Jurnal Kejuruteraan 38(7) 2026: 3251-3262
https://doi.org/10.17576/jkukm-2026-38(7)-07

Sediment Characteristics and Coastal Erosion Vulnerability Assessment Along the Batu Pahat Coast, Malaysia

Azreen Shafiqa Nabilla Azlan[a], Nur Amirah Mat Zain[a], Nor Baizura Hamid[b], Mardiha Mokhtar[b*], Aslila A bd Kadir[b], Muhamad Syamil Sabri[a] & Mohd Effendi Daud[a]

[a]*Department of Civil Engineering, Faculty of Civil Engineering and Built Environment,*

Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia

[b]*Department of Civil Engineering, Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia,*

Pagoh, 84600 Muar, Johor, Malaysia

[*]*Corresponding author: mardiha@uthm.edu.my*

Received 9 February 2026, Received in revised form 23 June 2026
Accepted 23 July 2026, Available online 30 October 2026

ABSTRACT

This study evaluates sediment characteristics and coastal erosion vulnerability along the Batu Pahat coastline, focusing on Pantai Punggur, Pantai Perpat, and Pantai Parit Hailam in Johor, Malaysia. Eight sediment samples were analysed to determine specific gravity, moisture content, and bulk density, providing insights into the physical behaviour of coastal sediments that influence shoreline stability. Specific gravity values ranged from 2.78 to 2.96, consistent with earlier findings in eroded coastal areas, while moisture content varied between 70.1% and 122.6%, reflecting the heterogeneous sediment composition across sites. Bulk density values ranged from 1.14 to 1.36 g/cm³, largely governed by soil texture, where higher clay and silt contents contributed to lower densities and sandy compositions showed higher values. To assess erosion vulnerability, the Coastal Erosion Risk Assessment (CERA) framework was applied following the Source–Pathway–Receptor–Consequence (SPRC) model. Eleven physical and environmental parameters were integrated to generate a final CERA risk map that synthesises susceptibility, value, exposure, vulnerability, and consequences. The results classify Pantai Punggur as a high-risk area (Level 4), driven by moderate shoreline change rates, weak coastal defences, and proximity of infrastructure to the active shoreline. Pantai Perpat and Pantai Parit Hailam fall within moderate-risk levels (Level 3), reflecting the influence of high exposure and variable sediment properties despite lower erosion rates. Overall, the study highlights the combined role of sediment characteristics and coastal processes in driving erosion vulnerability and provides essential guidance for targeted coastal protection and management.

Keywords: CERA framework, SPRC model, sediment properties, coastal vulnerability and integrated approach

INTRODUCTION

Coastal zones are among the most dynamic and sensitive environments on Earth, continuously shaped by natural forces such as tides, waves, and currents. These processes regulate the transport, deposition, and erosion of sediments, which ultimately determine shoreline morphology and ecosystem stability. In recent decades, rising anthropogenic pressures such as land reclamation, coastal construction, and rapid urbanization have disrupted sediment balance and intensified shoreline retreat in many tropical coastal regions. Malaysia's west coast, bordering the Strait of Malacca, is particularly vulnerable due to its low-lying terrain, muddy substrates, and exposure to monsoonal influences (Mokhtar et al. 2023). The Batu Pahat coastline in Johor, located along the southern reaches of the Strait of Malacca, has been undergoing substantial morphological adjustments in recent years. These changes are particularly evident in Pantai Punggur, Pantai Perpat, and Pantai Parit Hailam, where rapid shoreline modification has been closely linked to expanding urbanisation, coastal infrastructure development, and alterations to natural landforms. Such activities have disrupted sediment transport processes, resulting in heightened erosion, the degradation of mangrove habitats, and greater exposure of coastal communities to flooding and land loss. Between

2011 and 2013, an estimated 415.47 hectares were affected by erosion, with nearly 86% of the area experiencing severe degradation (Maulud and Rafar 2015). Future projections suggest that a 1-m rise in sea level may displace more than 5,700 residents and inundate major development zones within the district (Ehsan et al. 2019), underscoring the increasing vulnerability of the coastline.

Persistent anthropogenic pressures including land-use conversion, population expansion, and historical clearing of natural vegetation have further altered sediment supply and destabilised the shoreline system. These long-term modifications have compounded the impacts of climatic stressors, such as sea-level rise and changing wave regimes, intensifying the rate and spatial extent of erosion. Although several studies have identified Batu Pahat as a high-risk coastal segment (Sabri et al. 2022; Siddiq et al. 2022), comprehensive assessments that integrate sediment characteristics, shoreline movement, and erosion drivers remain limited. Recent analyses highlight ongoing shoreline retreat and sediment redistribution across Pantai Punggur, Pantai Perpat, and Pantai Parit Hailam, driven by the dominance of fine-grained muddy sediments and the complexities of tidal asymmetry (Azlan et al. 2024). These factors often constrain the accuracy of traditional hydrodynamic models, indicating the need for more robust, multi-method evaluation frameworks.

To address these knowledge gaps, this study adopts an integrated approach that combines sedimentological assessment, multi-temporal satellite image analysis, and geospatial modelling using the Coastal Erosion Risk Assessment (CERA) framework. This methodology allows for a more holistic examination of the interactions between sediment properties, shoreline behaviour, and erosion susceptibility along the Batu Pahat coast. The findings aim to improve scientific understanding of coastal evolution in sediment-dominated environments and to provide essential evidence for strategic coastal planning, ecosystem conservation, and long-term erosion mitigation in southern Johor.

