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SELECTION OF MUARA ABU BEACH SAFETY SYSTEM IN KUPANG CITY USING ANALYTICAL HIERARCHY PROCESS METHOD

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Abstract— *Kupang City has a large coastal area, most of them live so close to the coastline that there is no longer a coastal buffer zone. One of the beaches close to the settlement is Muara Abu beach, which is located in Oesapa Barat Village, Kelapa Lima Sub-district, Kupang City. This research uses the Analytical Hierarchy Process (AHP) method with the following objectives are Establishing a coastal safety system at Muara Abu beach location based on the decision results of the AHP method used optimally and Analyze the coastal safety system using the AHP method. The criteria used in the selection of coastal safety systems are Waves (history, vulnerability, probability, and threat), Erosion (Shoreline change, scouring at the foot of the building, length of eroded beach), Abrasion (Width of abraded beach, length of abraded beach), Sedimentation (Length of closed estuary, percentage of estuary opening, and influence of sedimentation) and Environment (Sea water quality, coral reefs, mangroves). And the alternative system chosen is structural coastal protection, namely Seawall, Groin and Jetty. The results of calculations with the AHP method show the priority scale for securing Muara Abu Beach can be sorted as follows are Jetty is 46.53%, Seawall is 33.37% and Groin is 20.10% The selection of coastal safety systems using the AHP method provides objective results in determining the best alternative. Jetty is the main solution recommended to be implemented in Muara Abu Beach. Further research is recommended to examine the effectiveness of Jetty implementation in the long term.*

Keywords: *alternative, analytical hierarchy process, beach safety system, decision, muara abu beach.*

Intisari— Kota Kupang memiliki wilayah pesisir yang luas, sebagian besar dari mereka tinggal sangat dekat dengan garis pantai sehingga tidak ada lagi daerah penyangga pantai. Salah satu pantai yang dekat dengan pemukiman tersebut adalah pantai Muara Abu yang terletak di Kelurahan Oesapa Barat, Kecamatan Kelapa Lima, Kota Kupang. Penelitian ini menggunakan metode Analytical Hierarchy Process (AHP) dengan tujuan sebagai berikut: Menetapkan sistem pengaman pantai pada lokasi pantai Muara Abu berdasarkan hasil keputusan metode AHP yang digunakan secara optimal dan Menganalisis sistem pengaman pantai menggunakan metode AHP. Kriteria yang digunakan dalam pemilihan sistem pengaman pantai adalah Gelombang (riwayat, kerentanan, probabilitas, dan ancaman), Erosi (Perubahan garis pantai, gerusan pada kaki bangunan, panjang pantai yang tererosi), Abrasi (Lebar pantai yang terabrasi, panjang pantai yang terabrasi), Sedimentasi (Panjang muara yang tertutup, persentase pembukaan muara, dan pengaruh sedimentasi) dan Lingkungan (Kualitas air laut, terumbu karang, mangrove). Dan sistem alternatif yang dipilih adalah pengamanan pantai secara struktural yaitu Seawall, Groin dan Jetty. Hasil perhitungan dengan metode AHP menunjukkan skala prioritas pengamanan Pantai Muara Abu dapat diurutkan sebagai berikut Jetty sebesar 46,53%, Seawall sebesar 33,37% dan Groin sebesar 20,10% Pemilihan sistem pengaman pantai dengan metode AHP memberikan hasil yang objektif dalam menentukan alternatif terbaik. Jetty merupakan solusi utama yang direkomendasikan untuk diterapkan di Pantai Muara Abu. Disarankan untuk dilakukan penelitian lebih lanjut untuk mengkaji efektivitas penerapan Jetty dalam jangka panjang.

Kata Kunci: *alternatif, proses hierarki analitis, sistem keselamatan pantai, keputusan, pantai muara abu.*

INTRODUCTION

Kupang City has an extensive coastal area with high tourism potential, but its shoreline faces environmental degradation due to erosion, abrasion, and climate change. The region frequently experiences flooding, extreme weather, and rising

sea levels, which exacerbate coastal damage. Muara Abu Beach, situated in Oesapa Barat Village, Kelapa Lima Sub-district, has been severely impacted by these factors, threatening both settlements and tourism activities.

According to the Ministry of Public Works and Housing (2021), shoreline changes result from sediment transport disruptions, reduced sediment supply, construction activities, and weak coastal structures. Coastal protection is an important effort in mitigating coastal damage due to abrasion, erosion and high waves. Non-structural approaches such as coastal forest rehabilitation and sand filling have long been used as environmentally friendly alternatives. In contrast, structural approaches by building hard infrastructure, such as revetments and seawalls, provide more direct protection but often cause environmental impacts (Yuwono, 1992; Paotonan, 2012).

