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Coastal Erosion Index Using AHP Analysis – Telipot Beach Terengganu

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Abstract: Coastal erosion is a complex process influenced by natural factors and human activities capable of changing coastlines at an extraordinary rate, thereby the classification of erosion introduced by the National Coastal Erosion Study (NCES) needs to be reviewed to be relevant to current conditions. Thus, this study aims to introduce a community-based erosion index to improve the level of erosion categorization by NCES and then validate the index on beach erosion in Telipot, Terengganu. In particular, each erosion category will be divided into three subcategories: 1) slow, 2) medium, and 3) fast. The index's main variables are gathered from secondary sources, including journals, papers, reports, and books. Based on these main variables, a set of questions was created and distributed to thirty-four respondents who are living along Kuala Nerus's coast, as well as ten coastal experts to categorize the level of beach erosion. The Analytic Hierarchy Method (AHP) was used to analyze the questionnaire data and determine the weight of each important variable. According to the questionnaire responds coastal structure has the greatest influence on beach erosion, with a value of 0.555, followed by human activity, which has weightings of 0.222 as well 0.048, and 0.1750 for wind and waves, respectively. Based on the erosion index calculated using the weights obtained, Telipot's coastal area is classified as Category 1 erosion with moderate erosion speed

Keywords: Coastal erosion, causes of erosion, AHP

1. Introduction

The world's coastlines have a critical role as both an industrial asset and a source of livelihood for many people. The coastal zone plays an important role in human growth, both economically and socially (Bagheri et al., 2021). Since 1985, Malaysian beaches have experienced erosion and land loss due to increased human activity (Ghazali, 2006). According to the National Coastal Erosion Survey (NCES) 2015 (DID, 2015), 1,324 km of Malaysia's coastline were eroded. Coastal erosion is most severe in quickly growing places, including the northern Terengganu River estuary and the Kuala Nerus shoreline. Human activities can impact coastal dynamics, leading to changes in shoreline morphology over time (Prasad & Kumar, 2014). The Terengganu International Airport expansion is a prime example of this. Since the completion of the airport's 500-meter-to-the-sea projection, coastal erosion in the structure's northern part has been visible. NCES reports that since 2015, both natural and man-made factors have contributed to the erosion of the 1.7 km of coastline around Kuala Nerus, particularly in the immediate vicinity of the airport. These degraded areas are anticipated to deteriorate more quickly without interventions, particularly when the variables causing long-term erosion rise. Because of the earlier listed causes, figuring out how much each parameter affects coastal erosion is a crucial part of coastal management. For the purpose of managing the risk of coastal disasters as well as long-term growth and development, it is imperative to identify the most important elements that could impact the current coastal conditions in the case of a disaster (Rangel-Buitrago et al., 2020; Rudiastuti et al., 2020; Sheik Mujabar & Chandrasekar, 2013). Thus, this study aims to examine the most significant factors in depth, taking into account the weights assigned to each component, and apply the findings to the erosion on the Terengganu Telipot Beach. An Analytic Hierarchy Process (AHP) was used to analyse the information gathered from the questionnaire and calculate the weights of each primary factor before obtaining the index for the level of coastal erosion

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2. **Methodology**

2.1 **Study Area: Telipot Beach Terengganu**

The study area stretches from the beach at Tok Jembal to the beach at Telipot, about three kilometers in length. With semi-daily and yearly average tide temperatures ranging from 25 to 27 degrees Celsius, the northeast monsoon predominates over Terengganu's coastal region (Chalabi et al., 2005). As per the 2015 National Coastal Erosion Survey (NCES), the annual erosion rate in Kuala Nerus ranges from 2 to 11 meters. But as of 2016 (Fig. 1), the rate of erosion at Mengabang Telipot and Mengabang Telung, Kuala Nerus, has increased to 20 m/year. In the surrounding area, the rate of erosion has also sharply increased.

Fig.1- Erosion site at the study area.

2.2 **Method and Material**

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.

