). Various methods exist to assess coastal erosion risks, including the Coastal Vulnerability Index (CVI), RISC-KIT Coastal Hazard Assessment Module (CHAM), Smartline, and Coastal Erosion Risk Assessment (CERA) (Narra *et al.*, 2019; Bukvic *et al.*, 2020; Anfuso *et al.*, 2021; Su *et al.*, 2021). These tools help identify vulnerable areas, but many are site-specific and not easily adapted to different environments (Torresan *et al.*, 2008; Hinkel & Klein, 2017). The CERA method, widely used in sandy coastal regions, integrates scientific, socio-economic, and environmental data to manage coastal erosion (Narra *et al.*, 2017; Ferreira *et al.*, 2020). It has been applied in regions like Portugal, Mexico, Mozambique, and China, but more research is needed to assess its effectiveness in non-sandy environments (Su *et al.*, 2023). In Malaysia, where coastal erosion is significant along its 8,000 km coastline, CERA can provide insights into erosion patterns, especially in vulnerable areas like Batu Pahat, Johor (Ahmad *et al.*, 2021).

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Batu Pahat, located along the Strait of Malacca, faces erosion due to soft soil, sandy beaches, and human activities like land reclamation (Rashidi *et al.*, 2021). The application of CERA in Batu Pahat helps predict future shoreline changes and prioritize mitigation efforts (Deepika *et al.*, 2013; Ghiffari & Armono, 2021). Incorporating socio-economic data, CERA also provides insights into how erosion impacts communities and infrastructure, supporting balanced environmental protection and economic development strategies (Colak, 2024). This study aims to assess coastal erosion vulnerabilities in Pantai Perpat, Pantai Parit Hailam, and Pantai Punggur in Batu Pahat using the CERA tool. The findings will inform coastal management strategies to enhance resilience and sustainability in the region, offering valuable resources for policymakers and planners.

Methodology

Study Area

This study was conducted at Pantai Perpat, Pantai Punggur and Pantai Parit Hailam (Figure 1). The total distance for this study area is 10 km of coastline with the inland distance to shoreline of 500 m and was divided into ten sections with 1 km for each section as described in Figure 2. The coastline starts at latitude of 1°40'14.56" N, longitude 103° 7'4.31" E, and ends at latitude 1°43'13.13" N, longitude 103° 2'34.63" E.

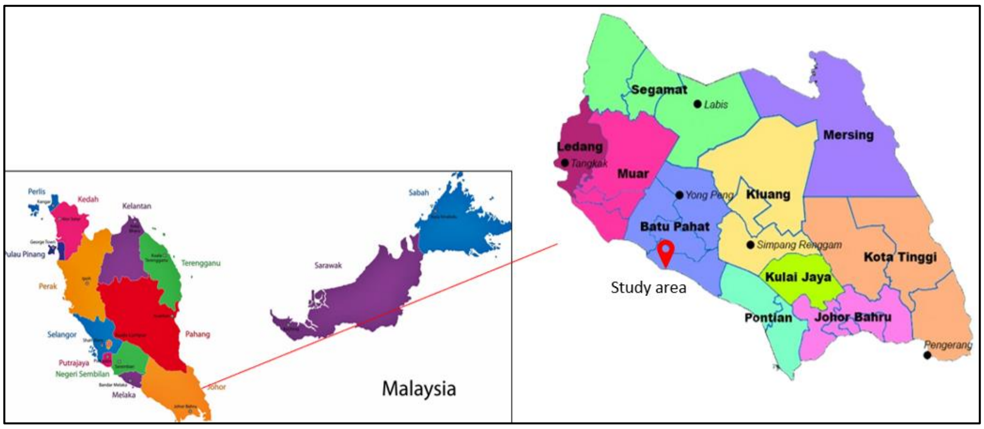

Figure 1: Study Area (Pantai Punggur, Pantai Perpat and Parit Hailam)
Source: Indos82, Dreamstime.com; Hey, Visitselangor.com

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Figure 2: Divided Sections of Study Area

Source: Google Earth Pro, 2022

Data Collection

The data used for the study was secondary data and was obtained from respected agencies, remote sensing, as well as from previous literature. This study focused on evaluating five parameters associated with coastal erosion, which are geomorphology, coastal defenses, population density, infrastructure and ecology. The parameters information and its data sources were described in Table 1.