In the context of multi-criteria decision-making, the selection of a coastal protection system requires a thorough evaluation of various alternatives and criteria. The AHP method has been recognized as one of the effective techniques to assist decision-making by breaking down complex problems into hierarchical elements and determining the weight of each criterion through pairwise comparisons (Saaty, 1993; Saaty, 2000).

This study references research by Arifah et al. (2023), which applied the AHP method in coastal structure selection, serving as a foundation for this research. The AHP method was chosen over other decision-making techniques due to its structured, hierarchical approach that allows for the systematic assessment of multiple criteria. Unlike other methods, AHP enables decision-makers to incorporate both subjective and objective factors, ensuring a more balanced and informed decision. The objectives of this research are:

1. Determining the coastal safety system at Muara Abu beach location based on the decision results of the AHP method used optimally.
2. Analyzing the coastal safety system using the AHP method

This research is limited to the following problems, namely:

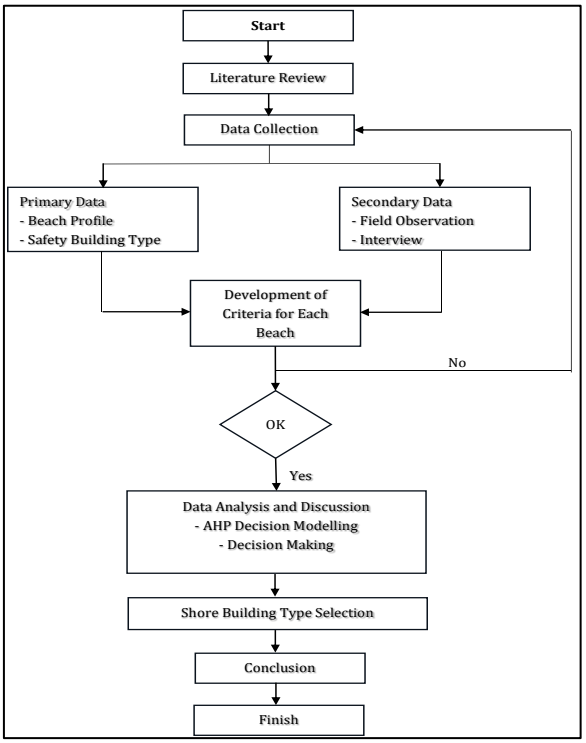
1. The criteria used are not taken based on the results of a fairly in-depth survey.
2. Not using non-structural type coastal safety buildings.
3. The criteria used include hydro-oseanography, terrestrial influence, socio-economic impact, environmental influence, and local damage level.

MATERIALS AND METHODS

The research site was located at Muara Abu Beach, Kelapa Lima District, Kupang City. The research time was conducted from the beginning of May 2024 starting from preparation, literature study, data collection, to the preparation of research results.

The methodology used in this research includes literature review and study, data collection, preparation and application of Analytical Hierarchy Process decision model, decision output. It is briefly explained as follows:

a. Review and study of literature.
b. Data collection
c. Data analysis.
d. Conclusions and suggestions



Source: (Research Result, 2024)

Figure 1. Research Flow Chart

Several recent studies were used as references related to the AHP Method in the context of coastal security. For example, Simbar et al. (2022) applied AHP in a case study at Amurang Boulevard Beach, South Minahasa Regency to select the optimal type of safety building based on technical and economic criteria. In addition, research by Arifah et al. (2024) used hydro-oseanographic data to determine the type of beach building through AHP in Laok Bindung Hamlet, Situbondo.

Some of the main stages in the AHP Method used are:

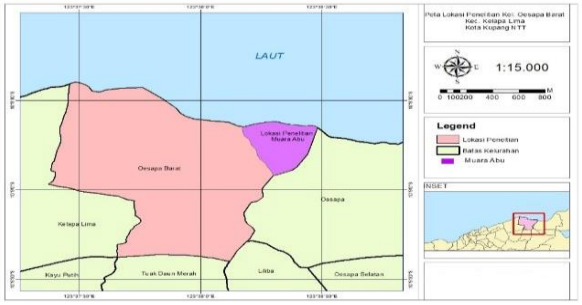
a. Hierarchy Building: Defining the main objective, criteria, sub-criteria, and alternatives. In the context of coastal protection, the main objective is to select the optimal coastal protection system. The criteria used include technical aspects (e.g. effectiveness of the structure in overcoming waves, erosion and abrasion), economic aspects (construction and maintenance costs), social aspects (community acceptance) and environmental aspects (impact on coastal ecosystems).
b. Pairwise Comparison: Each criterion and alternative is compared in pairs to determine relative weights using a predetermined comparison scale.
c. Determination of Weight and Consistency: The results of pairwise comparisons are analyzed to obtain the priority of each criterion and alternative. The calculation of the consistency ratio (CR) is carried out to ensure that the assessments given are not contradictory.
d. Synthesis and Decision Making: Criteria weights and alternative scores are combined to obtain the final ranking of the best coastal safety system.