METHODOLOGY

The methodology of this study consists of four main components: (1) study area definition, (2) data collection, (3) shoreline change analysis, and (4) coastal vulnerability assessment. The study area involves identifying and delineating the coastal stretch of Batu Pahat, focusing on Pantai Punggur, Pantai Perpat, and Pantai Parit Hailam which exhibit significant erosion and sediment redistribution. The data collection phase includes acquiring both primary data, such as sediment samples for laboratory analysis, and secondary data, including satellite imagery and topographic information, to support spatial and temporal assessments. The shoreline change analysis utilizes multi-temporal satellite imagery processed through GIS tools to quantify shoreline movement, erosion, and accretion trends over time. Finally, the coastal vulnerability assessment integrates multiple physical and environmental parameters using a Coastal Erosion Risk Assessment (CERA) framework to classify the coastline into zones of low, moderate, and high susceptibility to erosion.

STUDY AREA DEFINITION

The study was undertaken along the Batu Pahat coastline in Johor, situated in the southern region of Peninsular Malaysia and forming part of the southern sector of the Strait of Malacca. The investigated shoreline spans approximately from latitude 1.62° to 1.87° N and longitude 102.78° to 103.19° E, encompassing the coastal stretches of Pantai Parit Hailam, Pantai Punggur, and Pantai Perpat, as illustrated in Figure 1. These locations were selected due to their characteristic sand–mud beach environments, which are representative of the geomorphological and sedimentary settings of the Batu Pahat coastal system (Mokhtar et al. 2023; Mat Zain et al. 2024).

The selected coastal sites along the Batu Pahat shoreline exhibit noticeable variability in shoreline position, characterised by alternating periods of erosion and accretion between 2012 and 2022 (Azlan et al. 2024). These changes have contributed to gradual morphological adjustments that are closely linked to the nature and distribution of coastal sediments. The coastal environment is mainly characterised by fine-grained sandy–muddy sediments that play an important role in governing sediment transport processes and shoreline stability. These site characteristics make the Batu Pahat coast suitable for analysing sediment properties and evaluating its susceptibility to coastal erosion. The spatial extent of the study area is illustrated in Figure 1.

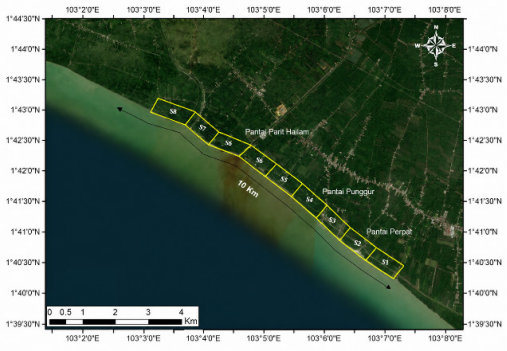


FIGURE 1. Map of study area

DATA COLLECTION

Data collection involved field measurements and secondary datasets to support the assessment of coastal erosion risk along the Batu Pahat coastline. The datasets provided the physical and environmental inputs required for the Coastal Erosion Risk Assessment (CERA) at Pantai Perpat, Pantai Punggur, and Pantai Parit Hailam.

Sediment sampling was conducted along the intertidal zones during low tide to obtain representative surface samples for laboratory analysis. The samples were collected using the Hand Auger boring method and scoop technique, following the British Standard BS5930 sampling procedure. This approach was chosen for its effectiveness in collecting near-surface sediment samples in coastal environments. Sampling was performed at depths ranging between 0.2 and 0.5 meters from the surface. Each sample was sealed in labeled plastic bags, wrapped in multiple layers of cling film to preserve its natural moisture content and prevent contamination or loss. In the laboratory, analyses were carried out to determine grain size distribution, specific gravity, bulk density, and sediment texture in accordance with standard methods such as British Standard BS1377. These analyses provided essential parameters for classifying sediment types and understanding their erosion susceptibility. Figure 2 shows the distribution of sampling stations along the Batu Pahat coastline, including Pantai Punggur and Pantai Perpat. A total of eight sampling points were established across the three study sites, and their respective locations are presented in Table 1.

TABLE 1. Location of sampling points

Coastal Area	Sampling Point
Pantai Perpat	PP 1
	PP 2
	PP 3
Pantai Punggur	PG 1
	PG 2
	PG 3
Pantai Parit Hailam	PH 1
	PH 2

