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Risk Management of Coastal Ring Roads to Rate Abrasion on The Lhokseumawe City

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ABSTRACT

This paper presents an approach for developing risk management strategies for ring roads in coastal abrasion Lhokseumawe ring roads. Currently, management strategies in these regions are designed to rubble mount breakwaters on coastal performance under traffic loads. However, recent large-scale waves and their associated damage to coastal areas have demonstrated the need to consider the height when making coastal management decisions. This paper aims to develop a risk management strategy that includes handling/controlling accelerated beach abrasion which damages coastal infrastructure buildings and the application of the ALARP scheme as an acceptable risk control limit for decision makers in risk management so as to minimize the potential impact at any given time... The methods consider the rate of coastal abrasion associated with hazards and the economic, social, and environmental consequences of collapse under high tide. The data were collected from the satellite Landsat range of the 1995-2021 year. The analysis adopted Digital Shoreline Analysis System with Enhanced Thematic Mapper (ETM). The risk management strategies are achieved by formulating and solving a multi-objective optimization problem. This problem's findings include abrasion -2.11 m/year and accretion maximum at 111.34 m or 4.45%. The height of the wave was found approximately range 2.33-10.25 sec, and the period average 4.57 m/year. In addition, the periods of the wave were in the range of 2.33-10.25 sec, and the average period was 4.57 sec. The topography characteristics were found between 0 and 8.60 meters, with an average level, is 4.30 meters. The percentage of the slope of the shoreline was found to be 2.90 to 4.47%, and the average beach slope was 3.76%. The risk management achieved in ring roads was relevant to the application scheme ALARP zone to solve the problem from very high to hight risk. The rubble mound breakwaters along the coast were believed to minimize abrasion and mitigate disasters to protect infrastructure ring roads for a long time.

1. Introduction

Coastal ring roads are subjected to abrasion and accretion in marine environments. It must be safe from multiple hazards, such as being hit by waves and abrasion. While initially designed to traffic

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public service for growth up field economic, social, political, and government employment. The capacity of ring roads decays over time due to various aging phenomena such as loads by hit sea waves. The damage to the coast has been identified by Ramakrishnan *et al*., [1] in their research on wave-induced coastal flooding along the southwest coast of India during tropical cyclone Tauktae. Irham *et al*., [2] proposed the management of coastal Aceh Province to maintain coastal zones, coastal development, and future environmental challenges. Nicholls *et al*., [3] have examined the potential investment costs for a global report in the 21st century amounting to US$18.3 trillion. The government does not explicitly release the required investment for Lhokseumawe regions because the entire designed infrastructure implemented plan is not available for any problem. However, the management program must provide the hazards concerns to be competent in establishing a proper infrastructure in Lhokseumawe.

Ring roads along the eastern and west coasts of the Lhokseumawe regions are subjected to multiple extreme natural hazards over their rate abrasion, cost management, and evaluated risk response with principle As Low as Reasonably Practicable (ALARP). The ALARP principle (as low as reasonably practicable) is a scheme used by policymakers to determine the acceptable level of risk for handling the impact of risk [4]. In addition, the Ring Road failure is not only damaged by the multi-hazardous along the Lhokseumawe coast, but also the traffic contributes to the crack of the road surface. The crack tension on the surface road was increasing with the rainy season and congestion on traffic volume. The annual average daily traffic volume (LHRT) on the ring roads was 4,279 vehicles per day at 2017 [5]. Their study were obtained of difference in total time value is 189,877 IDR per vehicle, and the difference in vehicle operating cost (BOK) is 3,289 IDR.

This paper aims to develop a risk management strategy that includes handling/controlling accelerated beach abrasion, which damages coastal infrastructure buildings, and the application of the ALARP scheme as an acceptable risk control limit for decision-makers in risk management to minimize the potential impact at any given time.

The Lhokseumawe Ring Road has been planned since 2012. It is a road connecting the Loskala, Ujong Blang, Pusong, and Kandang villages, which is an alternative route to downtown Lhokseumawe. Currently, the ring road has three bridges to connectivity in the Lhokseumawe region. Furthermore, the existing road from Simpang Lestari to Loskala which is a trace of the ring road along Ujong Blang beach. The construction of the Lhokseumawe city ring road has been built along 3 km of the planned 7 km. The starting point for development starts from the Loskala village, and the endpoint of the road is in the village of Ujong Blang. The research is concerned with the alignment of the Lhokseumawe ring road, the boundary between the Loskala and Pusong villages because it is along the coast. The trace ring road along the beach has been abrasive.

2. Methodology

This study focused on two stages of observing the beach vulnerability categories that affect the abrasion rate of Ujong Blang Lhokseumawe beach, namely physical vulnerability and socio-cultural vulnerability. Physical vulnerability affects abrasion caused by several natural factors and sea wave conditions; socio-cultural vulnerability is a vulnerability caused by treatment or artificial conditions. Each type of vulnerability will be measured by the level of risk that can affect the magnitude of the impact. Data were obtained from observations of locations along Ujong Blang, and Lhokseumawe (primary data) and from previous research/reference sources (secondary data). The complete stages of the research (study plan) are presented in Figure 1.

