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Community based index of coastal erosion using ahp analysis

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Abstract. Coastal erosion can be seen on practically every beach in Malaysia, but it is especially common on the country's east coast. Depending on the severity of the erosion, coastal erosion has been addressed using a variety of methods and treatments. However, it is critical for coastal managers and responsible authorities to have an erosion index that can be used to determine the level of erosion so that suitable mitigation and treatment methods may be designed. The factors that contribute to coastal erosion must be identified and classified, and this study will use a literature review and community feedback questionnaires to identify the primary factors that contribute to coastal erosion. The AHP method will be used in this paper to assess the level of contribution of each parameter influencing coastal erosion. According to the findings of the AHP analysis, coastal structure was the most influential factor in coastal erosion, followed by human activity, waves, and wind, with weights of 0.5333, 0.2404, 0.1804, and 0.0459, respectively. This weighting of factors will be supplementary to existing guidelines such as NCES in making quick decisions, particularly in coastal areas that require immediate mitigation, and will serve as an additional guide to local agencies in planning.

1. Introduction

The world's coastlines are a complex and crucial area since they are a major industrial asset and home to a significant number of people. The coastal zone is critical for human development in terms of economic and social worth (Bagheri et al., 2021; Silva et al., 2014). Beaches in Malaysia have witnessed continual coastal erosion and land loss since 1985 as a result of the rapid growth and expansion of human activities along the coast (Ghazali, 2006). It was found that 1,324 kilometres of Malaysia's coastline were eroded by the National Coastal Erosion Survey (NCES) 2015 (DID, 2015).

The most severe coastal erosion occurs in rapidly developing areas, such as the northern Terengganu River estuary, particularly the Kuala Nerus coastline area. Over time, any human activity that alters coastal dynamics will result in a change in the shoreline's morphology (Prasad & Kumar, 2014). For example, the extension of International Airport in Terengganu, Malaysia, is a clear example of this. Since the completion of the airport's 500-meter-to-the-sea projection, coastal erosion in the northern part of the structure has been clearly visible from year to year. According to NCES, the 1.7km coastline around Kuala Nerus (particularly the area near the airport) has been eroding since 2015 due to natural and external factors. With no countermeasures in place, these eroded areas are expected to deteriorate at a faster rate, especially as the factors that cause long-term erosion increase.

Due to the aforementioned factors, determining the extent to which each parameter influences coastal erosion is an important aspect of coastal management. Recognizing the most significant factors that can affect existing coastal conditions in the event of a disaster is critical for coastal disaster risk management and long-term growth and development (Rangel-Buitrago et al., 2020; Rudiastuti et al., 2020; Sheik Mujabar & Chandrasekar, 2013). As a result, the purpose of this paper is to examine the weights for each element in order to thoroughly analyse the most influential factors. The assessment of these factors can provide clear fundamental guidance in determining the extent to which a factor's tendency to erode. Because the weights obtained in this study are based on questionnaires from local communities, the weights created are only for Malaysian beaches.

2. Methodology

2.1. Test area: Telipot beach, Kuala Nerus, Terengganu

The study area is approximately 3 kilometres long, ranging from Tok Jembal beach to Telipot beach. The northeast monsoon dominates Terengganu's coastal area, with semi-daily and annual average tidal temperatures ranging from 25 to 27 degrees Celsius (Chalabi et al., 2005). According to the National Coastal Erosion Survey (NCES) 2015, the rate of erosion in Kuala Nerus is between 2 and 11 metres per year. However, since 2016, the erosion rate in Kuala Nerus' Mengabang Telipot and Mengabang Telung has grown to 20 m/year (Figure 1). The rate of erosion in the nearby area this area has also accelerated dramatically.

Figure 1. Erosion site at the study area.

2.2. Method and materials

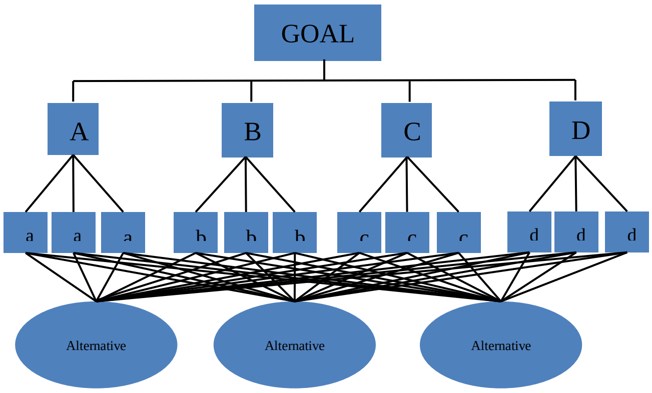
The main factors influencing coastal erosion are discussed in this topic, as well as the AHP method for calculating the weights of each factor influencing coastal erosion.