Table 1: Parameters Information And Its Source

Module	Parameter	Source	Description	Time
Susceptibility	Geomorphology (Geo)	Previous literature (Maulud *et al.*, 2015; Muhammad & Rahmat, 2016; Mohtar *et al.*, 2017; Ehsan *et al.*, 2019; Razi *et al.*, 2022)	Pantai Punggur, Pantai Perpat, Pt Hailam	2023
	Coastal defence (Cd)	Google Earth	< 80m precision	2022
Value	Population density (Pop)	Department of Statistics Malaysia	Senggarang, Rengit	2022
	Infrastructure (Inf)	Open Street Map	< 80m precision	2022
	Ecology (Eco)	Google Earth	< 80m precision	2022

CERA Framework – Vulnerability Assessment

CERA is relatively straightforward, with the most complex step being the classification of individual indicators, which requires some GIS knowledge. The indicators are combined using the weighted average method published by Narra *et al.* (2017) via the raster calculator. To facilitate this process, a QGIS plugin was developed and is available on GitHub (Narra *et al.* 2017).

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Vulnerability assessment involves a systematic examination of factors contributing to the susceptibility and value of a particular area to potential hazards. This analysis typically comprises two main modules, which are, susceptibility and value (Figure 3). The susceptibility module assesses the inherent vulnerability of the area to hazards, incorporating parameters such as geomorphology and coastal defences. On the other hand, the value module considers the significance of assets at risk, including infrastructures, population density, and ecological resources. Table 2 describes the risk classes corresponding to the characteristics of each parameter.

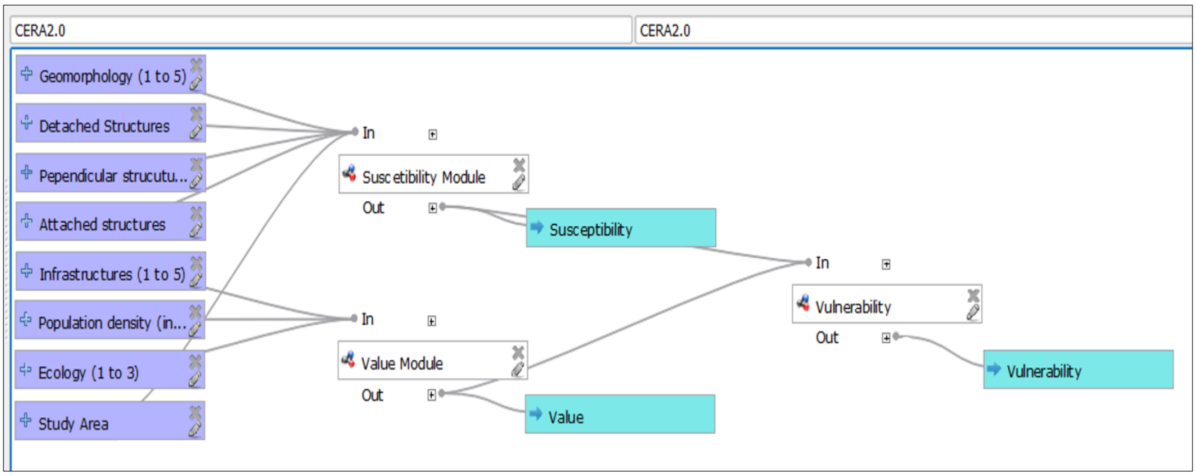

Figure 3: CERA Framework for Vulnerability Assessment

Table 2: Characteristics Class of Each Parameter

Parameter	**Characteristic class**				
	Very low 1	**Low 2**	**Moderate 3**	**High 4**	**Very high 5**
Geo	rock coast	consolidated sedimentary cliffed coast;	saltmarsh; coral reef;	pebble beach; dune presence	exposed beach; mudflat; deltas
Pop (pers/km^2)	[0, 500]	[500, 1000]	[1000, 2000]	[2000, 4000]	[4000, +∞]
Inf	no structures	rural agglomeration	urban agglomeration	city centres, main highways	critical infrastructures
Eco	moderate	high			

Evaluation of Each Module

The coastal erosion susceptibility assessment evaluates an area's vulnerability to erosion by focusing on two key indicators: geomorphology (Geo) and coastal defences (Cd). The final susceptibility score is calculated by summing the classifications of these two factors, with values ranging from 1 to 5, as described in Equation 2.