2.1 Study Plan

The following are the procedures and research work steps as shown in Figure 1 which shall be elaborated in the following subsections :

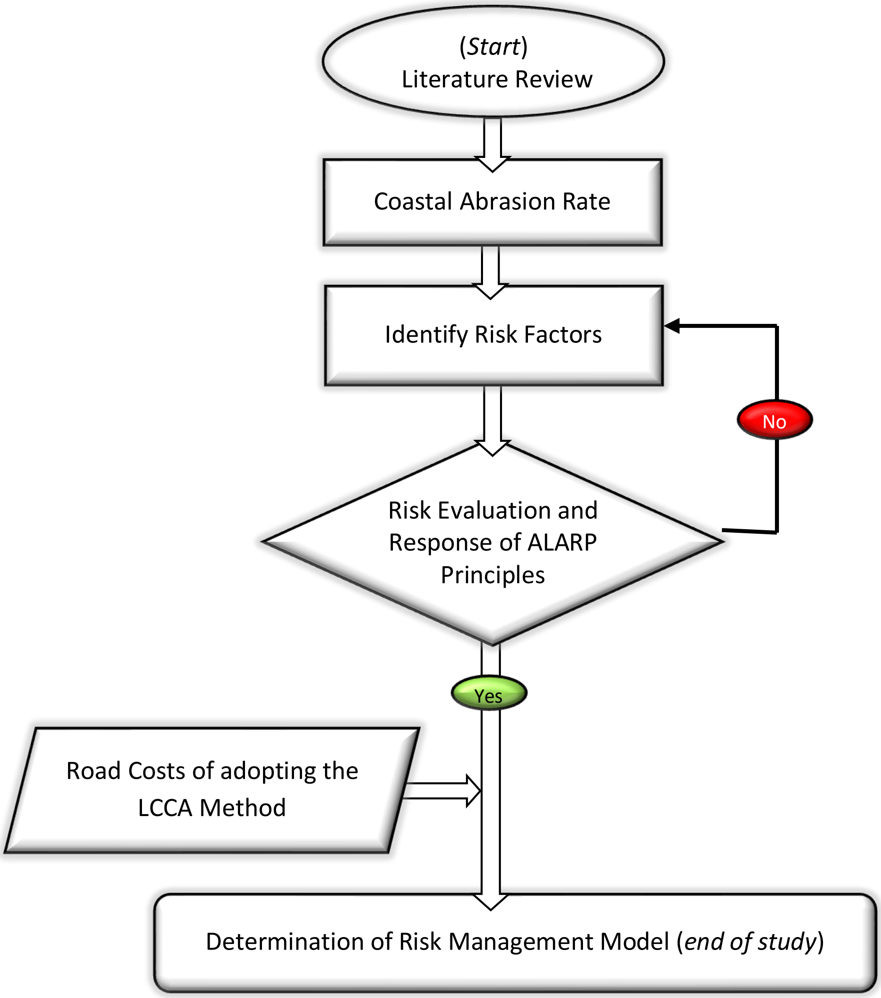

Fig. 1. Flowchart of Study

2.2 Determination of Coastal Abrasion Rate

Determination of the rate of coastal abrasion as stated above, namely by determining the physical vulnerability that occurs along Ujong Blang Lhokseumawe Beach, then 8 points for measuring beach slope are determined, 1 point for observing tides and 1 point for observing sea waves as shown in Figure 3.

The process carried out in this study consisted of two analyses, namely: analysis and interpretation of satellite imagery (Landsat) data for mapping shoreline changes and statistical analysis for the degree of shoreline change over the last 25 years. Landsat data analysis and interpretation consist of image cropping, image restoration, image enhancement, geometric correction, digitization, and overlay. Statistical analysis to determine the level of shoreline change or the level of beach abrasion was carried out using DSAS (Digital Shoreline Analysis System) software.

Furthermore, the application used for the process is ArcGIS. ArcGIS is a program that can process geographic data and information. The processed output is usually in the form of map visualization and is often used in spatial-related fields [6]. The use of software in research (including DSAS) is used to accelerate research achievements, in data analysis it is easier to understand and greatly increases the efficiency of data management [18].

2.3 Tools and Materials

The tools used include software for data analysis ArcGIS, Ocean Data View, and Digital Shoreline Analysis System (DSAS). The data used are Landsat 5 TM, Landsat 7 ETM+, and Landsat 8 OLI satellite images, Tidal Data, and Bathymetry and Topography Data.

2.3.1 Coastline Change Analysis

The shoreline change analysis in this study adopts the Digital Shoreline Analysis System software integrated with ArcGIS software. Analysis of shoreline changes using the NSM (Net Shoreline Movement) method. The NSM method is a module for calculating the distance between the oldest and youngest shorelines for each transect [7]. In this study, virtual transects were used with a distance between transects of 10 m. The results of making virtual transects along the coastline of the research location obtained 601 virtual transects. To ensure the distance between transects and actual distance measurement/matching was also carried out in the field.

2.3.2 Socio-economic Vulnerability

The relative population is a statistical calculation that relates to the average number of inhabitants of an area and the physical space it includes. The Ujong Blang Beach area is located in 3 villages in Banda Sakti District, Lhokseumawe City, with an area of 11.24 km2 with a population of 14,000 people. The area along Ujong Blang Beach is relatively dense. Most of the Ujong Blang Beach area is designated as a tourist area. Coastal vulnerability sub-index related to vulnerable targets, covering socio-economic, ecological, and cultural aspects [6].

2.3.3 Road Costs Estimation

Cost estimation for determining alternative design strategies for constructing the Lhokseumawe Ring Road using the Life Cycle Cost Analysis (LCCA) method with sensitivity parameters to variations in interest rates and inflation rates based on the cost of managing each alternative pavement thickness design. The use of the LCCA method is to minimize discounted life cycle costs [8-9]. This application is following the rules of Road Pavement Planning Guidelines Number 02/M/BM/2013 Ministry of Public Works Directorate General of Highways of Indonesia.

3. Results

3.1 Tidal Range

The results of tidal data analysis show that the average sea level (MSL) of Ujong Blang Beach waters is 2.24 m. The highest tide in the waters of Ujong Blang Beach is at a level of 3.35 m, while at low tide, the sea level is at 1.12 m (Figure 2). The results of the analysis of the characteristics of the waves obtained a tidal range of 1.16 m, with the highest height at full moon at 2.61 m, and the lowest altitude at low tide at spring tide is 2.44 m. Meanwhile, during the neap tide, the highest peak at high tide is 2.03 m, and the lowest altitude at low tide is 1.86 m.