RESULTS AND DISCUSSION

Site Overview

Muara Abu Beach is located in East Nusa Tenggara Province, precisely in Kupang City, West Oesapa Village, Kelapa Lima District. West Oesapa has an area of ± 6 km (6,000 m). Muara Abu Beach is ± 6.8 km from the city center. The location can be reached by land transportation (car) ± 15 minutes from the center of Kupang City. Based on its geographical position, Kelurahan Oesapa Barat has the following boundaries:

1) The north is bordered by Kupang Bay
2) The South is bordered by TDM village
3) The West is bordered by Kelapa Lima urban village
4) The East is bordered by Oesapa urban village

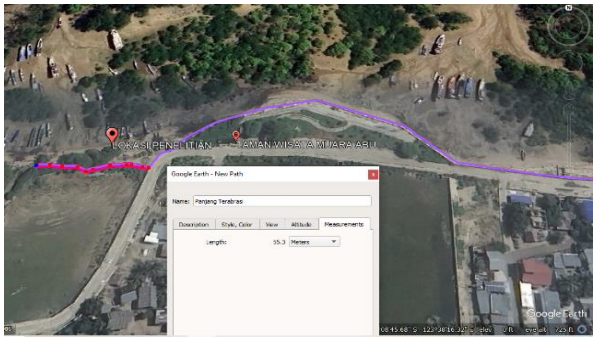


Source: (Research Result, 2024)
Figure 2. Research Location

Site Condition From Survey Results

The problem of coastal abrasion often has a negative impact on settlements and disrupts the coastal area, this can be prevented one of them by making beach buildings in the sea. The area that is often hit by high waves, erosion and coastal abrasion during the heavy rainy season is Muara Abu Beach in Oesapa Barat Village, Kelapa Lima District, Kupang City.

Data obtained from the local community, previously a concrete fence had been built to limit sea water, but since 2016 tidal waves have eroded land and residential areas, even tidal floods and coastal abrasion occur now ± 55.3 meters and the highest damage is 150 cm and the lowest is 26.72 cm, since Hurricane Seroja attacked Kupang City in 2021, mangroves have become damaged, abandoned, and dirty due to the motion of sea water or waves that are destructive.



Source: (Research Result, 2024)
Figure 3. The length of abrasion on Muara Abu Beach is 55.3 M

The high waves that occurred at Muara Abu Beach were ± 4 meters where sea water hit boats and houses on the shoreline, causing moderate to severe damage to houses. With these conditions, if left unchecked, it can endanger lives and damage the environment due to land retreat in this area. The residents suggested that the government immediately create an appropriate safety system.

(a)

(b)

(c)

Source: (Research Result, 2024)

Figure 3. (a),(b),(c). The condition of Muara Abu Beach which is experiencing abrasion

Problem Definition

The AHP criteria taken are the Compilation of criteria for each criterion that has a significant influence on the system. The criteria set for the selection of coastal safety buildings include:

a. Wave.
b. Erosion.
c. Abrasion.
d. Sedimentation.
e. Environment.

Level of Vulnerability

The vulnerability level of Muara Abu Beach is explained through the following table:

Table 1. Muara Abu Beach Vulnerability Level

No	Component	Indicator	Evaluation			Total Score
			Category	Factor Weight	Score	
1	Wave	History	High	2	9	18
		Insecurity	High	5	9	45
		Threat	Medium	10	5	50
		Probability	High	7	9	63
				Score Sub 1		**176**
2	Erosion	Shoreline Change	Medium	5	5	25
		Scour Beach	Medium	3	5	15
		Length	Medium	10	5	50
				Score Sub 2		**90**
3	Abrasion	Irradiated Width	Medium	6	5	30
		Irradiated Length	Medium	8	5	40
				Score Sub 3		**70**
4	Sedimentation	Long Closed	High	10	9	90
		% Open	Medium	6	5	30
		Estuary Effect of Sedimentation on Surrounding Areas	Low	3	3	9
				Score Sub 4		**129**
5	Environment	Seawater Quality	Low	5	3	15
		Coral Reefs	Low	10	3	30
		Mangrove Forest	Low	10	3	30
				Score Sub 5		**75**
				Total Score		**540**
		Lewel Vulnerability and Damage				**Medium**

