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Hazard Index and Efforts to Mitigate Extremed Wave and Abration Disaster in Teluk Pakedai District

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Abstract

Coastal areas face threats from hydro-oceanographic activities and human actions, leading to disasters such as extreme waves and coastal erosion. In Indonesia, particularly in Teluk Pakedai sub-district, these issues are prominent. Effective mitigation strategies tailored to the region's characteristics are essential. This research provides critical insights into extreme wave and abrasion threats in Teluk Pakedai, offering actionable data for targeted mitigation strategies such as mangrove restoration and community-based risk management. Using the Indeks Ancaman Bahaya Gelombang Ekstrim dan Abrasi (GEA) method outlined in BNPB's 2012 guidelines, factors like wave height, ocean currents, beach typology, vegetation, and coastline shape will be assessed and mapped using ArcGIS. From 2018-2023, significant erosion and accretion were observed, with the highest erosion in Kuala Karang Village (16.93 Ha) and the most accretion in Tanjung Bunga Village (57.79 Ha). Seven villages face medium to high danger from these threats. Recommended mitigation strategies include mangrove planting, constructing breakwaters, establishing early warning systems, and enhancing public awareness of extreme wave and abrasion risks.

Keywords: Abrasion, Accretion, Extreme waves, Indeks Ancaman Bahaya Gelombang Ekstrim dan Abrasi (GEA), Mitigation strategies

1. INTRODUCTION

West Kalimantan covers an area of 147,307 km², situated between 2° 05' N - 3° 05' S and 108° 30' - 114° 10' E. The region can be divided into three parts: coastal and island areas, interior, and border areas. The coastal region includes Sambas Regency, Singkawang City, Bengkayang Regency, Mempawah Regency, Pontianak City, Kubu Raya Regency, Ketapang Regency, and Kayong Utara Regency, with a coastline of 1,398 km. Its marine area spans 30,364.59 km², consisting of 156 islands, of which 217 are inhabited. According to Undang-Undang No. 1 of 2014, coastal areas are a transition zone between terrestrial and marine ecosystems, vital both physically for settlement and industry, and ecologically as habitats for various marine ecosystems and mangroves.

Coastal areas are vulnerable to threats from changes in hydro-oceanographic activity and human activities on land. These changes, often driven by global warming, can lead to rising sea levels and altered wind patterns, resulting in extreme storms and waves. Strong waves cause erosion and sediment movement along the coast (Kadir & Winarto, 2023). In Indonesia, this phenomenon has severely impacted coastal regions, such as Teluk Pakedai in Kubu Raya, where villages face significant erosion and extreme waves. Over the years, this has worsened, damaging homes and threatening the local economy. If the effects of climate change continue unchecked, they could lead to severe conditions for coastal communities [1].

To address the threats of extreme waves and coastal erosion, it is necessary to implement mitigation efforts that align with the characteristics of disasters in coastal areas [2]. This research aims to create a threat map in the Teluk Pakedai District using methods from the Peraturan Kepala (Perka) BNPB No. 2 (2012) concerning General Guidelines for Disaster Risk Assessment. This method is relevant to the local geographical conditions, where natural disasters can threaten the livelihoods of the community. This threat map will serve as a guideline for disaster management and response in the area.

2. METHODS

2.1. Time and Place

This research was conducted in October 2023 – August 2024 in the Teluk Pakedai District, Kubu Raya Regency, with a total days count of 280 days.

2.2. Procedure

This research procedure starts from determining the background, formulating the problem, conducting literature studies, collecting primary data (observation) and secondary data (wave height data, ocean current speed, beach topology, coastline shape, land cover, land map/administrative boundaries), data processing and analysis, creating hazard analysis maps using ArcMap 10.8, disaster mitigation planning, and ending with research conclusions. ArcGIS analysis and the GEA method were chosen for their proven effectiveness in creating actionable hazard maps

2.3. Research Methods

This research uses quantitative research methods and qualitative methods. Quantitative research methods are an objective approach to describing situations using numerical data, including collection, interpretation and presentation of data [3]. Meanwhile, qualitative methods, based on post-positivism philosophy, are used to examine objects in natural conditions without data manipulation, with the researcher as the main instrument. Sampling was carried out purposely and snowball, and analysis was inductive, emphasizing meaning over generalization. Data is generally obtained through interviews and observation. Observations are carried out by observing research objects directly, such as making direct observations of physical conditions in the field and taking documentation to collect physical evidence or data. This documentation can be in the form of a written statement or other form that can be used as a source of accurate information.