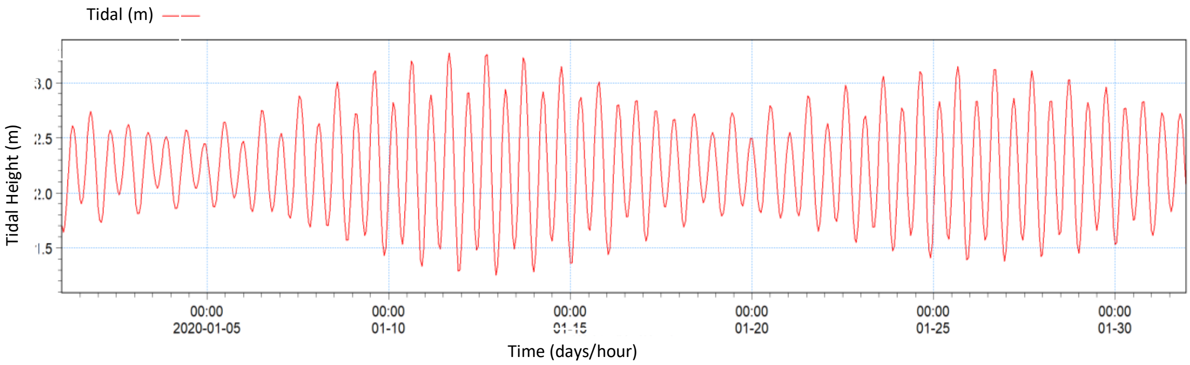

Fig. 2. Tidal pattern at the research location

3.2 Sea Wave

Sea waves around the study site in the 1995-2020 timeframe are shown in Figure 3. Sea level height ranges from 0.10-2.01 m with an average of 0.48 m, while sea waves are 2.33- 10.25 s with an average period of 4.57 s. For 25 years, the dominant sea waves have moved from the northwest, northeast, and north with a pattern of propagation perpendicular to the coast.

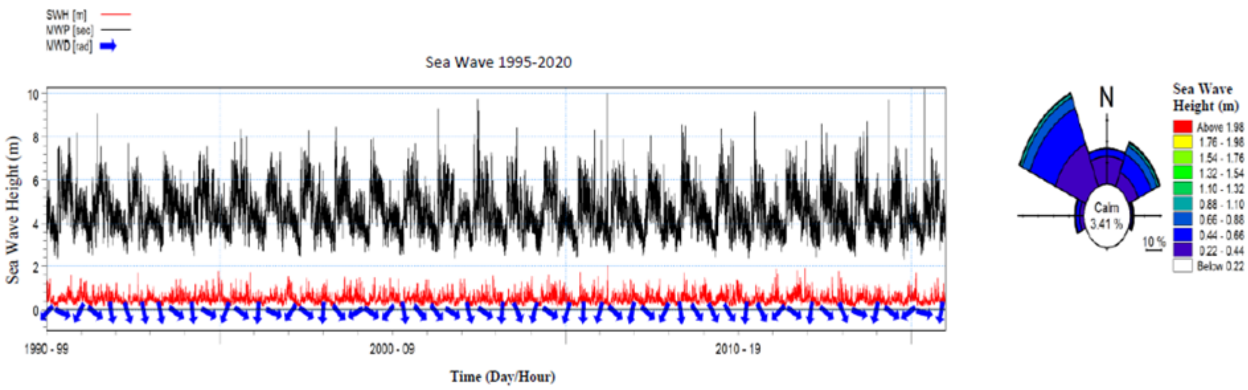

Fig. 3. Characteristics of sea waves at the research location in 1995-2020

3.3 Topography and Slope

The coastal area of Ujong Blang Lhokseumawe Beach's coastal topography ranges from 0.00-8.60 m with an average slope of 4.30 m (Figure 4). The coastal topography of Ujong Blang Beach is a coastal area with a high level of vulnerability [10-11]. The slope was observed at 8 locations with a beach slope range of 2.90-4.47% with an average gradient of 3.76%.

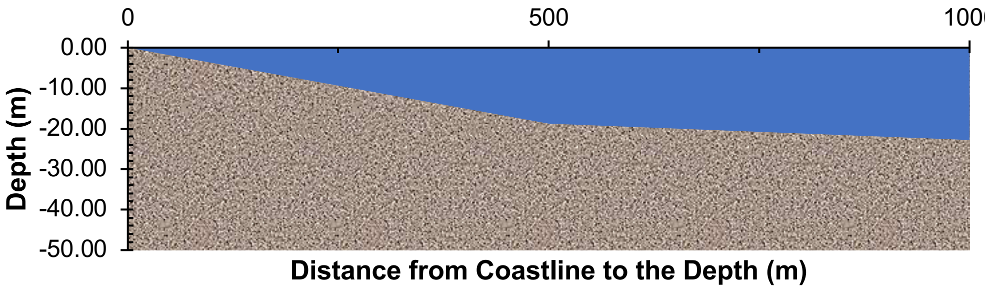

Fig. 4. Slope profile of Ujong Blang Beach at observation point 8

3.4 Shoreline Change

Changes in the coastline of Ujong Blang Lhokseumawe in 1995-2020 underwent many transformations both due to natural physical processes on the beach and human activities around Ujong Blang Beach. During 1995-2020, Ujong Blang Beach experienced the farthest abrasion of -52.70 m (transect 598) or around -2.11 m/year, and the farthest accretion occurred on the coast on transect 83 with an accretion distance of up to 111.34 m or around 4.45 m/year (Figure 5). If seen from its position, it is possible that accretion occurred around transect 83 and could be caused by a sedimentation process in the estuary around the area that experienced accumulation. The coast's geography is in transect 83, and there are rivers around the space. Accretion in this section may be caused by sedimentary material carried from the sea to the river or from the river to the sea and accumulating around transect 83 (Figure 5).