Source: (Research Result, 2024)

Analysis of the level of vulnerability shows that Muara Abu Beach is in the medium vulnerability category with a total score of 540. Based on the evaluation results, waves and sedimentation are the dominant factors in the abrasion problem at this location.

Shore protection building type selection

In the AHP method of selecting a coastal safety system, the steps for determining the weight of criteria and validity are carried out as follows:

1. Pairwise comparison matrix in decimal
2. Eigen Value
3. Priority Weight
4. Total Sum
5. Divide each column by the total sum
6. Synthesis Weight
7. Max Eigen (X)
8. λ max(lamda max)
9. CI (consistency Index)
10. CR (consistency Ratio)

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The next calculation uses AHP as follows:

Table 2. Criteria Comparison Matrix

Criteria	Wave	Erosion	Abrasion	Sedimentation	Environment	Eigen Value	0.2 Priority Weight
Wave	1.0000	2.5900	3.4087	3.4087	2.5900	2.3898	0.3839
Erosion	0.3861	1.0000	1.9680	4.4006	4.2129	1.6973	0.2727
Abrasion	0.2934	0.5081	1.0000	4.5826	3.8730	1.2148	0.1951
Sedimentation	0.2934	0.2272	0.2182	1.0000	3.8730	0.5626	0.0904
Environment	0.3861	0.2374	0.2582	0.2582	1.0000	0.3607	0.0579
Total	2.3589	4.5628	6.8531	13.6500	15.5489	6.2252	1.0000

Source: (Research Results, 2024)

This table shows the pairwise comparisons between criteria in matrix form with the priority scale calculated using the AHP method. The main criteria considered include Wave, Erosion, Abrasion, Sedimentation and Environment. That result show that :

a. The criterion with the highest weight is Wave (0.3839), which indicates that the wave factor has the greatest influence in determining the coastal safety system.
b. The criterion with the lowest weight is Environment (0.0579), which means that the environmental aspect has the least influence compared to other factors.
c. The calculation results of λ max (lamda max) = 5.2409, CI (Consistency Index) = 0.0602, and CR (Consistency Ratio) = 0.0538, which shows that this calculation is consistent and can be used in decision making.

Table 3. Criteria Value Matrix

Criteria	Wave	Erosion	Abrasion	Sedimentation	Environment	Synthesis Weight	Eigen Maks (X)
Wave	0.4239	0.5676	0.4974	0.2497	0.1666	1.9052	4.9631
Erosion	0.1637	0.2192	0.2872	0.3224	0.2709	1.2633	4.6335
Abrasion	0.1244	0.1114	0.1459	0.3357	0.2491	0.9665	4.9525
Sedimentation	0.1244	0.0498	0.0318	0.0733	0.2491	0.5284	5.8467
Environment	0.1637	0.0520	0.0377	0.0189	0.0643	0.3366	5.8085
Total							**26.2043**

λ maks(lamda maks)	CI (consistency Index)	CR (Consistency Ratio)		IR (Index Ratio) 5 Criteria
5.2409	**0.0602**	**0.0538**	KONSISTEN	1.12

Source: (Research Results, 2024)

This table presents the synthesis weight values obtained from normalizing the criteria comparison matrix. This value shows the relative contribution of each criterion in the selection of coastal safety systems. That result show that :

a. The Wave criterion has the highest synthesized weight (1.9052), which indicates that the wave factor is more dominant than the other criteria.
b. The Sedimentation criterion has the lowest synthesized weight (0.5284), which means that the influence of sedimentation in the decision to select a coastal safety system is relatively smaller.
c. The calculation results in λ max = 5.2409, CI = 0.0602, and CR = 0.0538, which means the calculation is valid and consistent.