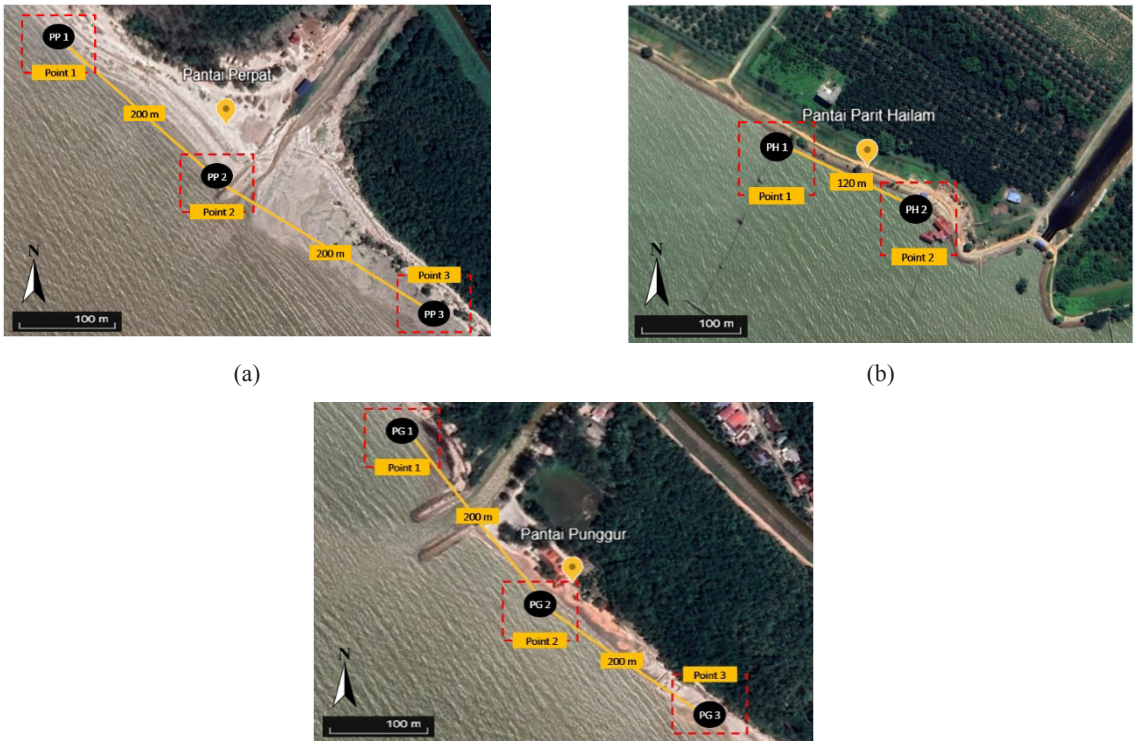


FIGURE 2. Sampling stations along the Batu Pahat coastline (a) Pantai Perpat (b) Pantai Parit Hailam and (c) Pantai Punggur

Secondary datasets were obtained from multiple agencies and open-access platforms to support shoreline change and coastal vulnerability analyses. Topographic data were sourced from the Department of Irrigation and Drainage (DID), while wind and wave data were retrieved from the European Centre for Medium-Range Weather Forecasts (ECMWF). Satellite imagery was obtained from Google Earth Pro, supplemented with historical datasets

from the United States Geological Survey (USGS) archives.

Historical images were processed and analyzed using Global Mapper and Pix4D for image correction, orthorectification, and georeferencing. QGIS was used for spatial analysis and data integration with the Coastal Erosion Risk Assessment (CERA) tool to evaluate coastal vulnerability. In addition, ArcGIS software equipped with the Digital Shoreline Analysis System (DSAS) extension was utilized to compute shoreline-change statistics, including Net Shoreline Movement (NSM) and End Point Rate (EPR), to quantify the rate and direction of shoreline movement over the study period.

CERA FRAMEWORK

Within the CERA framework, the assessment follows a reverse SPRC sequence, beginning with consequences and concluding with sources. The susceptibility module evaluates physical coastal characteristics, such as geomorphology and coastal defences, to identify erosion-prone areas. The value module assesses socio-economic and environmental importance, including population, infrastructure, and ecological assets. The exposure module examines the influence of coastal features and topography on vulnerability to direct forcing mechanisms, such as storm surges. Finally, the coastal erosion (hazard) module estimates erosion likelihood and intensity based on wave climate, storm occurrence, and historical shoreline trends. This modular approach integrates physical, social, and environmental dimensions to provide a comprehensive assessment of coastal erosion risk. Figure 3 illustrates the interaction among the CERA modules.

SHORELINE CHANGE ANALYSIS (DSAS)

For the distance-to-shoreline indicator, it is crucial first to identify a consistent geomorphic feature for shoreline digitisation. Given the influence of tidal variability, seasonal fluctuations, and the long-term behaviour of coastal systems, a stable reference such as the foredune toe is recommended as the shoreline proxy. To further reduce short-term noise and high-frequency variability, a minimum temporal separation of 10 years between shoreline datasets is applied. The corresponding classification scheme for shoreline change is presented in Table 2.

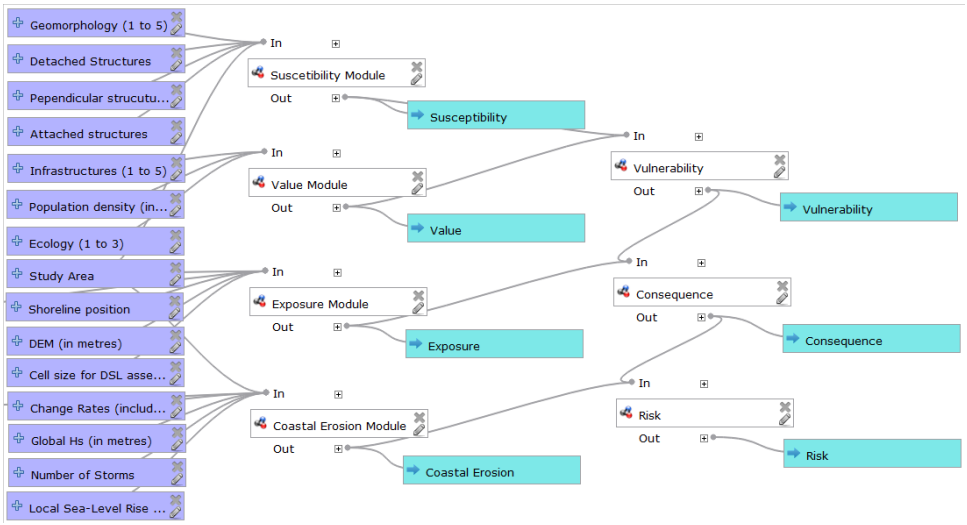


FIGURE 3. Framework of CERA

TABLE 2. Shoreline change rate classification

Class	Description	Shoreline change rate (m/yr)
1	Accretion shoreline	[+0.5; +∞]
2	Stable shoreline	[-0.5; +0.5]
3	Erosion shoreline	[-1.5; -0.5]
4	Intense erosion shoreline	[-2.5; -1.5]
5	Severe erosion shoreline	[-∞; -2.5]

Note: The semicolon (;) is used to separate the lower and upper bounds of each distance range in the classification levels.