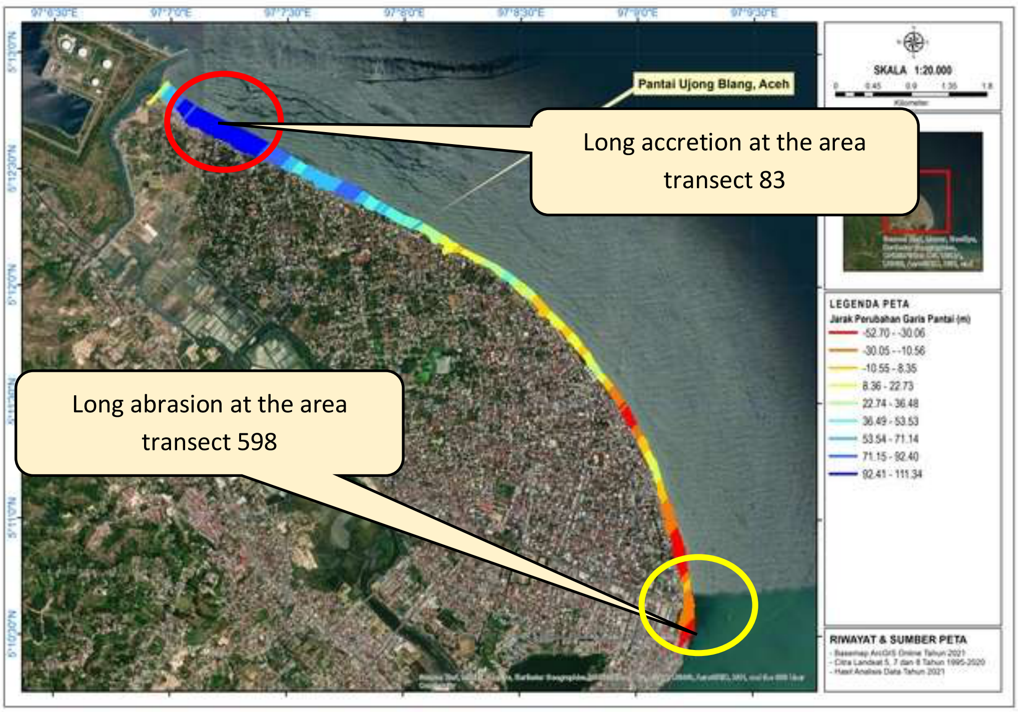

Fig. 5. Changes in the coastline at Ujong Blang Beach during (1995-2020)

Meanwhile, on the beach that experienced the farthest abrasion on the 598 transects, the abrasion was most likely caused by propagating waves and ocean currents along the coast around the site. The geographical location of the beach at transect 598, which forms an indentation towards the sea and tends to be perpendicular to the sea, allows the beach around transect 598 to be quickly eroded by alongshore currents and waves coming from the sea towards the coast. This process can cause the release of coastal sedimentary material and be carried to other places resulting in significant abrasion around the area. The frequency of accretion and abrasion are shown in Figure 6. The abrasion was dominant to accumulation after the sea level wave hit the coastal compared to accretion.

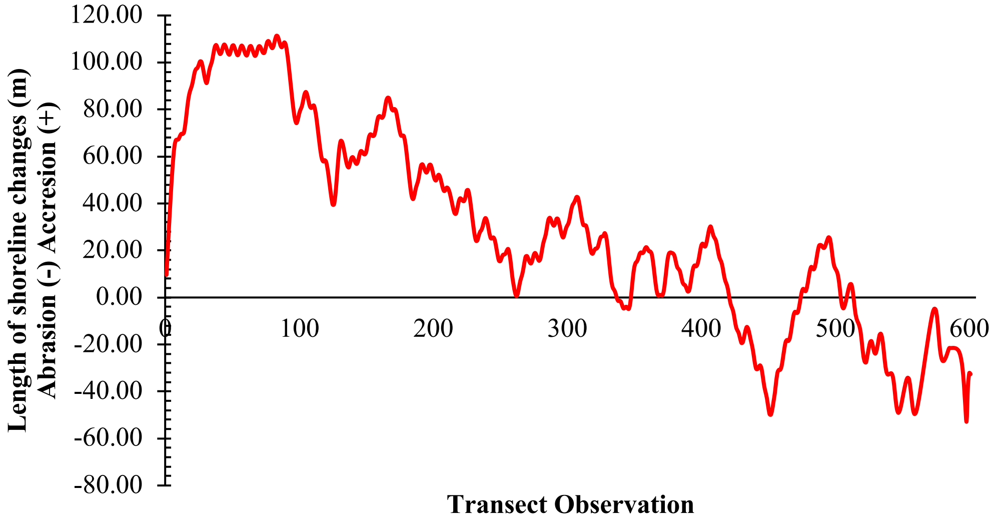

Fig. 6. Shoreline change profile at Ujong Blang Beach 1995-2020 at each observation transect

Based on the results of the field survey and the recording of existing data, Table 1 provides a tabulation of several conditions, the magnitude, and level of socioeconomic vulnerability of the people living in the villages of Hagu Barat Laut, Ulee Jalan, and Ujong Blang.

Table 1
Records of Socio-Economic Vulnerability Data

Vulnerability Socio-Economic	Condition/Amount/ Vulnerability Level	Data Source
Population Density Km2)	Tourism and Residential Areas	Observation
Land Use and Growth	22 %	Observation
Urbanized Area Percentage	47.39	BPS Lhokseumawe 2021
Dependent Population (Unproductive population; %)	0.20	BPS Lhokseumawe 2021
Number of Illiterate Population (%)	1 – 2 Km	BPS Lhokseumawe 2021
Road Network	Maritime Tourism Area	Observation
Tourism Area	Tourism and Residential Areas	Data Records Aceh Utara Goverment

3.5 Cost of Road Maintenance

The initial construction costs for each work item can be seen in Figure 7. While maintenance costs and replacement costs are costs that will be incurred in the next few years, the calculation is influenced by inflation and interest rates. The final value is the output value. The road life for the upper layer is 20 years and for the lower layer is 40 years [12-13].

The results of the LCC analysis of each pavement thickness can be presented in Figure 7.