2.2.1. The Analytic Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP), the decision analytic method used in this study, is a theory of measurement based on pairwise comparisons that derives priority scales using expert judgement (Saaty, 2002). The essence of AHP's mathematics and computing approaches is to build a matrix describing the relative importance of a series of attributes, and each step in the AHP calculation is as follows;

- Step 1: Define the problem and select the criteria;
- Step 2: Pair-wise comparison matrices;
- Step 3: Summarize the decision and estimate the relative weight; and
- Step 4. Determine how important each choice element is in order to come up with a set of ratings for the options/strategies of decision.

The typical form of Analytic Hierarchy Process (AHP) as illustrates in figure 2.



Where;
- Goal represents an Index erosion
- A, B, C, and N represent the parameter dimension of coastal erosion
- a, b, c, d and n represent the parameters or factors

Figure 2. Typical model of AHP analysis.

2.3. Parameter's identification

A literature search of previous studies was used to identify the initial parameters that influence erosion in this study. There are a number of elements that contribute to coastal erosion around the world, and this stage is critical in identifying them. As one of the most comprehensive abstract and citation databases for peer-reviewed literature, including scientific journals, books, and conference proceedings, the Scopus database has been particularly searched for credible data (Nobre & Tavares, 2017). List was then inspected in the manner depicted in figure 3. The parameters will be listed in table 1 following the findings of the comprehensive literature review.

1st STEP	2nd STEP	3rd STEP	Final STEP
General Topic Key word: Coastal Erosion **244,000 Documents**	Specific topic Key word: Coastal erosion factors, Causes of coastal erosion, Coastal Erosion phenomenon **139,000 Documents**	Specific topic on specific Journal Key word: Coastal erosion factors, Causes of coastal erosion, Coastal erosion phenomenon in Terengganu **905 Documents**	Specific papers Key word: Erosion causes and Coastal erosion factors, Coastal erosion in Terengganu **63 Documents**

Figure 3. Literature review key word searching mapping process.

Table 1. Summary of coastal erosion factors identified through literature review.

Dimensions	Factors	Dimensions	Factors
Man-made Factors	Human activities Ecosystem Destruction	Natural Factors	Wave Wind Sea Level Rise Storm Tides Water Temperature Ecosystem destruction
Socio-Economic Factors	Coastal Structure		

2.4. Parameter's selection

After identifying all relevant components, they must be further detailed to identify the key contributors to erosion. This phase ensures that the AHP analysis' input is not excessive, ensuring an accurate result. The most important factors influencing erosion were identified through a literature review and community surveys in this study.

2.4.1. Based on literature

The abstracts of the retrieved papers were examined for the keywords "erosion causes," "coastal erosion factors," and "coastal erosion in Terengganu." The present study uses 63 papers on coastal erosion that all express the same causes. In addition to scholarly resources, the articles were chosen from famous international conferences and journals with high Impact Factors (JCR). As a result, criteria will be defined based on an assessment of the principal causes of erosion. Table 2 summarizes all identified parameters as percentages. They will be classified into three categories: natural, man-made, and socio-economic. Within each of the three dimensions, only the highest percentage parameters will be considered sub-criteria. The percentage (Table 2) is calculated by multiplying the frequency of each eroding factor.

Table 2. Summary of parameters in the literature.

Dimensions	**Factors**	**Percentage**	**Dimensions**	**Factors**	**Percentage**
Nature Factors	Wave	15	Man-Made Factors	Human activities	25
	Wind	10		Ecosystem Destruction	1
	Sea Level Rise	2	Socio-Economic Factors	Coastal Structure	41
	Storm	3			
	Tides	2			
	Water Temperature	1			

2.4.2. Based on questionnaires

The perspectives and opinions of long-time residents of coastal areas are used as a second way to discover issues that contribute to local erosion. Interviewed at two beach locations, Tok Jembal and Menggabang Telipot, to ensure each person interviewed fit the study's scope, and at evening because more people were on the beach. The survey started at Tok Jembal Beach and ended at Telipot Beach (before Pengkalan Maras), with the intention of receiving 25 to 30 replies. On a scale of one to five, respondents ranked each cause of erosion. Table 3 shows the Likert scale used to measure each component's impact on coastal erosion. The questionnaire is written in Bahasa Melayu, and the aim of each question will be explained. Table 4 illustrates the questionnaire's scope.