2.4. Data Analysis

2.4.1 Preparation of a Hazard Threat Index

The preparation of the Indeks Ancaman Bahaya Gelombang Ekstrim dan Abrasi (GEA) follows the method in Perka BNPB No. 2 (2012). The parameters used include wave height, ocean currents, beach typology, vegetation cover and coastline shape. Each parameter is identified to determine the class and assessed based on the level of importance using a scoring method.

Table 1. Extreme Wave Hazard and Abrasion Suspension Parameters

Parameter	Score			Weight
	0,333	0,666	1	
Wave Height	<1m	1-2.5 m	>2.5 m	30%
Current	<0,2	0.2 – 0,4	>0,4	30%
Beach Typology	Coral Rock	Sandstone	Muddy	10%
Vegetation Cover	> 80% Forest	40% - 80%	<40%	15%
Coastline Shape	Bay	Straight-Beveled	Straight	15%

For this research, parameter data will be input into ArcGIS software. Before analysis, the coordinate system must be standardized to UTM or World Mercator so that mathematical analysis can be carried out in meters.

2.4.2 Coastline to Land Buffer

Coastline data uses data that has been created by the authorized Ministry/Institution (BIG). In this study, the coastline in Teluk Pakedai District was used. Indeks Ancaman Bahaya Gelombang Ekstrim dan Abrasi (GEA) is focused on the coastal border area as far as 200 m from the coastline. Vector shoreline data is buffered into an area 200 m inland. Next, a new column is added in the Area_GEA layer for parameters input with the Float field type. Parameter values are filled in using the Field Calculator, with Select by Attribute to select villages according to the data.

The vector coastline data was then converted to raster using the Polygon to Raster toolbox in ArcToolbox. Area_GEA which has been filled with score attributes is used as input, with Cell Size 30 based on DEM data. Processing Extent and Snap Raster settings on the DEM layer are carried out to ensure the suitability of the area and position of the grid. Land Cover Data Classification is divided into three classes according to scores and weights based on Perka BNPB No. 2 (2012).

Table 2. Classification of Land Cover Types

Parameter	Score		
	0,333	0,666	1
Land Type	Forest	Garden/plantation	Moorland/Fields, bushes, grasslands, settlements, bodies of water

After scoring the data, the danger index for the threat of extreme waves and abrasion is determined through an overlay of five parameters. Hazard classification based on Perka BNPB No. 2 (2012) are as follows:

- Low Hazard: ≤ 1
- Medium Danger: 1 < 3
- High Danger: > 3

The overlay process is carried out with the following steps:

1. Use the Raster Calculator toolbox in ArcToolbox.
2. Enter raster data from Gel_Score, Current_Score, BP_Score, TP_Score, and PL_Score.
3. Write the formula in the raster calculator.
4. Create a Land Score raster using Polygon to Raster and set the environment for area coverage and grid position.
5. Parameters are multiplied by the weight per parameter.
6. Save the output as GEA_hazard_index.

With this index value, we can classify the extent and class of danger from the threat of extreme waves and abrasion in the form of maps and tables according to the BNPB Perka standard No. 2 (2012).

3. RESULTS AND DISCUSSION

3.1. Analysis of the Threat Index of Extreme Waves and Abrasion

3.1.1 Coastline Changes

Analysis of coastline changes was carried out using ArcGIS 10.8 software with Landsat OLI (Operational Land Imager) data from 2013, 2018 and 2023 to monitor the impact of abrasion. The technique used is overlay (overlapping) between beach images from different years. By using this method, changes in coastlines can be seen in units of ha/year.

Identification was carried out on the coast of Teluk Pakedai District, focusing on areas facing the ocean. The analysis process includes image cropping for storage efficiency, image restoration and sharpening to improve quality, as well as geometric correction and digitization to draw coastlines. Image sharpening is a combination of bands needed to emphasize land and water boundaries so that it will simplify the process of digitizing coastlines. Map digitization is carried out to depict the boundary line between land and water which is the position of the coastline for each year of selected satellite data. Overlapping images from different years allows identification of areas of abrasion and accretion. These results are then sorted, then grouped into Abrasion changes or Accretion changes. After identifying the location of coastal abrasion and accretion by overlapping the stacks (overlay) the oldest year's coastline with the most recent year's coastline.