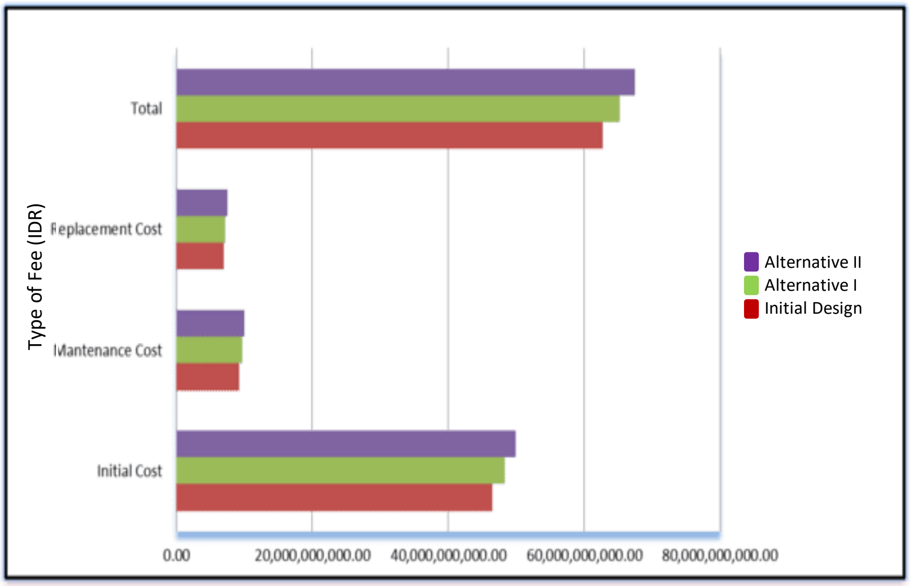

Fig. 7. LCC analysis results for each alternative pavement thickness

3.6 Risk Identification and Measurement

A coastal erosion vulnerability assessment that integrates physical and social components is necessary to limit coastal erosion and promote sustainable development [14]. The final output of research results is very effectively used by coastal management authorities and decision makers to better manage coastal zones and to ensure efficient adaptation measures to minimize losses due to potential impacts of predicted sea level rise through appropriate actions to protect life, property, and environment can be planned in a timely manner [15]. The coastal vulnerability criteria used to determine the range of values for each criterion are adjusted according to the indicators or parameters of each unit. Each range of vulnerability criterion values is classified with a vulnerability rating that corresponds to the respective class criterion parameters from 1 to 5. The risk management framework includes the inclusion of risk frequency in the calculation of risk ratings, risk criteria parameters for risk probability and risk severity [17]. Based on observations of physical and socio-cultural vulnerabilities in the Ujong Blang Lhokseumawe Beach area, it can be concluded as shown in Table 2.

Table 2
Identification of Vulnerabilities and Risk Impacts of Ujong Blang Beach

Classification of Vulnerability	Sites of Vulnerability	Range	Level	Category
Physical	Geomorphology	Sloping sandy beach	3	Medium
	Shoreline Proximity	< 1 Km	5	Very High
	Tidal	1.12 – 3.35 m	5	Very High
	Sea Wave	0.10 – 2.01 m	4	High
	Topography and Slope	2.90 – 4.47 %	3	Medium
	Shoreline Changes	-2.11 m/year	4	High
	Rate of Accretion and Erosion (m/year)	< - 2.0 (Erosion)	5	Very High
Socio-Economic	Population Density (Km^2)	1.256 Km	4	High
	Land Use and Growth	Tourism and Residential Areas	5	Very High
	Urbanized Area Percentage	22 %	2	Low
	The Population is Dependent (population is not productive; %)	47.39	2	Low
	Number of Illiterate Population/Literacy Level (%)	0,20	5	Very High
	Road/Infrastructure Network	1 – 2 Km	4	High
	Areas of Tourism/Cultural Heritage/Ethnographic Interest	Maritime Tourism Area	4	High

Meanwhile, Table 3 shows the physical and socio-economic vulnerability probability at Ujong Blang Beach.

Table 3
Identification of the Probability of Ujong Blang Beach

Category Vulnerability	Type of Vulnerability	Vulnerability Potential	Level	Category
Physical	Geomorphology	Hardly Happened	1	Very low
	Shoreline Proximity	Sometimes Happen	3	Medium
	Tidal	Almost Certain Happen	5	Very High
	Sea Wave	Seldom Happen	2	Low
	Topography and Slope	Sometimes Happen	3	Medium
	Shoreline Changes	Sometimes Happen	3	Medium
	Rate of Accretion and Erosion	Often Happen	4	High
Socio-Economic	Population Density	Sometimes Happen	3	Medium
	Land Use and Growth	Seldom Happen	2	Low

Urbanized Area Percentage	Seldom Happen	2	Low
Unproductive population	Sometimes Happen	3	Medium
Number of Illiterate Population/Literacy Level	Sometimes Happen	3	Medium
Road/Infrastructure Network	Sometimes Happen	3	Medium
Areas of Tourism/Cultural Heritage/Ethnographic Interest	Sometimes Happen	3	Medium

Furthermore, based on the Impact and Probability of Risk, the value of the risks that occur along the Ujong Blang coastline can be identified in Table 4.

Table 4
Value and Risk Rating of Ujong Blang Beach

No.	Type of Vulnerability	Probability	Impact	Risk Value	Category
A	**Physical Vulnerability**				
1.	Geomorphology	1	3	3	Very Low
2.	Shoreline Proximity	3	5	15	High
3.	Tidal	5	5	25	Very High
4.	Sea Wave	2	4	8	Medium
5.	Topography and Coastal Slope	3	3	9	Medium
6.	Shoreline Change	3	4	12	High
7.	Rate of Accretion and Erosion	4	5	20	Very High
B	**Socio-Economic Vulnerability**				
1.	Population Density	3	4	12	High
2.	Land use and Growth	2	5	10	High
3.	Urbanized Area Percentage	2	2	4	Low
4.	Unproductive Population	3	2	6	Low
5.	Number of Illiterate Population	3	5	15	High
6.	Road/Infrastructure Network	3	4	12	High
7.	Tourist Area	3	4	12	High

Based on the determination of the type and rating of the risk assessment that significantly affects the alignment of the Lhokseumawe Ring Road due to the physical vulnerability of the coast, namely the ebb and flow in one day, there are two highs and two lows. The accretion is low, but the erosion was maximum rate. Another influencing factor is changes in the coastline which impact the ring road foundation. Meanwhile, another risk that can also affect the existence of the ring road is a large number of illiterate people because most of them are fishermen. Safety and risk management can be accomplished by creating a risk management framework and enhancing risk assessment procedures [19].