Alternative Conditions

Based on the description of the factors that are the criteria for coastal assessment, the requirements for determining the type of coastal safety should be reviewed in relation to these factors. The requirements set for the types of coastal safety structures are as follows:

1. Seawall

A structure built parallel to the shoreline to protect the beach from wave attack and wave runoff

onto land. Seawalls are usually used to protect residential areas and public facilities located near the shoreline. Seawalls can take the form of vertical, sloping, curved or stepped walls. Seawall is a building that serves to protect the coast from erosion and small waves.
The requirements are as follows:

a. There is no river
b. Large wave conditions
c. Low quality environmental conditions
d. Large erosion and abrasion rate
e. Sedimentation process in the estuary is low

2. Groin

A structure built perpendicular to the shore to protect the shore from damage caused by waves and currents. Groins function to regulate the flow of the sea so that water can flow quickly and safely during floods. Groins also function to direct the flow to the center of the sea channel so that the sea cliffs are not eroded.
The requirements are as follows:

a. Relative river conditions, present and absent
b. Medium wave conditions
c. Large erosion and abrasion rate
d. Environmental quality is in the low - medium interval
e. Sedimentation process in the estuary is low

3. Jetty

A structure that protrudes into the sea to control the closure of a river mouth or channel by sediment. In addition, the jetty also functions as a berth for barges and small boats.
The requirements are as follows:

a. There is a river
b. The wave state is in the low - medium interval
c. Erosion and abrasion rates are in the low - medium interval
d. Environmental quality is in the low - high interval
e. Sedimentation process in large estuaries

The calculation of the alternative comparison matrix is described in the following table:

Table 4. Alternative Comparison Matrix for Wave Criteria

				Eigen Value	
WAVES Criteria	Sea wall	Groin	Jetty	0.333	Alternative Weight
Seawall	1.0000	7.000	7.000	3.6593	0.7662
Groin	0.1429	1.0000	3.000	0.7539	0.1579
Jetty	0.1429	0.3333	1.0000	0.3625	0.0759
	1.2857	8.3333	11.000	4.757	1.0000

Source: (Research Results, 2024)

This table compares three alternative coastal safety systems (Seawall, Groin and Jetty) based on the Wave factor. The results show that :

a. Seawall has the highest weight (0.7662), which means that in the face of waves, seawall is considered the best solution
b. Jetties have the lowest weight (0.0759), indicating that in the face of waves, jetties are less effective than seawalls and groins.

Table 5. Alternative Comparison Matrix for Erosion Criteria

				Eigen Value	
EROSION Criteria	Sea wall	Groin	Jetty	0.333	Alternative Weight
Seawall	1.0000	0.200	0.1429	0.3057	0.0668
Groin	5.0000	1.000	0.200	1.0000	0.2185
Jetty	7.0000	5.000	1.0000	3.2711	0.7147
	13.000	6.200	1.3429	4.5768	1.0000

Source: (Research Results, 2024)

This table compares the effectiveness of alternatives in addressing erosion. That result show that :

a. Jetties have the highest weight (0.7147), indicating that they are most effective in preventing erosion.
b. The seawall has the lowest weight (0.0668), which means that the seawall is less effective than the other alternatives in dealing with erosion.

Table 6. Alternative Comparison Matrix for Abrasion Criteria

				Eigen Value	
Kriteria ABRASI	Sea wall	Groin	Jetty	0.3333	Alternative Weight
Seawall	1.0000	0.2000	0.1429	0.3057	0.0668
Groin	5.0000	1.0000	0.200	1.0000	0.2185
Jetty	7.0000	5.0000	1.0000	3.2711	0.7147
	13.000	6.2000	1.3429	4.5768	1.0000

Source: (Research Results, 2024)

This table assesses the effectiveness of each alternative in dealing with abrasion. The calculation results show that Jetty is again the alternative with the highest weight (0.7147), which confirms that jetty is the best solution in dealing with coastal

abrasion. While Seawall has the lowest weight (0.0668), which shows its low effectiveness in dealing with abrasion.

Table 7. Alternative Comparison Matrix for Sedimentation Criteria

				Eigen Value	
Kriteria SEDIMENTASI	Seawall	Groin	Jetty	0.333	Alternative Weight
Seawall	1.0000	0.1429	0.1111	0.2513	0.0549
Groin	7.0000	1.0000	0.3333	1.3264	0.2897
Jetty	9.0000	3.0000	1.0000	3.0000	0.6554
	17.000	4.1429	1.4444	4.5777	1.0000

Source: (Research Results, 2024)

This table compares the three alternatives in dealing with sedimentation. Jetties have the highest weight (0.6554), which indicates that they are most effective in controlling sedimentation.
The seawall has the lowest weight (0.0549), which means that the seawall is not very effective in dealing with sedimentation compared to groins or jetties.