Table 3. Likert scale.

Least relative significance	1
Have relative significance	2
Neutral	3
High relative significance	4
Highest relative significance	5

Table 4. Questionnaire of erosion considerations on coastal erosion.

Scope	Questionnaire
Description of Coastal Erosion	• Give an overview of the Malaysian shoreline. • Malaysia's current situation as a result of coastal erosion. • Identify and list the primary cause(s) of coastal erosion in Malaysia.
Coastal Erosion related to the nature factors. ▪ Scoring parameter of wind, wave, sea level rise, water temperature, and tides Coastal Erosion related to the man-made factors. ▪ Scoring parameter of coastal structure, human activities, and ecosystem destruction.	• In order to determine the score points for the AHP analysis, participants will be asked a series of questions about the level of effect for each parameter. • In addition, respondents will be asked to rate a pair-wise factor comparison.

2.4.3. Summary of parameter's selection

Based on a literature review and feedback from community questionnaires three dimensions and four parameters were chosen as AHP analysis criteria for analysing factor weighted, as below;

- Natural Factor : Wave, wind
- Man-made Factors : Human activities
- Socio-economic Factors : Coastal structure

2.4.3.1. Wave

The Terengganu coastal area is most affected by monsoon-generated waves (Ariffin, Mathew, et al., 2018; Ariffin, Sedrati, et al., 2018; Saadon et al., 2020). Annual and monthly plots from the Wave-watch III (WW3) historical model retrieved from location 6°N, 103.2°E in Terengganu waters were used to create the wave data/roses. figure 4 show the annual waves rose diagram for 1985 until 2019 in Kuala Terengganu. The majority of the prevailing wave energy looks to be originating from 55°N.

2.4.3.2. Wind

The research area is influenced by monsoon winds and wave conditions. The South China Sea shoreline is susceptible to monsoon winds during and between monsoons. Data from Kuala Terengganu were provided by Malaysian Meteorological Services Department (MET). Figure 6 depicts Kuala Terengganu's annual wind rose diagram. According to the wind rose, less than 5 m/s winds account for about 80% of the observation period, with 7.7% being quiet. These winds are widespread during the northeast and southwest monsoon seasons. The proportion of calm varies by month and monsoon, from 6.6 to 9.9% (November to March) (October).

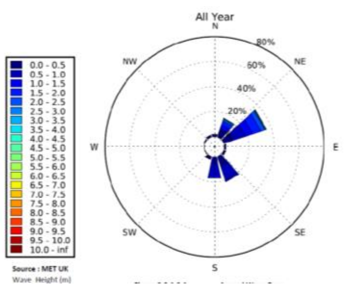


Figure 4. Annual wave rose for Kuala Terengganu (1985-2019).

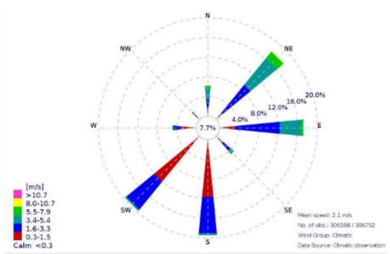


Figure 5. Annual wave rose for Kuala Terengganu (1985-2019).

2.4.3.3. Coastal structure

With all mitigation options available, the protective strategy using hard structures is often recognized as the best coastal erosion management practice, and it is the only option in many countries (Rangel-Buitrago, Williams, & Anfuso, 2018). These structures have been identified as a serious issue along many coastlines around the world because they affect longshore sediment movement or change the dynamical patterns of the nearshore current system (Hsu et al., 2007; Ndour et al., 2018; Prasetya, 2001; Rangel-Buitrago, Williams, Pranzini, et al., 2018). Changes in coastal dynamics caused by external structural disturbances were also discovered in the study area, which stretched from Sultan Mahmud Airport to Telipot Beach (Aziz et al., 2019; Chalabi et al., 2005; Yee Ling et al., 2019). Figure 6 and Table 5 show the location of the structure from the airport to the research area.