$$\text{Susceptibility module} = \begin{cases} 1, & \text{Geo} - \text{Cd} < 1 \\ \text{Geo} - \text{Cd}, & \text{Geo} - \text{Cd} \geq 1 \end{cases} \quad (1)$$

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The geomorphology of the study area was described as exposed sand mud coast [20, 27, 28], where the sediment textural were classified as slightly gravelly mud in Pantai Parit Hailam, whilst slightly gravelly sandy mud in Pantai Punggur and Pantai Perpat [26]. Additionally, the presence of mangroves, which thrive in muddy coastal environments due to fluctuating water levels and salinity [28], leads to a high susceptibility classification of 5 for the geomorphology

The data on coastal defenses were gathered through satellite imagery. Two types of coastal defense structures are recognized: Perpendicular defences (e.g., breakwaters, groynes) trap sediments and reduce wave impact, leading to a one-level reduction in susceptibility. Longitudinal defences (e.g., seawalls, revetments) stabilize shorelines and lower susceptibility by two levels, though they do not change the underlying geology.

For the value assessment, CERA considers population density, infrastructure, and ecology. Population and infrastructure data are combined using the Equation 2.

$$\text{Population} \cdot \text{Infrastructure (PopInf) index} = \begin{cases} 5, & \text{Inf} = 1 \\ \sqrt{\text{Pop} \times \text{Inf}} + 0.055, & \text{Inf} \neq 1 \end{cases} \tag{2}$$

In this area, population density data from the Department of Statistics Malaysia shows low density (below 1,000 people per square kilometre). Satellite imagery was also used to assess infrastructure, categorised into five levels based on importance. Ecological data, also obtained via satellite, captured features like vegetation and biodiversity. These indicators vary from moderate to high across different sections. The ecology score is added to population and infrastructure classifications to determine final susceptibility, capped at a maximum value of 5, as described in Equation 3.

$$\text{Value index} = \begin{cases} 5, & \text{int}(\text{PopInf} + \text{Eco}) > 1 \\ \text{int}(\text{PopInf} + \text{Eco}), & \text{int}(\text{PopInf} + \text{Eco}) \leq 1 \end{cases} \tag{3}$$

The susceptibility and value module results are merged to produce the vulnerability classification (Equation 4), assessing potential damages if erosion sources reach the study area.

$$\text{Vulnerability} = |\sqrt{\text{Susceptibility} \times \text{Value}} + 0.055| \tag{4}$$

Sensitivity Analysis – Monte Carlo

A sensitivity analysis using XLSTAT in Excel was conducted to evaluate the global applicability of CERA. A Monte Carlo simulation generated 10,000 random samples for each input. For the ecology indicator (0 to 2), values were limited to 0 or 1 if the combined population and infrastructure class exceeded 3, as the highest class is reserved for protected areas. Coastal defences were only considered if the geomorphology rating was 4 or 5, indicating the presence of beaches. Other indicators were treated independently.

Validation – RMSE Calculation

The Root Mean Square Error (RMSE) is a common statistical measure used to quantify the difference between predicted and observed values. In this study, RMSE was calculated to evaluate the accuracy of the coastal risk model by comparing its predictions with the results from the Monte Carlo sensitivity analysis. A lower RMSE indicates a better fit between the model and observed data. RMSE is computed using Equation 5.

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_i - A_i)^2} \tag{5}$$

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Where, P_i = predicted value for the i-th parameter, A_i = actual value observed from the Monte Carlo sensitivity analysis for the i-th parameter, n = total number of parameters being compared.

Results

Characteristics of Indicators

The susceptibility module assesses geomorphology (Geo) and coastal defences (Cd), classifying the shoreline as an exposed sand-mud beach (Class 5, Figure 4), indicating high erosion risk due to the easily erodible nature of the sediments. The uniform geomorphology across the shoreline shows that the entire region is exposed to erosion, with no naturally stable areas offering protection. To address this, coastal defences are essential, with 29 groynes and jetties (perpendicular structures) and 5 revetments (longitudinal structures) identified along the shoreline (see Figure 5). These defences reduce erosion by interrupting sediment transport or absorbing wave energy.