2.3 **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 objective of AHP's computational and mathematical methods is to create a matrix that illustrates the relative weights of several variables. The steps involved in the AHP computation are 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 fig.2.

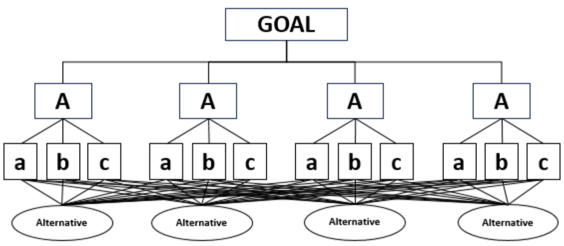

Fig.2 - Typical model of AHP analysis.

2.4 **Parameter's identification**

Finding the initial parameters that affect erosion in this study involved searching the literature for previous studies. Numerous variables contribute to coastal erosion globally, and understanding them at this point is crucial. A noteworthy source of reliable data has been the Scopus database, which is one of the most extensive abstract and citation databases for peer-reviewed literature, including books, scientific journals, and conference proceedings (Nobre & Tavares, 2017). Next, the list was examined using the technique shown in fig.3. Once the results of the thorough literature review are known, the parameters will be shown in Table 1.

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

Dimensions	Factors
Man-made	Human activities Ecosystem destructions
Socio-economic	Coastal structures
Natural factors	Wave Wind Tides Water Temperature

2.5 **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.

2.5.1 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.

2.5.2 Based on questionnaires

A secondary method for identifying factors that contribute to local erosion is to interview residents of coastal areas (Tok Jembal and Telipot) about their experiences and opinions. The goal of the survey was to get between 25 and 30 responses. Respondents ranked each cause of degradation on a five-point scale where's the Likert scale used to evaluate each component's influence on coastal erosion is displayed in Table 3. The questionnaire is written in Bahasa Melayu, and the aim of each question will be explained. Table 4 illustrates the questionnaire's scope.

Table 2 - Summary of parameters in the literature.

Dimensions	Factors	Percentage
Man-made	Human activities	25
	Ecosystem destructions	1
Socio-economic	Coastal structures	41
Natural factors	Wave	15
	Wind	10
	Tides	2
	Water Temperature	1

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	Questionnaires
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.

2.5.3 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

2.5.2.1 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.

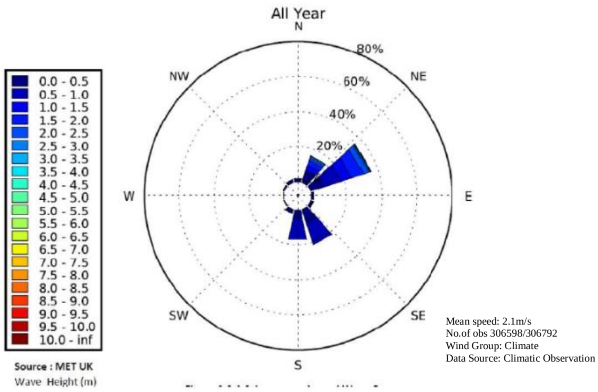

Fig.4-Annual wave rose for K.Terengganu (1985-2019)

2.5.2.2 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 5 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).

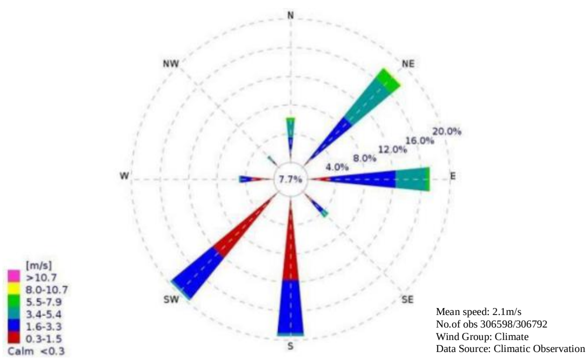

Fig.5- Annual wind rose for K.Terengganu (1985-2019)

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Coastal structure

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; Masselink et al., 2018; Ndour et al., 2018; Prasetya, 2001). 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). Figure 6 show the location of the structure from the airport to the research 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

Fig.6-Location of structures along Telipot beach.