Based on the results of risk identification and analysis (Figure 8), the Ujong Blang Lhokseumawe Beach area has a very high tidal risk (A3), and accretion and erosion rate (A7) (inherent risk). Managers must control both types of risk. Furthermore, a risk evaluation is carried out using the ALARP principle for risk control. Risk assessment and risk management are identified as very important fields and make important contributions to practical decision-making [16]. The ring road management policy is needed to determine the maturity level of road damage handling and risk control/mitigation using the ALARP principle. Ring road managers use the ALARP principle as an acceptable risk limit (risk appetite). Following are the results of the evaluation and risk response based on the ALARP principles shown in Table 5.

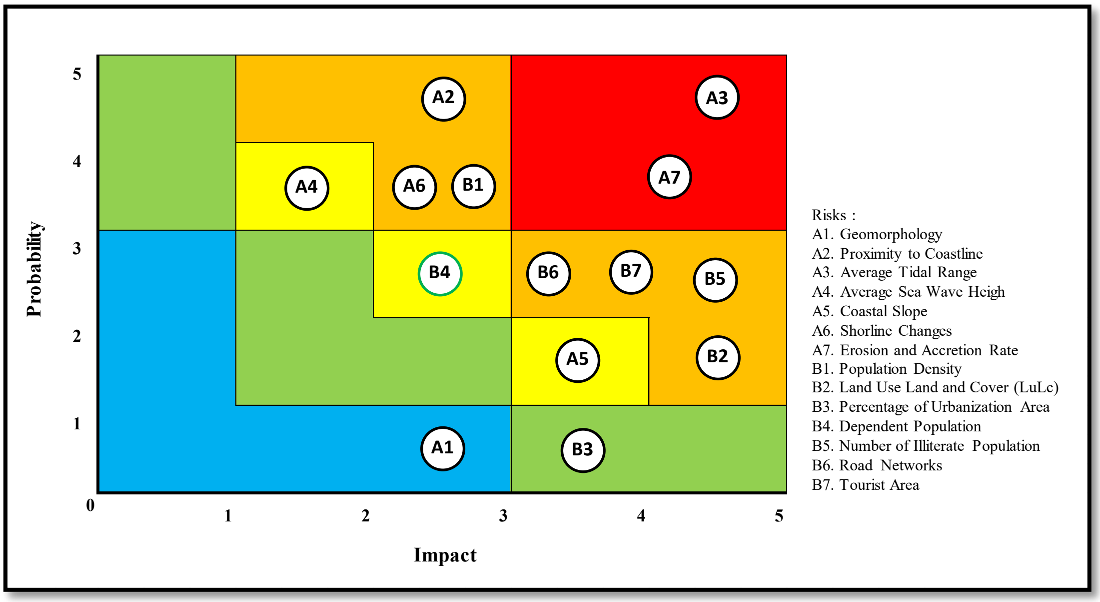

Fig. 8. RACM of the Ujong Blang Lhokseumawe Beach Area (Before Control, Inherent Risk)

Table 5
Evaluation Results and Risk Priority based on the ALARP Scheme

Risk Type	Risk Value	Risk Priority	Principle of ALARP Scheme: Risks that Need to be Controlled	Criterion
Tidal	25	I		Intolerance Zone
Level of Erosion and Accretion	20			
Shoreline	15	II		ALARP Zone
The Number of People Illiterate	15			
Shoreline changes	12			
Population Density	12			
Road Network	12			
Tourist Area	12			
Land use and Growth	10			
Slope of Coastal	9	III		
Sea Wave	8			

Unproductive Population	6	IV		Ideal Zone
Persentase Area Urbanisasi	4			
Geomorphology	3	V		

Based on the ALARP scheme, tidal risk and levels of erosion and accretion are categorized into intolerable zones, meaning that the manager must be able to control the two risks referred to. To minimize the impact of tidal, accretion, and erosion risks (maximum risk) with a minimum maintenance cost and the availability of building materials is a conventional type breakwater structure. So with risk control, the acceptable risk value (risk appetite) follows the ALARP scheme, so the Risk Assessment Criteria Matrix (RACM) for the Ujong Blang Lhokseumawe beach area after residual risk is shown in Figure 9.

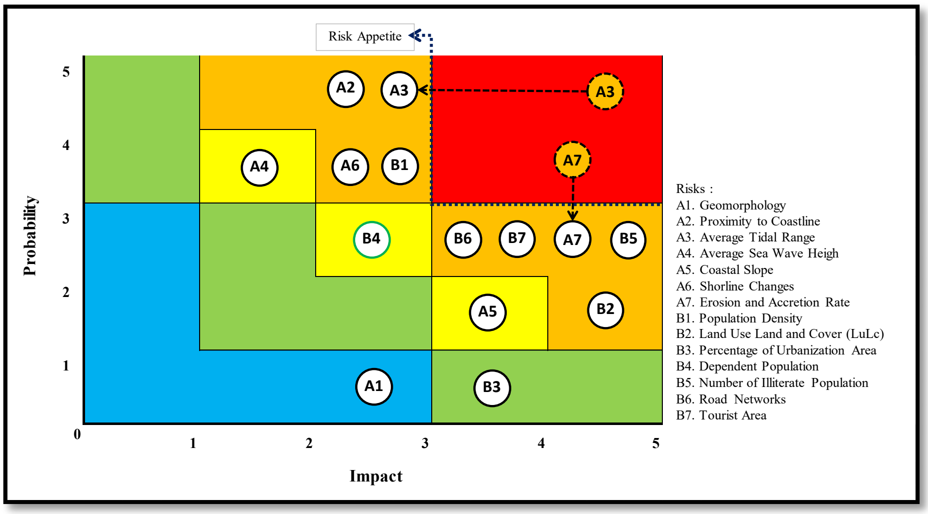

Fig. 9. RACM of the Ujong Blang Lhokseumawe Beach Area (After Control, Risk Appetite)