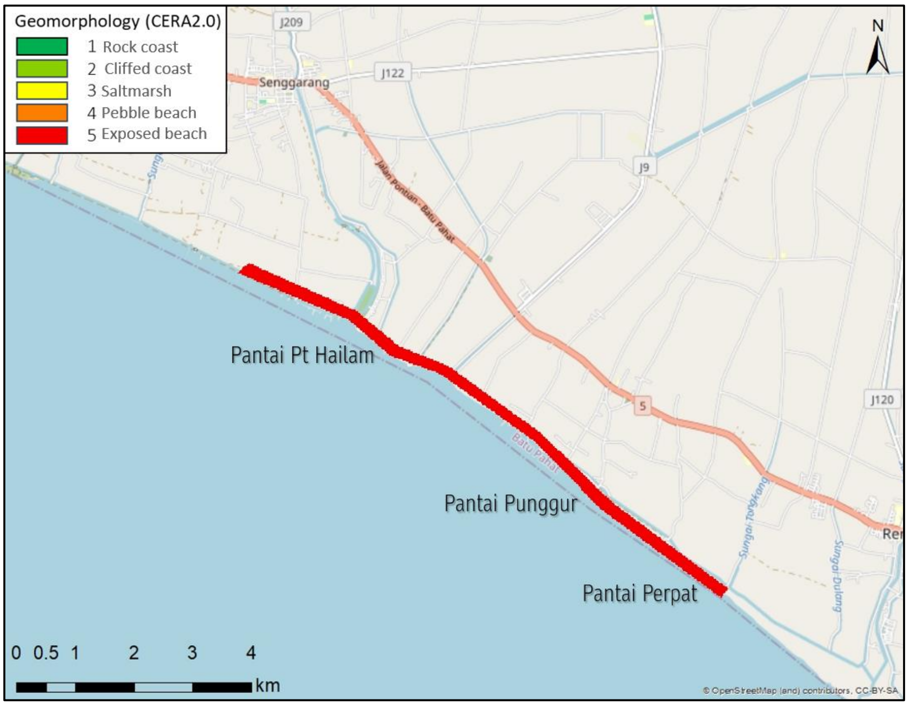

Figure 4: Geomorphology Classification

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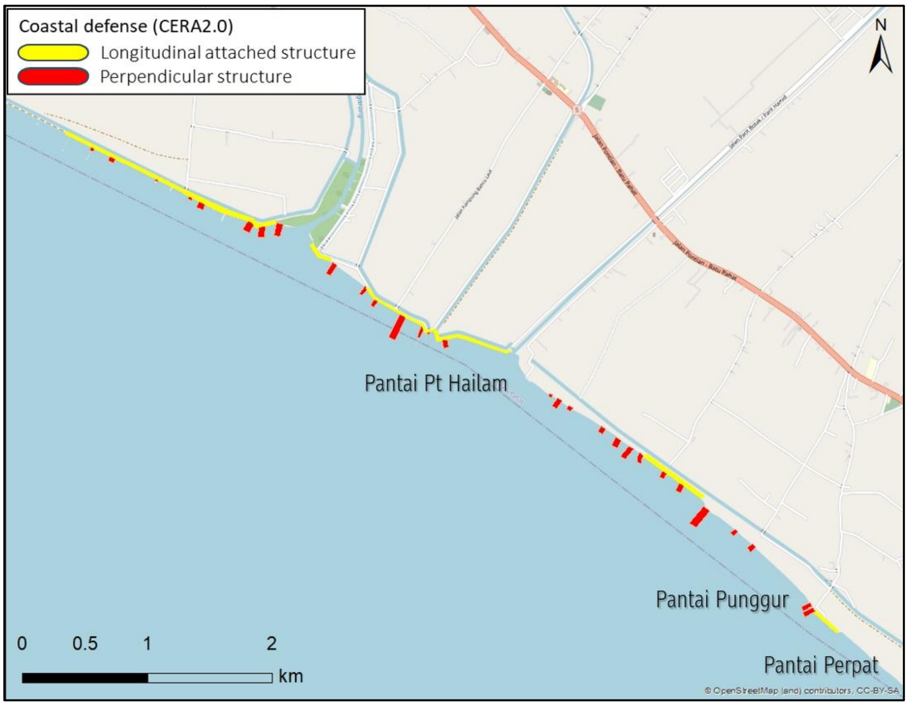

Figure 5: Location of Coastal Defences

The value module evaluates infrastructure, population, and ecological importance. Most of the study area falls into Level 1 (undeveloped, minimal infrastructure) and Level 2 (minor roads or low-density development), suggesting a low economic impact from coastal hazards (see Figure 6). Population density is low, with most areas sparsely populated (see Figure 7). Ecological zones, such as wetlands and mangroves, are vital for coastal protection and biodiversity, offering natural defences (see Figure 8).