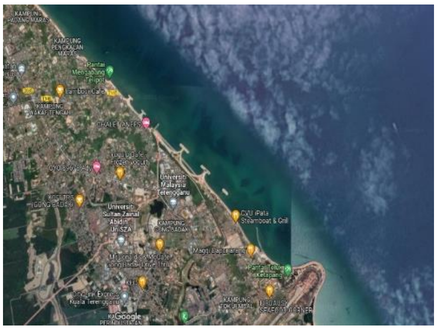


Figure 6. Location of structures along Kuala Nerus until study area.

Table 5. Structures in the Kuala Nerus beach.

Location	Location	Structures
P1	Pantai Tok Jembal	Breakwater
P2	Pantai Tok Jembal	Groyne, Revetment
P3	Pantai Menggabang Telipot	Rock cove, Revetment

2.4.3.4. Human activities

Humans and natural forces shape our beaches and coastal landforms in various areas (Sheik Mujabar & Chandrasekar, 2013). This is due to rising demand factors such as industry, trade and commerce, tourism, human population growth, and migration along the coast, which are all contributing to global pressures in the coastal zone (Zhang et al., 2000). Human activities on the coast typically involve engineering projects such as land reclamation for urban and airport expansion, navigation dredging, and the construction of ports, harbors, and jetties. As a result of disturbances inherent on the coast that act as a buffer for incoming coastal transport, such activities in coastal areas will cause sediment circulation currents to deviate from normal (Zulfakar et al., 2020). Figure 7 and table 6 below depict the activities to be considered in this study.

Figure 7. Extent of study area for human activities consideration.

Table 6. Existing activities summary in study area.

Location	Remarks/Activities
Batu Rakit	Airport Extension
Batu Rakit	Submerged rock 640m from shore. Erosion occurring. Scarp formation
Sg. Mengabang Panjang	Small sand mining from year 2017-2018.
Mengabang Tapah Besar	Small sand mining from year 2018-2019.
Mengabang Tapah Kecil	

3. Results and discussion

3.1. Parameters ranking

Respondents were asked to prioritize parameters based on the evaluation system using a Likert scale ranging from 1 to 5. The analysis was carried out using equation (1), and the results are shown in table 7.

$$\text{Average Value} = \frac{(v1 \text{ x } 1) + (v2 \text{ x } 2) + (v3 \text{ x } 3) + (v4 \text{ x } 4) + (v5 \text{ x } 5)}{(\text{Total number of respondents})} \quad (1)$$

Where;

v1: number of responses for least significance value
v2: number of responses for partially significance value

Table 7. The level of importance of parameter.

Parameter	Less significance	Partially Significance	Significance	More significance	Most significance	Average Value	Importance Index	Level	Ranking
	1	2	3	4	5				
	Evaluation								
Natural Factors (2)									
Wave (N1)	1	2	7	0	0	2.6	52%	M	4
Wind (N2)	0	0	3	6	0	3.3	66%	M	3
Man-made Factors (1)									
Human activities (M1)	0	1	0	6	3	4.1	82%	H	1
Socio-economic Factors (1)									
Coastal Structure (S1)	1	2	0	1	6	3.9	78%	H	2

3.2. Pair-wise comparison

The initial weights for each dimension (natural, man-made, and socioeconomic) were determined using the AHP "pair-wise" method. The results of paired comparisons between factors were obtained from the results of community questionnaires. To address the final aggregate paired comparison matrix, values with a higher number of feedback repetitions were picked (table 8). For example, if 7 respondents gave the same score of 1/2 in a paired comparison of human activities and coastal structures, a score value of 1/2 was chosen for this comparison. To help with additional computations and to evaluate the rationale and correctness of the factor comparisons, the AHP excel spreadsheet was created. Then, as shown in table 9, the fractional values in each row were converted to decimals and the averages determined.

Table 8. Normalized Matrix with a regard to the Cause Criteria.

Criteria	Wave, b_1	Wind, b_2	Coastal structures, b_3	Human activities b_4
Wave, b_1	1	5	1/5	1
Wind, b_2	1/5	1	1/7	1/7
Coastal Structures, b_3	5	7	1	2
Human Activities, b_4	1	5	1/2	1
TOTAL	**36/5**	**20**	**129/70**	**29/7**

Table 9. The normalized matrix with row average values for the cause criteria.