Table 8. Alternative Comparison Matrix for Environmental Criteria

				Eigen Value	
Kriteria LINGKUNGAN	Seawall	Groin	Jetty	0.333	Alternative Weight
Seawall	1.0000	0.2000	0.1111	0.2811	0.0581
Groin	5.0000	1.0000	0.2000	1.0000	0.2067
Jetty	9.0000	5.0000	1.0000	3.5569	0.7352
	15.000	6.2000	1.3111	4.8380	1.0000

Source: (Research Results, 2024)

This table evaluates the impact of each alternative on the environment. The result show that :

a. The jetty has the highest weight (0.7352), indicating that the jetty is better at maintaining environmental quality compared to other alternatives.
b. The seawall has the lowest weight (0.0581), indicating that the environmental impact of the seawall is greater than the other alternatives.

After calculating the comparison matrix of criteria and alternatives using the Analytical Hierarchy Process (AHP) method, the next step is to calculate the alternative value matrix and the relationship matrix of criteria and alternatives to determine the priority of the most suitable coastal safety system for Muara Abu Beach.

Table 9. Alternative Value Matrix

	Seawall	Groin	Jetty	Bobot Sintesa	Eigen Maks (X)
Seawall	1.0571	0.9713	1.0108	3.0392	3.0007
Groin	1.6254	0.8453	0.9539	3.4246	3.1381
Jetty	2.3174	3.1835	3.0353	8.5362	2.9477
Total					**9.0865**

λ maks(lamda maks)		
3.0288		
CI (Consistency Index)		
0.0144		
CR (Consistency Ratio)		IR (Index Ratio) 3 kriteria
0.0249	CONSISTENT	0.58

Source: (Research Results, 2024)

This table presents the results of the calculation of the synthesis weight of each alternative (Seawall, Groin, and Jetty) based on the Analytical Hierarchy Process (AHP) method. This synthesis weight reflects the extent to which each alternative is able to fulfill the predetermined criteria, namely Wave, Erosion, Abrasion, Sedimentation, and Environment.
Calculation results show:

a. Jetties have the highest synthesized weight (8.5362), indicating that Jetties are the best alternative in addressing various aspects of coastal protection.
b. Groins had the second highest synthesized weight (3.4246), which means they are quite effective, but not as optimal as Jetties.
c. Seawall has the lowest synthesized weight (3.0392), indicating its effectiveness in shore protection is lower than the other two alternatives.

The calculation results show that the Jetty has advantages in dealing with erosion, abrasion, and sedimentation, making it the most recommended alternative.

After calculating the Comparison Matrix and Criteria Value Matrix, the next step is to calculate the Criteria and Alternative Relationship Matrix which is explained in the following table:

Table 10. Criteria and Alternative Relationship Matrix

	Wave	Erosion	Abrasion	Sedimentation	Environment	Matrix Value
Seawall	0.7662	0.0668	0.0668	0.0549	0.0581	0.3337
Groin	0.1579	0.2185	0.2185	0.2897	0.2067	0.2010
Jetty	0.0759	0.7147	0.7147	0.6554	0.7352	0.4653

Source: (Research Results, 2024)

This table shows the relationship between each criterion (Wave, Erosion, Abrasion, Sedimentation and Environment) and the alternative coastal safety systems (Seawall, Groin and Jetty).

That result show that :

a. Jetties have the highest overall weight (0.4653), confirming that Jetties are the best option because they have the best ability to handle erosion, abrasion, sedimentation, and provide better environmental impacts than other alternatives.
b. Seawall has the second highest weight (0.3337), indicating that this alternative is quite good, but less effective than Jetty especially in dealing with sedimentation and abrasion.
c. Groin has the lowest weight (0.2010), which means that its effectiveness in dealing with various problems in Muara Abu Beach is lower than other alternatives.

CONCLUSION

The development of coastal areas into residential areas and Tourism activities in Muara Abu Beach raises urgent coastal problems so that it becomes a priority for handling. The Analytical Hierarchy Process method is a method that is quite representative in helping the decision-making process for several alternatives that have positions that are close to each other. Decision making to choose the type of coastal safety building with AHP (Analytical Hierarchy Procces) for coastal safety buildings by taking into account local conditions. The results obtained are in the form of a priority scale that can be sorted as follows are Jetty is 46.53%, Seawall is 33.37% and Groin is 20.10%. The selection of coastal safety systems using the AHP method provides objective results in determining the best alternative. Jetty is the main solution recommended to be implemented in Muara Abu Beach. Further research is recommended to examine the effectiveness of Jetty implementation in the long term..

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