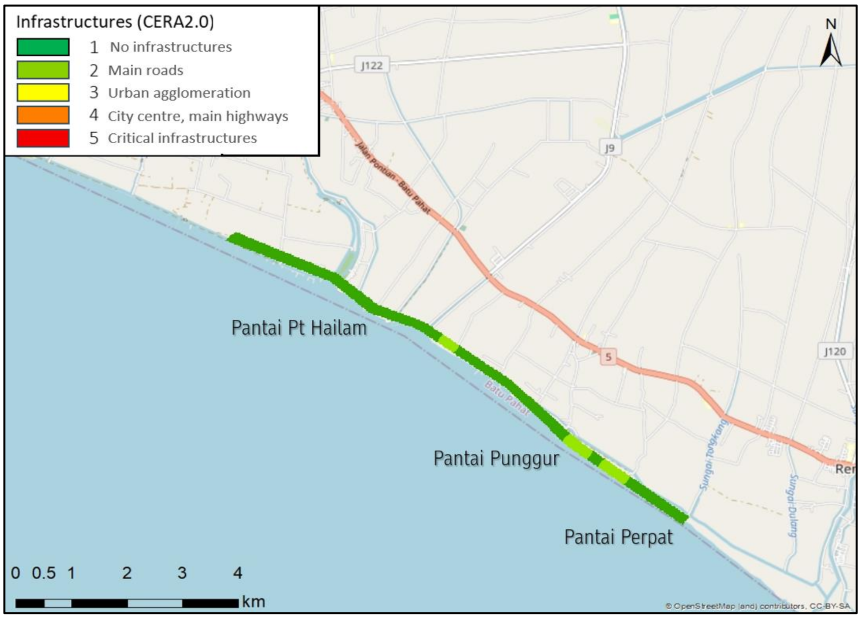

Figure 6: Classification of Infrastructures

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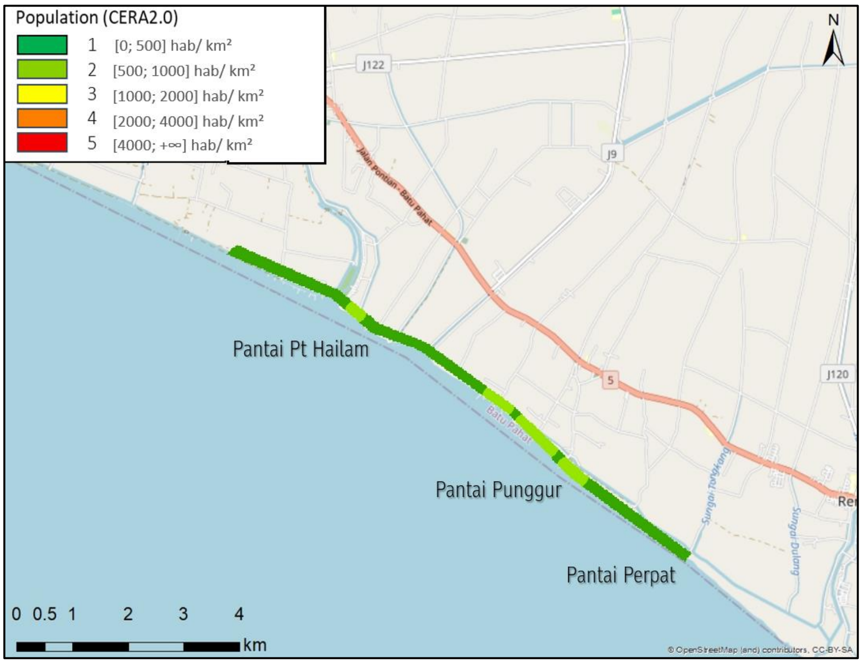