Criteria	Wave	Wind	Coastal Structures	Human Activities	Weightage
Wave	0.0347	0.0625	0.0795	0.0603	0.1804
Wind	0.0069	0.0125	0.0193	0.0086	0.0459
Coastal Structures	0.1736	0.0875	0.1356	0.1207	0.5333
Human Activities	0.0347	0.0875	0.0678	0.0603	0.2404
				TOTAL	**1.000**

3.3. Weightage for each aspect

The weights are supposed to be a continuous function from 0 to 1. The closer the weights are to 1, the more acceptable elements of coastal erosion become. For factors that have less impact on coastal erosion, the weights approach 0. Table 9 shows the final weighting attained for all aspects. The weight allocated to a parameter represented its importance for a certain application and has a significant impact on the index. The goal was not really to get the exact weight distribution to the decimals but to find a broad agreement on the appropriate relative weight of the different components.

Table 10. The Final Weightage for Each Criteria.

Criteria	**Weightage**
Coastal Structures	0.5333
Human Activities	0.2404
Wave	0.1804
Wind	0.0459

3.4. Consistency for AHP matrix

The next step is to double-check the overall matrix's consistency after obtaining the AHP results. This is essential because when comparing two factors side by side, respondents may lose sight of their previous responses. As a result, it's vital to double-check that all responses are genuine and consistent, as well as that the AHP method's basis is met. Inconsistencies appear frequently in AHP, particularly when respondents are requested to conduct too many pair-wise comparisons in the questionnaire. The Consistency Ratio (CR) was created to assess the matrices' consistency. Figure 8 shows the overall discrepancies of the AHP matrices constructed in excel (red box). A score of 0.1 or under (0.1) is considered acceptable, suggesting a moderate degree of matrix consistency (Franek & Kresta, 2014; Yang & Xu, 2016). By 0.1, the inconsistency is likely to be significant, and the AHP results may be inaccurate in determining the factor weightage.

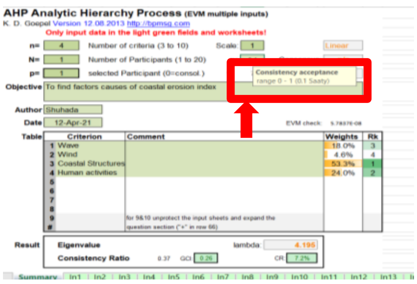


Figure 8. Overall inconsistency from AHP calculation.

The study's findings demonstrate that factors have varying influence on coastal erosion. The following are the study's findings:

i. According to community opinions gathered from questionnaires evaluated with AHP, coastal structural factors have the highest impact on coastal erosion. The existence of numerous coastal structures in the research area, such as offshore breakwaters, revetment, and groin, clearly has several consequences, including sand trapped at the structure's top and restricting sediment movement to nearby areas, causing coastal erosion along the adjacent shoreline. The most of the Kuala Terengganu/Kuala Nerus coastlines are classified as critical due to construction of erosion defense structures, (Chalabi et al., 2005; Muslim et al., 2011; Saadon et al., 2020; Zulfakar et al., 2020).

ii. Human activity in coastal areas is the second most significant contributor to the problem of coastal erosion. The Sultan Mahmud airport, which projects 500 meters into the sea, is one of the human activities that clearly has an impact on the Kuala Nerus coast. Following the completion of construction in 2008, erosion on the beach adjacent to the airport (north side) became visible, causing erosion along 290 to 360 meters in some places (Yee Ling et al., 2019).

iii. The research area faces the South China Sea. The primary wave generating mechanism for waves incident to the study area is wind conditions in the South China Sea and the Gulf of Thailand. Winds from the east and north east coincide with the north-eastern monsoon season, as can be seen. During this season, the waves and wind are at their most extreme, with wave heights reaching 3 to 4 meters. During this season, when the wave direction is perpendicular to the coast (cross-shore), the waves will carry a large amount of sediment and cause erosion.

4. Conclusion
A range of factors contribute to coastal erosion, each of which has a substantial impact. The AHP method has been found to be quite competent and simple in terms of calculation for evaluating the level of contribution of each factor to coastal erosion without the need for physical data from each factor. In this study, the AHP method was used to subjectively assess the experience and intuition of long-established coastal communities on the assessment of categories and levels of coastal erosion risk. The study findings are encouraging, implying that this method could be used in real-world situations. Through a detailed and extensive weighted analysis of several severely eroded areas in Malaysia, an index-based method of determining the erosion rate for each influential factor can be developed in the future.

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