Table 3. Coastline Changes in Teluk Pakedai District 2013-2018

No.	Village	X	Y	Change	Area (Hectares)
1	Kuala Karang	109° 6' 59.126" E	0° 26' 44.267" S	abrasion	38.253832
		109° 6' 58.276" E	0° 26' 39.046" S	accretion	0.016747
2	Pasir Putih	109° 11' 9.263" E	0° 13' 28.255" S	abrasion	0.975518
		109° 10' 35.358" E	0° 13' 40.216" S	accretion	3.470141
3	Selat Remis	109° 6' 51.765" E	0° 20' 5.233" S	abrasion	3.405765
		109° 6' 38.963" E	0° 19' 37.894" S	accretion	1.196671
4	Sungai Nibung	109° 6' 46.129" E	0° 28' 39.943" S	abrasion	111.236287
		109° 11' 35.498" E	0° 33' 47.873" S	accretion	0.223085
5	Tanjung Bunga	109° 6' 17.271" E	0° 23' 12.871" S	abrasion	83.99057
		109° 6' 24.820" E	0° 20' 54.939" S	accretion	0.198651
6	Teluk Pakedai Hulu	109° 6' 19.894" E	0° 18' 36.391" S	abrasion	0.458162

No.	Village	X	Y	Change	Area (Hectares)
7	Teluk Pakedai Satu	109° 6' 12.914" E	0° 18' 18.372" S	accretion	0.438689
		109° 7' 23.227" E	0° 15' 10.170" S	abrasion	4.09543
		109° 6' 29.589" E	0° 15' 57.777" S	accretion	30.89811

Analysis of changes in the coastline in Teluk Pakedai District shows that from 2013 – 2018, the area increased by 36.442 hectares, especially in Teluk Pakedai Satu Village and Pasir Putih Village. However, Sungai Nibung Village and Kuala Karang Village experienced a reduction in area due to abrasion, amounting to 111.236 hectares and 38.253 hectares respectively. Apart from those experiencing an increase in area area, there are also areas that experience a reduction in area area as a result of abrasion, namely the Sungai Nibung village area whose area area decreased by 111.236 hectares and the Kuala Karang village area which experienced abrasion with an area of 38.253 hectares. This change in coastline occurred in the 2013 – 2018 time period.

Figure 1. The Teluk Pakedai Satu Village area experienced accretion in 2013 – 2018

Figure 2. The Sungai Nibung Village area experienced abrasion in 2013 – 2018

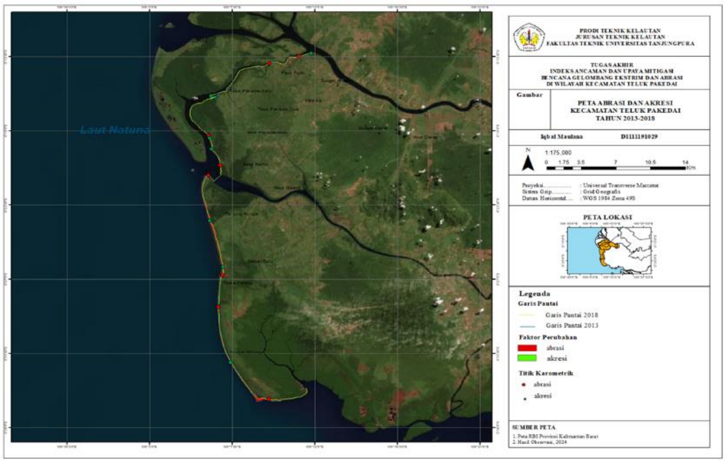
Figure 3. Accretion – Abrasion Map 2013 – 2018

Table 4. Coastline Changes 2018 – 2023

No.	Village	X	Y	Change	Area (Hectares)
1	Kuala Karang	109° 6' 54.211" E	0° 27' 7.651" S	abrasion	16.937887
		109° 6' 56.654" E	0° 25' 52.860" S	accretion	2.707607
2	Pasir Putih	109° 11' 4.529" E	0° 13' 28.303" S	abrasion	1.686587
		109° 11' 15.654" E	0° 13' 28.203" S	accretion	5.838491
3	Selat Remis	109° 6' 49.841" E	0° 19' 55.936" S	abrasion	0.192271
		109° 6' 36.694" E	0° 19' 31.012" S	accretion	4.659559
4	Sungai Nibung	109° 9' 44.840" E	0° 33' 36.988" S	abrasion	16.372268
		109° 7' 52.335" E	0° 32' 26.976" S	accretion	41.168017

No.	Village	X	Y	Change	Area (Hectares)
5	Tanjung Bunga	109° 6' 5.827" E	0° 20' 50.258" S	abrasion	3.542923
		109° 6' 21.325" E	0° 23' 32.928" S	accretion	57.799883
6	Teluk Pakedai Hulu	109° 6' 14.518" E	0° 18' 20.486" S	abrasion	0.067982
		109° 6' 14.863" E	0° 18' 25.410" S	accretion	1.124726
7	Teluk Pakedai Satu	109° 7' 9.738" E	0° 15' 29.688" S	abrasion	4.923097
		109° 6' 32.932" E	0° 15' 53.494" S	accretion	20.008353

Between 2018 – 2023, significant accretion occurred in Tanjung Bunga Village with the addition of 57.799 hectares and in Sungai Nibung Village with 41.168 hectares. Meanwhile, Kuala Karang Village experienced the impact of 16.937 hectares of abrasion.