Figure 7: Classification of Population Density

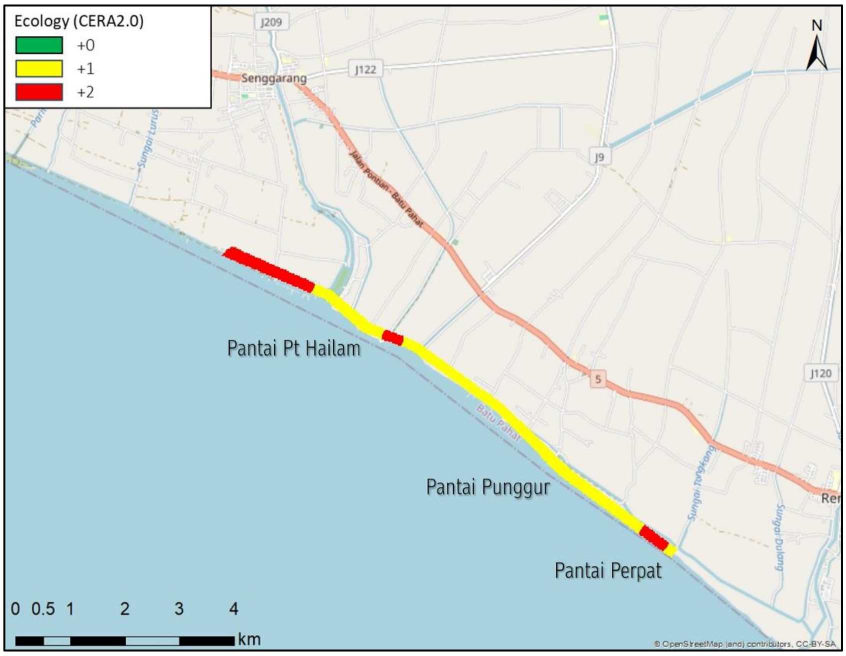

Figure 8: Classification of Ecology

Results of Modules

The susceptibility module results (Figure 9) indicate that most of the shoreline falls into the low to moderate susceptibility range, mainly due to the presence of coastal defences. However, regions with weaker natural features and insufficient protection are classified as highly susceptible (Levels 4 and 5). These areas remain vulnerable to severe erosion, as they lack effective defences. The value module results (Figure 10) show moderate value in nearshore areas. Though population density and infrastructure are limited, the ecological significance of these areas, particularly their natural habitats, increases their overall value in coastal management.

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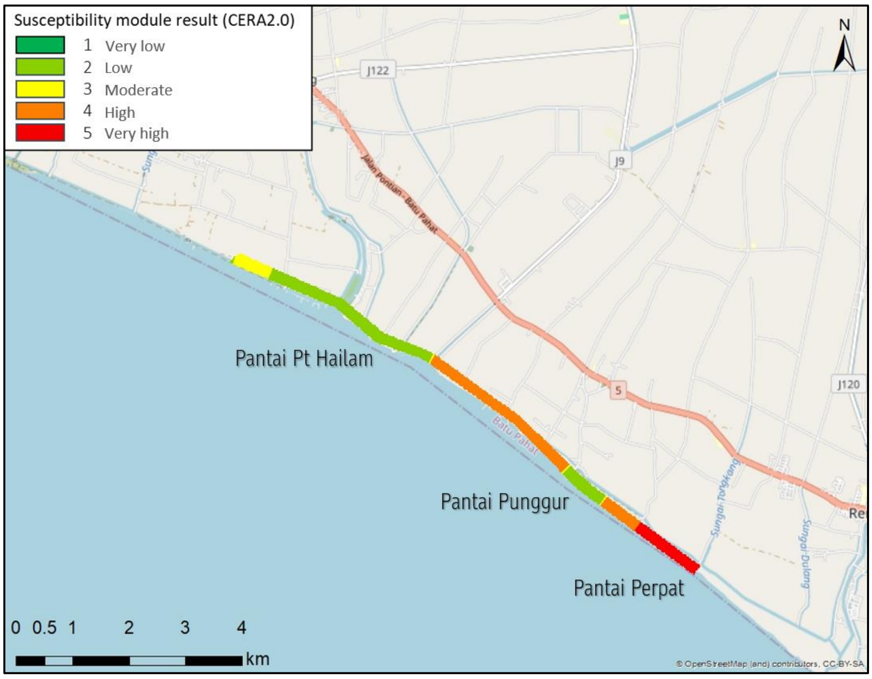