Following the extraction of shoreline positions for the selected time intervals, shoreline-change rates were quantified using the Digital Shoreline Analysis System (DSAS) within the ArcGIS environment. The resulting shoreline-change metrics were then integrated with wave-climate classification indices to support the coastal vulnerability assessment.

COASTAL VULNERABILITY ASSESSMENT

Following the shoreline change analysis, a coastal vulnerability assessment was conducted to determine the relative susceptibility of the Batu Pahat coastline to erosion and related hazards. This assessment aims to identify which coastal areas are most at risk by integrating physical, environmental, and anthropogenic factors within a structured analytical framework.

To achieve this, the study adopts the Coastal Erosion Risk Assessment (CERA) framework, which provides a systematic approach to evaluating coastal vulnerability. The CERA framework incorporates multiple biophysical and socio-environmental parameters, including shoreline change rate, coastal slope, sediment type, elevation, and land use. Each parameter was ranked and weighted according to its contribution to erosion risk, and the composite index was computed using a GIS-based multi-criteria analysis.

Risk assessment was carried out through four main modules: susceptibility, value, exposure, and erosion. The process begins with a vulnerability analysis, which evaluates the degree of exposure and sensitivity of the coastal system to erosional forces. This is followed by a consequence analysis, which examines the potential socio-economic and environmental impacts such as property damage, habitat loss, and community disruption by integrating findings from vulnerability and exposure modules. Finally, the results from all modules were synthesized within the GIS environment to generate a composite CERA map delineating low-, moderate-, and high-risk zones. This spatial output serves as a practical tool for prioritising coastal management strategies and guiding erosion mitigation planning along the Batu Pahat coastline.

COASTAL EROSION RISK ASSESSMENT

The Coastal Erosion Risk Assessment (CERA) framework was applied to evaluate the susceptibility of the Batu Pahat coastline to erosion. The assessment followed the Source–Pathway–Receptor–Consequence (SPRC) model, where wave climate represents the erosive source, the distance from the shoreline acts as the pathway, coastal zones function as the receptor, and the consequence reflects the potential loss or damage to the affected area. Eleven coastal erosion-related parameters were incorporated into the analysis, covering physical characteristics, exposure conditions, and socio-environmental values. These parameters are summarised in Table 3 together with their respective roles within the CERA framework.

The vulnerability component of the assessment integrates two modules: the susceptibility module, which evaluates the inherent physical sensitivity of the coastline (e.g., geomorphology, coastal slope, shoreline change, and coastal defences), and the value module, which considers the importance of elements at risk such as infrastructure, population density, land use, and ecological value. Each parameter was ranked, standardised, and weighted accordingly, and the combined results were used to produce the vulnerability map. Consequence analysis was then performed by integrating vulnerability outputs with exposure indicators including elevation and proximity to the coastline to estimate the potential severity of impacts in the event of erosion.

Finally, the overall coastal erosion risk was derived by synthesising the vulnerability, consequence, and exposure modules using a GIS-based multi-criteria evaluation. This procedure resulted in a CERA risk map categorising the coastline into low-, moderate-, and high-risk zones, providing a structured basis for identifying priority management areas. The complete workflow applied in this study is illustrated in Figure 4, which outlines the sequential steps from data input to final risk classification.

TABLE 3. CERA Framework Input Parameters and Corresponding Data References

Module	Parameter	Role in CERA	Source	Description	Year
Susceptibility	Geomorphology (Geo)	Evaluates the physical resistance and stability of coastal landforms against erosion processes.	Previous literature (Maulud and Rafar, 2015; Hassan and Rahmat, 2016; Mohtar et al. 2017; Ehsan et al. 2019; Rashidi et al. 2021; Razi et al. 2022; Razi et al. 2023)	Pantai Punggur, Pantai Perpat, Pantai Parit Hailam	2023

continue...

...cont.

	Coastal defence	Assesses the effectiveness of existing coastal protection structures in reducing shoreline erosion	Google Earth	< 80m precision	2022
Value	Population density (Pop)	Represents the socio-economic importance and potential human exposure to coastal erosion hazards.	Department of Statistics Malaysia	Location: Senggarang, Rengit	2022
	Infrastructure (Inf)	Identifies the presence and importance of built assets vulnerable to coastal erosion impacts	Open Street Map	< 80m precision	2022
	Ecology (Eco)	Evaluates the ecological significance and sensitivity of coastal ecosystems exposed to erosion risk	Google Earth	< 80m precision	2022
Exposure	Topography (Top)	Assesses land elevation and terrain characteristics influencing susceptibility to coastal inundation and erosion impacts	USGS Earth Explorer (ID: SRTM1N01E103V3)	30m precision	2022
	Distance to shoreline (Dsl)	Determines the degree of exposure based on proximity to the active shoreline	Google Earth	Coastline in 2022 as the baseline	2022
Coastal erosion	No. of storms per year (St)	Represents the frequency of storm events contributing to coastal erosion intensity and shoreline instability	DID Malaysia	Hyetograph by station: Senggarang, Rengit, JPS Batu Pahat	2023-2024
	Significant wave height (Hs)	Evaluates wave energy and hydrodynamic forcing responsible for sediment transport and erosion processes	ECMWF - ERA5 hourly data on single levels from 1940 to present	Latitude: 1.6806N to 1.7351N Longitude: 103.1439E to 103.0670E	2023
	Shoreline change rate (Scr)	Quantifies long-term shoreline retreat or accretion trends to indicate coastal instability	Google Earth	< 50m precision	2012-2022
	Sea-level trend (Slt)	Assesses the influence of long-term sea-level rise on shoreline retreat and coastal vulnerability	Previous literature (NAHRIM, 2017; Bagheri et al. 2021; Rashidi et al. 2021)	Monthly sealevel rise data (1993-2013) from NAHRIM	2017