Human activities

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). Table 5 below depict the activities to be considered in this study.

Table 5-Existing activities summary in study area.

Location	Remaks/Activities
Batu Rakit	Airport extension Submerged rock 640m from shore. Erosion occurring. Scarp formation
Sg. Menggabang Panjang	Small sand mining from year 2017 2018.
Menggabang Tapah Besar Menggabang Tapah kecil	Small sand mining from year 2017 2019.

3. Result 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 6.

$$\text{Average value} = \frac{(v^1 \times 1) + (v^2 x2) + (v^3 x3) + (v^4 x4) + (v^5 x5)}{\text{(Total number of respondents)}}$$

Where:

v1: number of responses for least significance value

v2: number of responses for partially significance value

Table 6-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 7). 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 8, the fractional values in each row were converted to decimals and the averages determined.

Table 7-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 8.-The normalized matrix with row average values for the cause criteria.

Criteria	Wave	Wind	Coastal Struc.	Human act.	Weightage
Wave	0.034	0.006	0.079	0.060	0.180
Wind	0.006	0.012	0.019	0.008	0.045
Coastal Struc	0.173	0.087	0.135	0.120	0.533
Human act.	0.003	0.087	0.067	0.060	0.240

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 9-The Final Weightage for Each Criteria.

Criteria	Weightage
Coastal Structures	0.0533
Human Activities	0.240
Wave	0.180
Wind	0.045

Thus, the final Erosion Index Score as below;

Erosion Index Score = 0.533 x sub-index of coastal structure
0.240 x sub-index human activities
0.180 x sub-index wave
0.045 x sub-index wind

Each sub-element's final weight value was entered into the formula, however for this test of study area, only the highest weight is used as shown below. By on-site observation, there are more than three structures available; as a result, the sub-index value is 3 (refer Table 10).

Erosion Index Score = 0.533x sub-index of coastal structure
= 0.533 x 3
= **<u>1.6 (medium)</u>**

Table 10-Coastal structures rating point description on the coastal area

Representative Description	**Rating/Point**
No available coastal structure at coastal area	1
There is one coastal structure at coastal area	2
There are more than two same structures or a combination of structures.	3

4. Conclusion

Concerning the NCES category table and the Erosion Index Score computation above, the coastal area of Telipot is categorized as Category 1 erosion, with a **'moderate'** class for erosion speed. To more precisely determine the level of erosion, the Telipot Beach index score is also compared to the consultant's report, JPS, and previous research. The findings of the index calculation showed that the beach is eroding at a moderate to rapid rate, which is consistent with reports and studies that have been conducted in Telipot.

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References

[1] Aziz, A., Rahman, A. B., Zainal, M. K., Aqiff, M., Wahid, A., Hamzah, M. L., Ariffin, E. H., & Awang, A. A. (2019). Multi Method Analysis for Identifying the Shoreline Erosion During Northeast Monsoon Season. *Journal of Sustainability Science and Management*, *14*(3), 43–54.

[2] Bagheri, M., Ibrahim, Z. Z., Mansor, S., Manaf, L. A., Akhir, M. F., Talaat, W. I. A. W., & Beiranvand Pour, A. (2021). Land-use suitability assessment using delphi and analytical hierarchy process (D-ahp) hybrid model for coastal city management: Kuala terengganu, peninsular malaysia. *ISPRS International Journal of Geo-Information*, *10*(9). https://doi.org/10.3390/ijgi10090621

[3] Chalabi, A., Mohd-Lokman, H., Mohd-Suffian, I., & Karamali, M. (2005). GEomorphological features of kuala terenganu spit from ikonos imagery and aerial phographs using segmentation method. *Asian Association on Remote Sensing - 26th Asian Conference on Remote Sensing and 2nd Asian Space Conference, ACRS 2005*, *1*(January), 577–583.

[4] DID. (2015). *National Coastal Erosion Study 2015*. *1*, ES 27.