Figure 9: Susceptibility Module Results

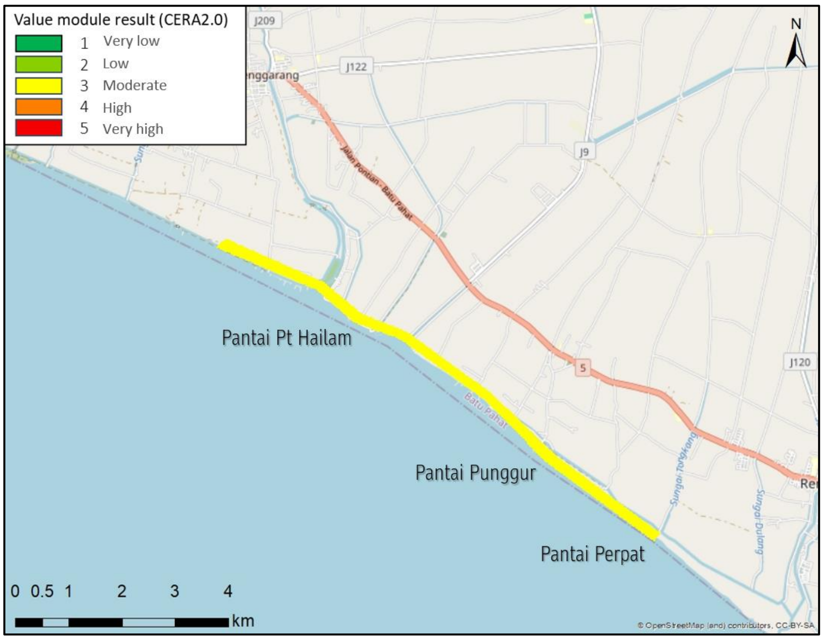

Figure 10: Value Module Results

Vulnerability Assessment Results

The vulnerability results integrate the susceptibility and value modules to offer a thorough assessment of coastal erosion in the study area. It is a critical tool for identifying areas where the impact of coastal hazards would be most severe, regardless of the likelihood or extent of these hazards. It is determined by both the physical susceptibility of the area to hazards (such as coastal erosion) and the value of the assets at risk (including infrastructure, population, and ecological significance). Following the processing of susceptibility and value module results, the combination of those is achieved through Equation (4), producing maps of vulnerability

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(Figure 11). Low vulnerability areas (Level 2) are those with strong natural defences and minimal human presence. Moderate vulnerability areas (Level 3) have some coastal defences but remain at risk during extreme events. Pantai Perpat, classified as Level 4, is the most vulnerable due to its high susceptibility, lack of coastal defences, and presence of infrastructure near the shore.

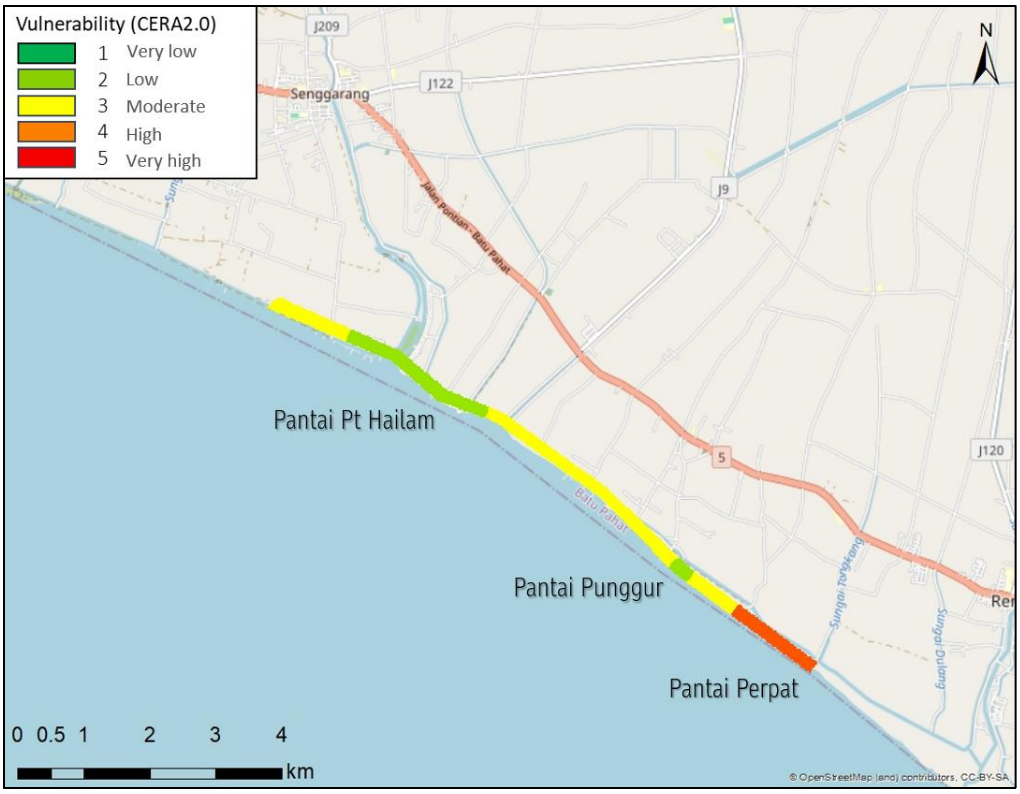

Figure 11: Vulnerability Map for Pantai Perpat, Pantai Punggur and Pantai Pt Hailam