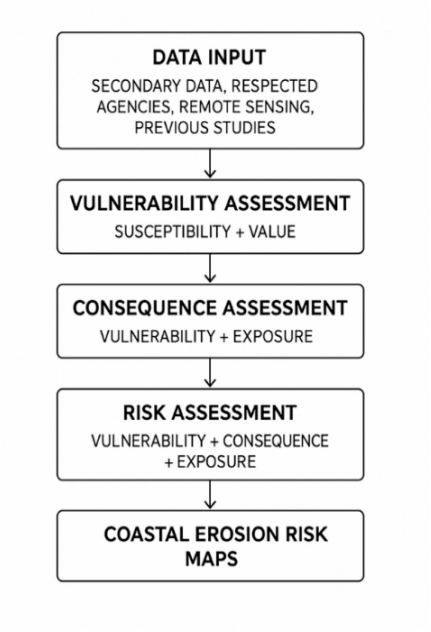


FIGURE 4. Workflow of the coastal erosion risk assessment

COASTAL VULNERABILITY ASSESSMENT USING THE CERA FRAMEWORK

The Coastal Erosion Risk Assessment (CERA) framework was employed to evaluate the relative susceptibility of Pantai Perpat, Pantai Punggur, and Pantai Parit Hailam to coastal erosion. The assessment follows the Source–Pathway–Receptor–Consequence (SPRC) model, where wave climate functions as the erosive source, the distance from the shoreline forms the pathway, the coastal zone serves as the receptor, and the consequence reflects the potential damage to environmental and socio-economic assets.

The CERA methodology integrates eleven erosion-related parameters covering physical, environmental, and socio-economic attributes. These parameters are organised into five modules susceptibility, value, vulnerability, exposure, and consequences which are subsequently combined to generate the final coastal erosion risk index. Each parameter was standardised, ranked, and weighted according to the CERA guidelines before being incorporated into the GIS-based multi-criteria evaluation.

Although each module was fully processed, the detailed spatial outputs are not individually presented in this paper. Instead, a summary of module scores is provided in a consolidated table (Table 4), while the Results section focuses solely on the final integrated CERA risk map, which represents the cumulative outcome of all assessment components.

TABLE 4. Summary of CERA module scores for the three study locations

Location	Susceptibility	Value	Vulnerability	Exposure	Consequence
Pantai Perpat	High (Level 4-5)	Moderate (Level 3)	Moderate High (Level 3-4)	Very High (Level 5)	High (Level 4-5)
Pantai Punggur	High (Level 4)	Moderate (Level 3)	Moderate (Level 3)	Very High (Level 5)	High (Level 4)
Pantai Parit Hailam	Low (Level 2)	Moderate (Level 3)	Low (Level 2)	Very High (Level 5)	Moderate (Level 3)

RESULTS AND DISCUSSION

SEDIMENT PROPERTIES

This section summarises the key sediment properties that influence coastal stability in Batu Pahat. Parameters such as specific gravity, moisture content, and bulk density were analysed to better understand the physical behaviour of sediments along the shoreline.

In this study, eight (8) soil samples were collected and analysed to determine the sediment characteristics at each sampling point. The outputs of this assessment are summarised in Table 5 to improve clarity and interpretation.

The specific gravity (Gs) was evaluated to establish its mean value, which is essential for understanding the weight–volume behaviour of the sediments. The specific gravity in this study ranged from 2.78 to 2.96, reflecting the mineral composition of sediments along the investigated coastline. These values are consistent with the findings of Mokhtar, et al. (2022), who reported a specific gravity of approximately 2.6 in eroded coastal zones at Pantai Punggur, indicating comparable sediment characteristics across similar coastal environments. Moisture content within the Batu Pahat sediments varied between 70.1% and 122.6%, which directly influenced sediment density and porosity (Mokhtar et al. 2023). These moisture variations, combined with mineral composition, collectively shape the observed weight–volume relationships in the coastal soils.

Bulk density is governed by several physical and chemical factors that change with soil structure. Clay content exerts a strong influence on bulk density, second only to sand content in its contribution, while silt content typically shows a weaker, negative relationship with bulk density (Cicek, 2022). As shown in Table 5, the highest bulk density recorded was 1.36 g/cm³ at station PP 3, whereas the lowest values, 1.14 g/cm³, were measured at stations PH 2 and PG 1. These spatial variations reflect the differing soil textures in the area, where higher clay and silt proportions generally result in lower bulk density. Conversely, sandy soils tend to exhibit greater bulk density due to their reduced content of fine, porous materials and organic matter (Guruprasad and Soraganvi 2014). Previous studies indicate that sandy soils commonly show bulk densities between 1.4 and 1.7 g/cm³, while clay-rich soils typically range from 1.0 to 1.3 g/cm³ (Singh et al. 2020), which aligns with the trends observed in this study.

TABLE 5. Sediment properties results

Sampling Point	Specific Gravity	Bulk Density (g/cm³)	Porosity
PP 1	2.89	1.29	0.55
PP 2	2.80	1.30	0.54
PP 3	2.90	1.36	0.53
PG 1	2.78	1.14	0.55
PG 2	2.81	1.33	0.53
PG 3	2.96	1.28	0.57
PH 1	2.79	1.16	0.55
PH 2	2.87	1.14	0.57

CLASSIFICATION OF SHORELINE CHANGE RATES

Shoreline-change rates were assessed through shoreline digitisation derived from multi-temporal satellite imagery obtained from Google Earth Pro. To minimise short-term variability and high-frequency fluctuations, a temporal window of at least 10 years was adopted, using shoreline positions from 2012 and 2022, with the 2022 shoreline serving as the baseline (Figure 5). The classification of shoreline changes for the study area is presented in Table 6. Once the shoreline positions for the selected period were established, the corresponding change rates were calculated using the Digital Shoreline Analysis System (DSAS) extension within the ArcGIS environment.