3.7 Determination of the Risk-Based Management Model

The following is the potential amount of damage to the construction of the Lhokseumawe Ring Road based on the risks that may occur along the Ujong Blang Lhokseumawe beach area for the next 25 years (without control). The potential damage as shown in Table 6.

Table 6
Potential Damage to the Lhokseumawe City Ring Road

RISK CATEGORY	RISK VALUE RANGE (SCORING)	RISK SCALE	ROAD DAMAGE CONDITION VALUE (PCI INDEX)	POTENTIAL COSTS DUE TO IMPACT (%)	BROAD CONSTRUCTION COSTS (Initial Design, X IDR. 1 Million)	PPOTENTIAL COST OF DAMAGE IMPACT OF LHOKSEUMAWE CITY RING ROADS (x IDR. 1.000.000)													
						PHYSICAL RISK							SOCIO-ECONOMIC RISK						
						A1	A2	A3	A4	A5	A6	A7	B1	B2	B3	B4	B5	B6	B7
VERY HIGH	16 - 25	5	0 - 25	≥ 100				46,481				46,481							
HIGH	10 - 15	4	25 -55	≥ 85			39,509				39,509		39,509	39,509			39,509	39,509	39,509
MEDIUM	7 - 9	3	55 - 70	≥ 70	46,481				32,537	32,537						32,537			
LOW	4 - 6	2	70 - 85	≥ 55											25,565				
VERY LOW	1 - 3	1	85 - 100	≤ 25		11,620													
AVERAGE TOTAL						35,525							36,521						
AVERAGE TOTAL (COMBINED)						36,023													

Determining the minimum cost (C_{min}) that the ring road management can allocate for preventing the impact of the risks that occur are:

$$RM_{OPT} = C_{min} = \left[\frac{(R_0 - Rmaks)}{(R_0)} \; x \; C_0\right] \leq C_p \quad (1)$$

$$RM_{OPT} = C_{min} = \left[\frac{(25-15)}{(25)} \; x \; 36{,}023{,}000{,}000 \text{ IDR}\right] \leq 46{,}481{,}000{,}000 \text{ IDR}$$

$$RM_{OPT} = C_{min} = 24{,}015{,}333{,}333 \text{ IDR} \leq 46{,}481{,}000{,}000 \text{ IDR}$$

From the results of the presentation of equation (1), it can be simplified into an optimum risk management model (RMopt) to minimize road maintenance costs and maximum risk during the road construction cycle on the waterfront is prone to coastal abrasion (Figure 10).

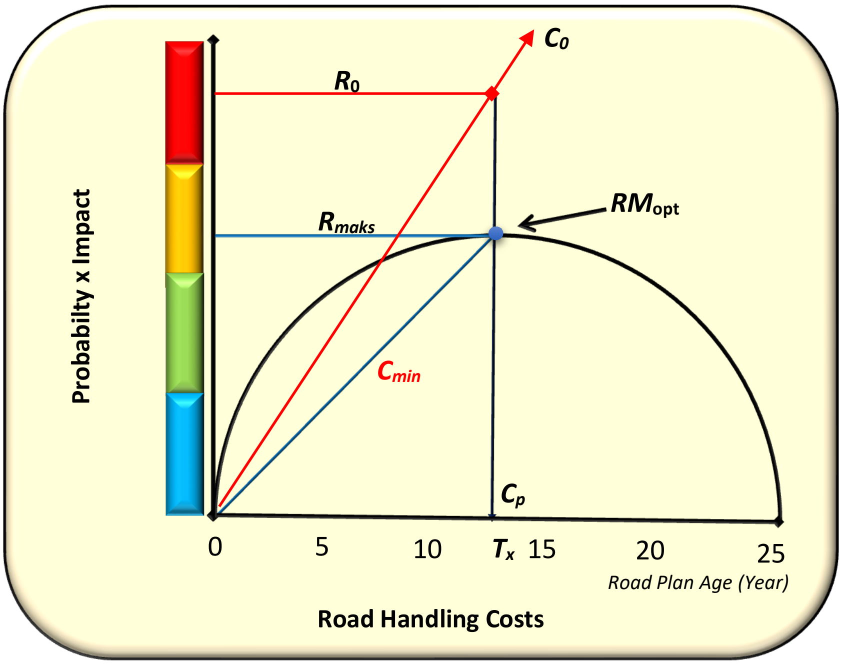

Fig. 10. Probability and Impact Relationship with Road Handling Costs (RMopt)

Figure 10 describes that optimum risk-based management (RMopt) is a relationship of handling road costs before a high risk has a big impact (R0) with a large handling cost (C0) becomes a maximum risk (Rmax) when the risk occurs (Tx) up to getting the cost handling as small as possible (Cmin) during the life of the road plan. The maximum risk (Rmax) referred to is a very high risk with a large impact (R0) that has been given treatment (Cp), or high risk has become moderate (ideal ALARP scheme) according to the type of risk that occurs. In this context, all risks that occur on the Lhokseumawe City Ring Road during the life of the road plan cannot be avoided or diverted, because this road is the main alternative road for entering and leaving Lhokseumawe City.