Sensitivity Analysis – Monte Carlo

The sensitivity analysis was conducted by focusing on susceptibility, value, and vulnerability. The results of the analysis are summarised in Tables 4, which show the percentage impact of each parameter on the outcomes of these modules.

Table 4: Monte Carlo Analysis – Initial Predictions of CERA Model and Actual Results Based on the Study Area

Results	Module	Geo	Cd	Inf	Pop	Eco
Model	Susceptibility	56.81	46.37	-	-	-
Actual		50.61	49.39	-	-	-
Model	Value	-	-	32.27	34.74	41.82
Actual		-	-	31.33	34.89	33.78
Model	Vulnerability	57.65	45.87	3.00	3.32	6.37
Actual		48.98	47.33	0.38	0.80	2.51

Note: - represents no data.

The susceptibility module is highly influenced by geomorphology and coastal defences. Weak coastal features, like exposed beach, are more prone to hazards, while effective defences, such as seawalls and groynes, reduce vulnerability. Sensitivity analysis shows that changes in either

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factor can significantly impact susceptibility, as seen in areas like Pantai Perpat with poor natural defences.

The value module is most sensitive to population density, infrastructure, and ecological importance. High population and critical infrastructure increase risks, while valuable ecosystems like wetlands provide natural protection. A balanced approach is required to assess both human and ecological factors at risk.

Overall, vulnerability is heavily influenced by geomorphology and coastal defences, like the susceptibility module, highlighting the critical role these factors play in coastal hazard risk. The close percentages suggest that both the physical coastline and defence structures are key to reducing vulnerability. While factors like population density and infrastructure contribute, their impact is much smaller. Sensitivity analysis confirms that geomorphology and coastal defences are the main contributors to vulnerability, as seen in Pantai Perpat, where weak defences and a fragile coastline increase the overall risk.

RMSE Calculation

The RMSE of 6.63, as shown in Table 5, offers a measure of the overall accuracy of the coastal vulnerability assessment. A lower RMSE would indicate greater precision, while a higher value points to discrepancies that warrant attention. Given the sensitivity values ranging from near zero to over 30%, an RMSE of 6.63 suggests the model is reasonably accurate but has potential for improvement. The results highlight areas where the model may have underestimated or overestimated the impact of factors like infrastructure and population density, compared to their observed influence in the Monte Carlo analysis.

Table 5: RMSE Calculation for Model Prediction Compared to Actual Result of Vulnerability

Parameter	Model prediction (%)	Actual result (%)	Difference	Squared difference
Geo	40.87	48.98	8.11	65.77
Cd	33.63	47.33	11.73	137.69
Inf	1.37	0.38	0.99	0.98
Pop	4.70	0.80	3.9	15.21
Eco	3.06	2.51	0.55	0.30
		Sum		219.95
		Mean squared difference		43.99
		RMSE		6.63

Conclusion

In conclusion, the research successfully applied the CERA tool to evaluate coastal vulnerability across Pantai Perpat, Pantai Punggur, and Pantai Parit Hailam. The findings demonstrate that areas with fragile geomorphological features, particularly sand-mud coastlines, are highly susceptible to erosion, especially where coastal defences are lacking or insufficient. Pantai Perpat was identified as the most vulnerable site, largely due to its weak natural defences and proximity to infrastructure. The study highlighted the importance of both natural and artificial defences in mitigating coastal risks. Geomorphology and coastal defences played a critical role in determining overall vulnerability, as supported by the Monte Carlo sensitivity analysis. Although population density and infrastructure were considered, their impact was less

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significant compared to coastal defences. Further experiments and refinements of the CERA tool are recommended, especially to enhance model accuracy, as suggested by the RMSE of 6.63. This ongoing research will provide valuable insights for policymakers to improve coastal management strategies, ensuring resilience against erosion in these high-risk coastal zones.

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