The computed shoreline-change rate provides a quantitative indication of the extent to which the coastline has advanced or receded because of erosion or accretion processes. This metric is fundamental for interpreting long-term patterns of coastal stability. Across the study area, shoreline-change rates generally fall within Level 2 to Level 3, with moderate change rates observed in locations such as Pantai Punggur (PG) and Pantai Parit Hailam (PH) (Figure 6).

The classification results suggest that several sections of the coastline faced moderate erosion or accretion, influenced by both natural coastal dynamics and anthropogenic pressures. Areas characterised by Level 3 changes exhibit more pronounced shoreline variability over time, indicating a higher susceptibility to coastal change and potentially greater risk to nearby infrastructure and ecological habitats.



FIGURE 5. Shoreline change rates from year 2012 to year 2022

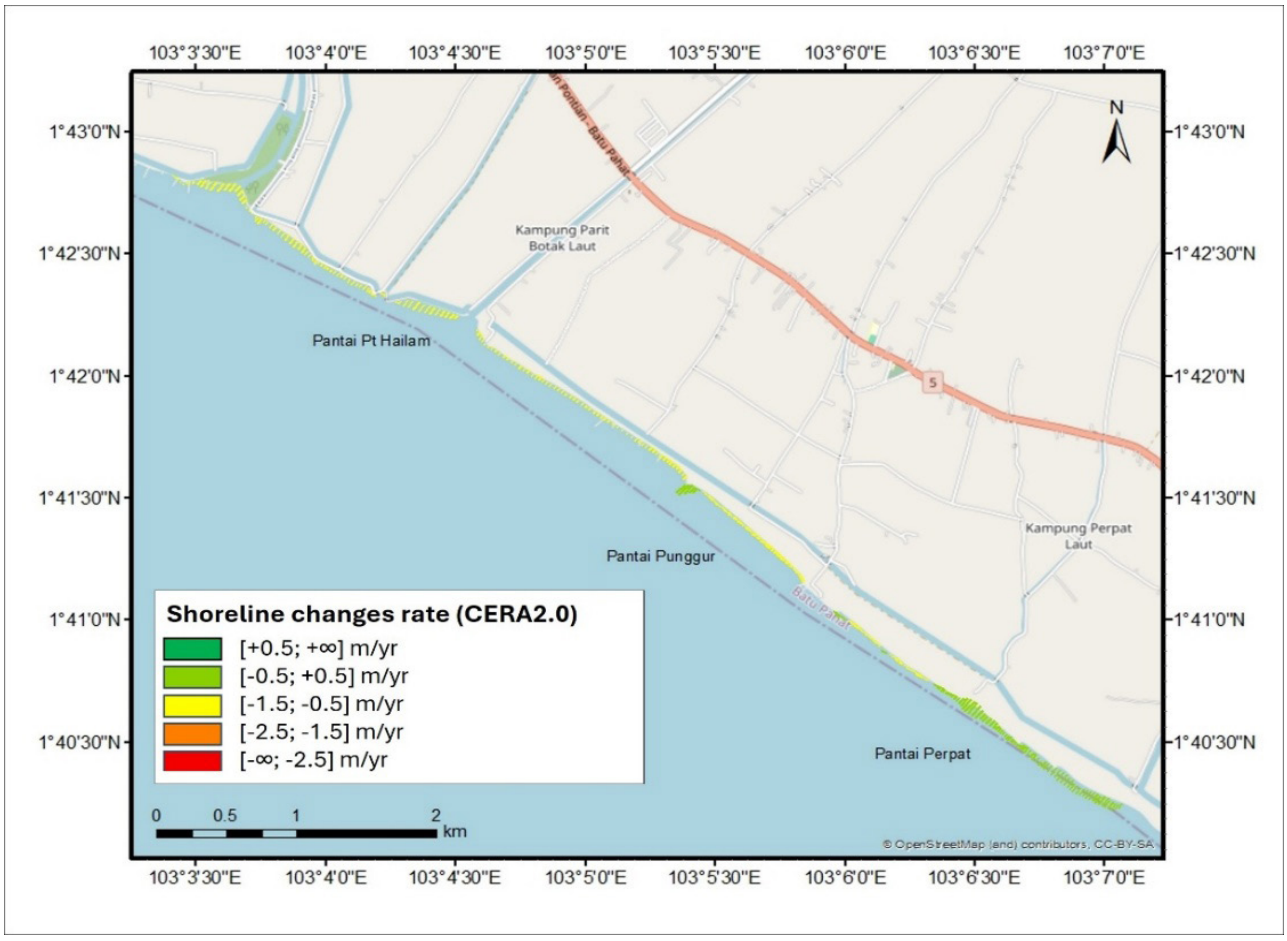


FIGURE 6. Classification of shoreline change rates

TABLE 6. Quantitative results of shoreline change rates (2012 to 2022)

Section/ Sampling Point	NSM (m) (± Uncertainty)	EPR (m/yr) (± Uncertainty)	Rank
S1/ PP 3	(-3.5 to +4.5)	(-0.35 to +0.45)	2
S2 / PP 2	(-2.5 to +5.5)	(-0.25 to +0.55)	2
S3 / PP 1	(-13 to -5)	(-1.3 to -0.5)	3
S4 / PG 3	(-15 to -6)	(-1.5 to -0.6)	3
S5 / PG 2	(-16 to -7)	(-1.6 to -0.7)	3
S6 / PG 1	(-14 to -6)	(-1.4 to -0.6)	3
S7 / PH 2	(-12 to -5)	(-1.2 to -0.5)	3
S8 / PH 1	(-11 to -4)	(-1.1 to -0.4)	3

CERA RISK ASSESSMENT RESULTS

The Coastal Erosion Risk Assessment (CERA) framework synthesises susceptibility, value, vulnerability, exposure, and consequence components to produce an integrated coastal erosion risk index for the study area. As the primary objective of this analysis is to characterise the spatial distribution of overall risk, only the final CERA risk map is presented (Figure 7), while the intermediate module outputs are summarised in Table 4.