4. Conclusions

The abrasion rate of Ujong Blang Beach is -2.11 m/year, and the farthest accretion occurs on the coast at transect 83 with an accretion distance of 111.34 m or around 4.45 m/year. A significant abrasion phenomenon occurred in 2012-2013, as indicated by transect 1 with an abrasion distance of -217.62 m which could affect damage to the Lhokseumawe City Ring Road alignment. Risk factors other than abrasion include sea waves with a period range of 2.33-10.25 s with an average of 4.57 s which are very dominant moving from the northwest, northeast and north with a pattern of propagation perpendicular to the coast, then the height of the beach topography ranges from 0.00-8.60 m with an average of 4.30 m. The slope of the beach observed at 8 observation sites obtained a range of 2.90-4.47% with an average slope of 3.76 %. The optimal risk-based management carried out by ring road managers is the ALARP scheme approach to control very high to high risks (ALARP Zones), namely by constructing preventive structures in the form of conventional type breakwaters with minimal handling costs to mitigate a greater impact on damage to the Lhokseumawe City Ring Road if the risk occurs during the life of the road plan.

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References

[1] Ramakrishnan, Ratheesh, P. G. Remya, Anup Mandal, Prakash Mohanty, Prince Arayakandy, R. S. Mahendra, and TM Balakrishnan Nair. "Wave induced coastal flooding along the southwest coast of India during tropical cyclone Tauktae." *Scientific Reports* 12, no. 1 (2022): 19966. https://doi.org/10.1038/s41598-022-24557-z.

[2] Irham, Muhammad, Muhammad Authar, Edy Miswar, and Anwar Deli. "Coastal management status of Banda Aceh city and Aceh Besar and the future trends." In *E3S Web of Conferences*, vol. 340, p. 04005. EDP Sciences, 2022. https://doi.org/10.1051/e3sconf/202234004005.

[3] Nicholls, Robert John, Jochen Hinkel, Daniel Lincke, and Thomas van der Pol. "Global investment costs for coastal defense through the 21st century." *World Bank Policy Research Working Paper* 8745 (2019).

[4] HSEbook. (2001). Reducing Risks, Protecting People, ISBN 0 7176 2151 0. https://www.semanticscholar.org.

[5] Qadri, Rijalul, Muhammad Isya, and Sofyan M. Saleh. "Kajian Manfaat Pembangunan Jalan Lingkar Kota Lhokseumawe (Studi Kasus Jalan Lingkar Kota Lhokseumawe)." *Jurnal Teknik Sipil* 1, no. 2 (2017): 461-474.

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

[7] Oyedotun, Temitope DT. "Shoreline geometry: DSAS as a tool for historical trend analysis." *Geomorphological techniques* 3, no. 2.2 (2014): 1-12.

[8] Dell'Isola, Alphonse J., and Stephen J. Kirk. *Life cycle costing for design professionals*. McGraw-Hill Companies, 1981.

[9] Scheving, Asta Guciute. "Life cycle cost analysis of asphalt and concrete pavements." PhD diss., 2011.

[10] Joesidawati, Marita Ika. "Penilaian kerentanan pantai di wilayah pesisir Kabupaten Tuban terhadap ancaman kerusakan." *Jurnal Kelautan: Indonesian Journal of Marine Science and Technology* 9, no. 2 (2016): 188-198. https://doi.org/10.21107/jk.v9i2.1667

[11] Suhana, Mario Putra, Risandi Dwirama Putra, Leica Febby Shafitri, Muhamad Muliadi, Khairunnisa Khairunnisa, I. Wayan Nurjaya, and Nyoman Metta N. Natih. "TINGKAT KERENTANAN PESISIR DI UTARA DAN TIMUR PULAU BINTAN PROVINSI KEPULAUAN RIAU TAHUN 2020." *Jurnal Teknologi Perikanan dan Kelautan* 11, no. 1 (2020): 11-27. https://doi.org/10.24319/jtpk.11.11-27

[12] PMBOK, 2010, A Guide to the Project Management Body of Knowledge (PMBOK Guide) Fourth Edition, Project Management Institute.

[13] Michigan Department of Transportation (MDOT. (2021). Pavement Design and Selection, Michigan Departement of Transportation, Edition Juni 24.

[14] Ahmed, Naser, Newton Howlader, Muhammad Al-Amin Hoque, and Biswajeet Pradhan. "Coastal erosion vulnerability assessment along the eastern coast of Bangladesh using geospatial techniques." *Ocean & Coastal Management* 199 (2021): 105408. https://doi.org/10.1016/j.ocecoaman.2020.105408

[15] Mohd, Fazly Amri, Khairul Nizam Abdul Maulud, Othman A. Karim, Rawshan Ara Begum, Nor Aslinda Awang, Anizawati Ahmad, Wan Ahmad Hafiz Wan Mohamed Azhary, Mohd Khairul Amri Kamarudin, Mokhtar Jaafar, and Wan Hanna Melini Wan Mohtar. "Comprehensive coastal vulnerability assessment and adaptation for Cherating-Pekan coast, Pahang, Malaysia." *Ocean & Coastal Management* 182 (2019): 104948. https://doi.org/10.1016/j.ocecoaman.2019.104948

[16] Aven, Terje. "Risk assessment and risk management: Review of recent advances on their foundation." *European Journal of Operational Research* 253, no. 1 (2016): 1-13. https://doi.org/10.1016/j.ejor.2015.12.023

[17] Amin, Zamree, and Roslina Mohammad. "Bowtie analysis for risk assessment of confined space at sewerage construction project." *Progress in Energy and Environment* (2023): 22-34. https://doi.org/10.37934/progee.24.1.2234
[18] Wang, Dan, Terh Jing Khoo, and Zhangfei Kan. "Exploring the application of digital data management approach for facility management in Shanghai's high-rise buildings." *Progress in Energy and Environment* (2020): 1-15.
[19] Yusof, Mohd Fahmi Mohd, and Roslina Mohammad. "Risk management framework and practices for boiler operations in Malaysia." *Progress in Energy and Environment* (2023): 26-38. https://doi.org/10.37934/progee.23.1.2638