[5] Ghazali, N. H. M. (2006). Coastal erosion and reclamation in Malaysia. *Aquatic Ecosystem Health and Management*, *9*(2), 237–247. https://doi.org/10.1080/14634980600721474

[6] Hsu, T. W., Lin, T. Y., & Tseng, I. F. (2007). Human impact on coastal erosion in Taiwan. *Journal of Coastal Research*, *23*(4), 961–973. https://doi.org/10.2112/04-0353R.1

[7] Masselink, G., Russell, P., Yanalagaran, R., Ramli, N. I., Prasad, D. H., Kumar, N. D., Mentaschi, L., Vousdoukas, M. I., Pekel, J. F., Voukouvalas, E., Feyen, L., Williams, A. T., Rangel-Buitrago, N., Pranzini, E., Anfuso, G., Narashid, R. H., Zakaria, M. A., Mohd, F. A. A., Pa'Suya, M. F., … Dalrymple, R. A. (2018). The management of coastal erosion. *Ocean and Coastal Management*, *620*(1), 1–11. https://doi.org/10.1016/j.ocecoaman.2015.06.004

[8] Ndour, A., Laïbi, R. A., Sadio, M., Degbe, C. G. E., Diaw, A. T., Oyédé, L. M., Anthony, E. J., Dussouillez, P., Sambou, H., & Dièye, E. hadji B. (2018). Management strategies for coastal erosion problems in west Africa: Analysis, issues, and constraints drawn from the examples of Senegal and Benin. *Ocean and Coastal Management*, *156*, 92–106. https://doi.org/10.1016/j.ocecoaman.2017.09.001

[9] Nobre, G. C., & Tavares, E. (2017). Scientific literature analysis on big data and internet of things applications on circular economy: a bibliometric study. *Scientometrics*, *111*(1), 463–492. https://doi.org/10.1007/s11192-017-2281-6

[10] Prasad, D. H., & Kumar, N. D. (2014). Coastal Erosion Studies—A Review. *International Journal of Geosciences*, *05*(03), 341–345. https://doi.org/10.4236/ijg.2014.53033

[11] Prasetya, G. (2001). Chapter 4: Protection from coastal erosion. *Coastal Protection in the Aftermath of the Indian Ocean Tsunami: What Role for Forests and Trees? Proceedings of the Regional Technical Workshop, Khao Lak, Thailand, 28–31 August 2006*, 103–132. http://www.fao.org/docrep/010/ag127e/AG127E00.htm

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

[13] Rudiastuti, A. W., Rahadiati, A., Dewi, R. S., Soetrisno, D., & Maulana, E. (2020). Assessing coastal vulnerability index of tourism site: The case of Mataram Coast. *E3S Web of Conferences*, *153*. https://doi.org/10.1051/e3sconf/202015303002

[14] Saaty, T. L. (2002). Decision making with the Analytic Hierarchy Process. *Scientia Iranica*, *9*(3), 215–229. https://doi.org/10.1504/ijssci.2008.017590

[15] Sheik Mujabar, P., & Chandrasekar, N. (2013). Coastal erosion hazard and vulnerability assessment for southern coastal Tamil Nadu of India by using remote sensing and GIS. *Natural Hazards*, *69*(3), 1295–1314. https://doi.org/10.1007/s11069-011-9962-x

[16] Zhang, K., Douglas, B. C., & Leatherman, S. P. (2000). Twentieth-century storm activity along the U.S. East Coast. *Journal of Climate*, *13*(10), 1748–1761. https://doi.org/10.1175/1520-0442(2000)013<1748:TCSAAT>2.0.CO;2

[17] Zulfakar, M. S. Z., Akhir, M. F., Ariffin, E. H., Awang, N. A., Yaacob, M. A. M., Chong, W. S., & Muslim, A. M. (2020). The effect of coastal protections on the shoreline evolution at Kuala Nerus, Terengganu (Malaysia). *Journal of Sustainability Science and Management*, *15*(3), 71–85.

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