The assessment reveals clear spatial contrasts in erosion risk along the Batu Pahat coastline. Pantai Punggur is identified as the highest-risk area (Level 4), driven by moderate shoreline change rates, limited coastal defences, and the proximity of built infrastructure to the active shoreline. Pantai Perpat and Pantai Parit Hailam fall within the moderate-risk category (Level 3). In Pantai Perpat, the elevated risk reflects the combined influence of high vulnerability, low elevation, and direct exposure to tidal forces, despite relatively lower observed erosion rates. Pantai Parit Hailam exhibits moderate risk due to its moderate susceptibility and consistently high exposure, although natural features in certain sections provide some degree of buffering.

These findings indicate that erosion risk across the study area is shaped by the interaction of physical sensitivity, asset importance, and coastal exposure. Overall, the results highlight the need for site-specific coastal management strategies, with priority attention recommended for Pantai Punggur due to its higher risk level, and targeted interventions in Pantai Perpat to address persistent vulnerabilities associated with weak protective features and low-lying terrain.

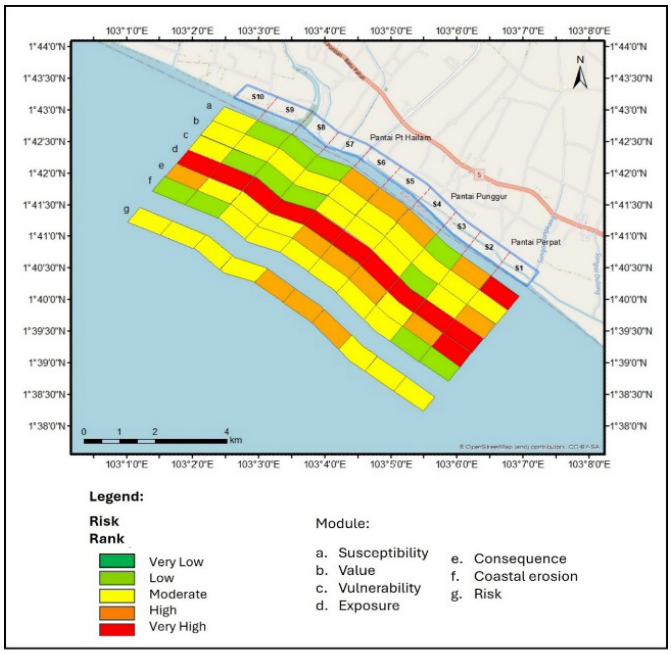


FIGURE 7. CERA map of Pantai Perpat, Pantai Punggur and Pantai Parit Hailam

CONCLUSION

This study provides an integrated evaluation of sediment characteristics and coastal erosion vulnerability along the Batu Pahat coastline, offering important insights into the relationship between sediment properties, shoreline dynamics, and erosion susceptibility. The sediment analysis revealed specific gravity values ranging from 2.78 to 2.96 and moisture contents between 70.1% and 122.6%, which are consistent with previously reported characteristics of eroded coastal environments in Batu Pahat. Bulk density variations (1.14–1.36 g/cm³) were strongly influenced by soil texture, where higher clay and silt contents corresponded to lower densities, while sandy sediments exhibited relatively higher densities. These findings demonstrate the significant influence of sediment composition on shoreline response and coastal stability.

The application of the Coastal Erosion Risk Assessment (CERA) framework successfully identified spatial variations in erosion vulnerability across the study area. Pantai Punggur was classified as the highest-risk zone (Level 4) due to continuous shoreline retreat, limited coastal protection, and the close proximity of infrastructure to active coastal processes. In contrast, Pantai Perpat and Pantai Parit Hailam were categorised as moderate-risk areas (Level 3), reflecting the combined influence of exposure conditions and geomorphological variability despite comparatively lower erosion rates.

Overall, the integration of sedimentological analysis, shoreline change assessment, and GIS-based CERA evaluation provides a more comprehensive understanding of coastal erosion processes along the Batu Pahat coastline. The findings highlight the importance of adopting site-specific mitigation and coastal management strategies, particularly in highly vulnerable areas such as Pantai Punggur. In addition, this integrated assessment framework may serve as a useful reference for future coastal vulnerability studies and support long-term shoreline monitoring, erosion mitigation planning, and sustainable coastal management in sediment-dominated coastal environments.

ACKNOWLEDGEMENT

This research was supported by Universiti Tun Hussein Onn Malaysia through Tier 1 (Vot Q970) and GPPS (Vot J183).

DECLARATION OF COMPETING INTEREST

None.

REFERENCES

Azlan, A.S.N., Mokhtar, M., Daud, M.E., Kaamin, M., Sahat, S. & Mohd Bukari, S. 2024. Coastal erosion vulnerabilities in Batu Pahat, Johor: An analysis using the CERA method. *Journal of Tourism, Hospitality and Environment Management* 9(38): 227–241. https://doi.org/10.35631/JTHEM.938016

Bagheri, M., Ibrahim, Z.Z., Akhir, M.F., Oryani, B., Rezania, S., Wolf, I.D., Pour, A.B. & Talaat, W.I.A.W. 2021. Impacts of future sea-level rise under global warming assessed from tide gauge records: A case study of the East Coast Economic Region of Peninsular Malaysia. *Land* 10(12): 1382. https://doi.org/10.3390/land10121382

British Standards Institution. 1990. *BS 1377:1990 Methods of Test for Soils for Civil Engineering Purposes*. London: British Standards Institution.

British Standards Institution. 1999. *BS 5930:1999 Code of Practice for Site Investigations*. London: British Standards Institution.

Cicek, B. 2022. *Revisiting Vernacular Technique: Engineering a Low Environmental Impact Earth Stabilisation Method*. PhD thesis. Bauhaus-Universität Weimar.

Ehsan, S., Begum, R.A., Nor, N.G.M. & Maulud, K.N.A. 2019. Current and potential impacts of sea level rise in the coastal areas of Malaysia. *IOP Conference Series: Earth and Environmental Science* 228(1): 012023. https://doi.org/10.1088/1755-1315/228/1/012023

Guruprasad, M.H. & Soraganvi, V.S. 2014. Impact of soil organic carbon on bulk density and plasticity index of arid soils of Raichur, India. *International Research Journal of Environment Sciences* 3(2): 48–58.

Hassan, M.I. & Rahmat, N.H. 2016. The effect of coastline changes to local community's social-economic. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* XLII-4/W1: 25–36. https://doi.org/10.5194/isprs-archives-XLII-4-W1-25-2016

Mat Zain, N.A., Mokhtar, M., Daud, M.E., Ibrahim, I.N., Hamid, N.B., Abd Kadir, A., Abd Mutalib, I., Muhamad Shahrulzaman, M.F.H. & Hussels, E. 2024. Surficial sediment and littoral environment data along the shoreface of Batu Pahat, Johor coastal. *Journal of Advanced Research Design* 123(1): 79–90. https://doi.org/10.37934/ard.123.1.7990

Maulud, K.N.A. & Rafar, R.M. 2015. Determination the impact of sea level rise to shoreline changes using GIS. In *2015 International Conference on Space Science and Communication (IconSpace)*, 352–357. IEEE.

Mokhtar, M. 2023. *A New Formulation for Assessing Coastal Erosion and Morphology Change in the Sand-Mud Beach Area*. PhD thesis. Universiti Tun Hussein Onn Malaysia.

Mokhtar, M., Ariffin, M.A.F.B., Daud, M.E., Kaamin, M., Azmi, M.A.M. & Hamid, N.B. 2022. Sediment properties of eroded coastal area at Batu Pahat, Johor, Malaysia. *Environment and Ecology Research* 10(2): 248–259. https://doi.org/10.13189/eer.2022.100214

Mokhtar, M., Daud, M.E., Kaamin, M., Sabri, M.S., Hayazi, F., Hisham, M.H., Siddiq, M.I., Azmi, M.A.M., Hamid, N.B. & Noor, H.M. 2023. Beach profile and shoreline sediment properties at eroded area in Batu Pahat. *Construction Technologies and Architecture* 4: 127–137. https://doi.org/10.4028/p-ny3700

Sabri, M.S., Daud, M.E. & Mokhtar, M. 2022. Effect of soil shear strength on shoreline changes at Batu Pahat coastal area. *Journal of Sustainable Underground Exploration* 2(1): 9–19. https://doi.org/10.30880/jsue.2022.02.01.002

Mohtar, W.H.M.W., Nawang, S.A.B., Maulud, K.N.A., Benson, Y. & Azhary, W.A.H.W.M. 2017. Textural characteristics and sedimentary environment of sediment at eroded and deposited regions in the severely eroded coastline of Batu Pahat, Malaysia. *Science of the Total Environment* 598: 525–537. https://doi.org/10.1016/j.scitotenv.2017.04.093

National Hydraulic Research Institute of Malaysia (NAHRIM). 2017. *Impact of Climate Change: Sea Level Rise Projection in Malaysia*. Selangor: National Hydraulic Research Institute of Malaysia.

Rashidi, M.A.H., Jamal, M.H., Hassan, M.Z., Sendek, M.S.S., Sopie, M.S.L. & Hamid, A.M.R. 2021. Coastal structures as beach erosion control and sea level rise adaptation in Malaysia: A review. *Water* 13(13): 1741. https://doi.org/10.3390/w13131741

Razi, M.A.M., Adnan, M.S., Ahmad, M.A., Salleh, A.M., Bukari, S.M., AlGheethi, A.A.S.A. & Mokhtar, A. 2022. Application of coastal protection structure for mangrove rehabilitation and rejuvenation of west coast Johor: Case study Tanjong Labuh, Batu Pahat, Johor. *IOP Conference Series: Earth and Environmental Science* 1022(1): 012064. https://doi.org/10.1088/1755-1315/1022/1/012064

Razi, M.A.M., Rahmat, S.N., Jamal, M.H., Tajul Baharuddin, M.F., Wang, M. & Husin, T.M. 2023. Evaluation of mangroves effectiveness in strengthening coastal bund using geophysical method at Tanjong Laboh, Batu Pahat, Johor. *International Journal of Integrated Engineering* 15(6): 160–167.

Singh, P.D., Kumar, A., Dhyani, B.P., Kumar, S., Shahi, U.P., Singh, A. & Singh, A. 2020. Relationship between compaction levels (bulk density) and chemical properties of different textured soil. *International Journal of Chemical Studies* 8(5): 179–183.

Siddiq, M.I., Daud, M.E., Kaamin, M., Mokhtar, M., Omar, A.S. & Duong, N.A. 2022. Investigation of Pantai Punggur coastal erosion by using UAV photogrammetry. *International Journal of Nanoelectronics and Materials* 15(Special Issue): 61–69.