Figure 4. The Tanjung Bunga Village area experienced accretion in 2018 – 2023

Figure 5. The Tanjung Bunga Village area experienced abrasion in 2018 – 2023

Figure 6. Documentation of abrasion in the Kuala Karang Village area

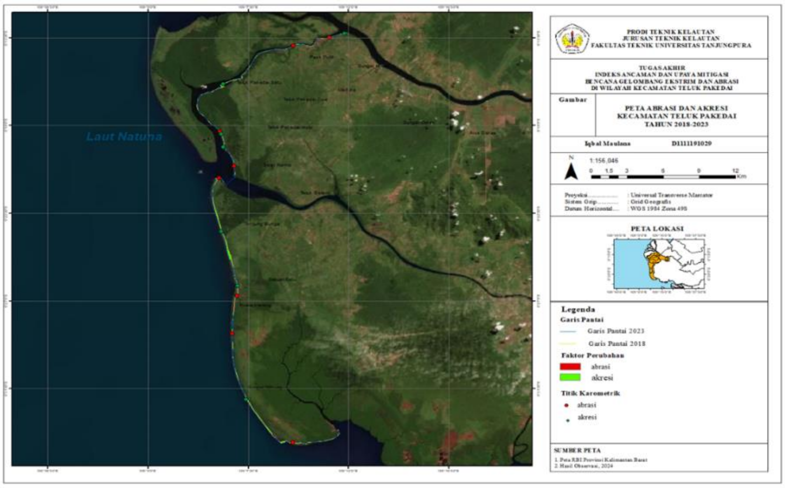

Figure 7. Accretion – Abrasion Map 2018 – 2023

Many villages in Teluk Pakedai District experienced greater abrasion than accretion, indicating a serious coastal erosion problem. This phenomenon can reduce land area and threaten coastal infrastructure, as well as destroying natural habitats such as mangrove forests and coral reefs that protect against sea waves and storms [4]. Significant abrasion has the potential to reduce land area, threatening coastal infrastructure such as settlements, roads and other public facilities [5].

3.1.2 Wave Height

Coastal dynamic processes are strongly influenced by littoral transport, which is defined as the movement of sediment near the shore by waves and currents. The rate of longshore transport depends on the angle of incidence of the waves, the duration and the energy of the waves. This results in large waves transporting more material per unit time and small waves that occur continuously can transport more sand than large waves [6]. The wave height in this study is an average that reflects the conditions on the coast of Teluk Pakedai District. Wave data was obtained from ECMWF and processed using ArcGIS. The average wave height ranges from 0.5 – 1 meter, where waves above 1 meter are categorized as moderate according to BNPB Regulation No. 2 of 2012, although it is generally influenced by wind speed.

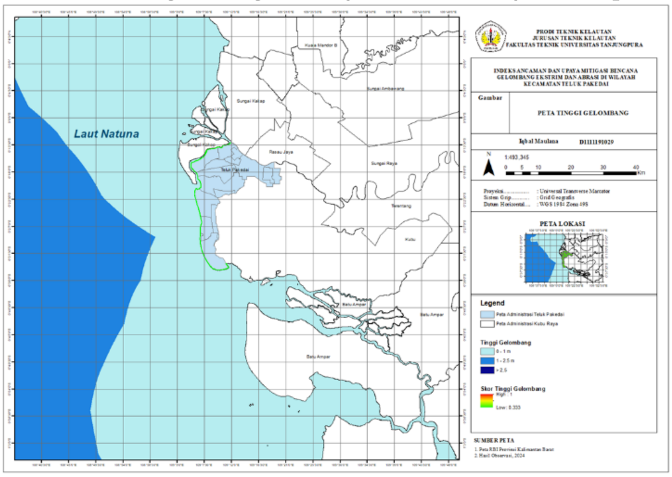

Figure 8. Wave Height Map 2013 – 2023

3.1.3 Flow Speed

Coastal areas generally have lower current speeds, while strong currents can increase the risk of abrasion and extreme waves, accelerating coastal erosion. Extreme waves that often occur in areas with strong currents can also erode the coastline [7], resulting in significant changes to the shape and structure of the coast [8]. Current speed can affect the movement of beach material to another place. The faster the current in an area, the faster the potential for beach material to be carried [9]. The speed of ocean currents varies between 0.1 to 1.0 m/s, influenced by topography, wind and tides. The current speed map shows dark blue areas as zones with strong currents, potentially affecting navigation. Currents with speeds above 0.4 cm/s and receiving a suspension value of 1 are considered high and can accelerate the removal of coastal material, potentially causing significant erosion.

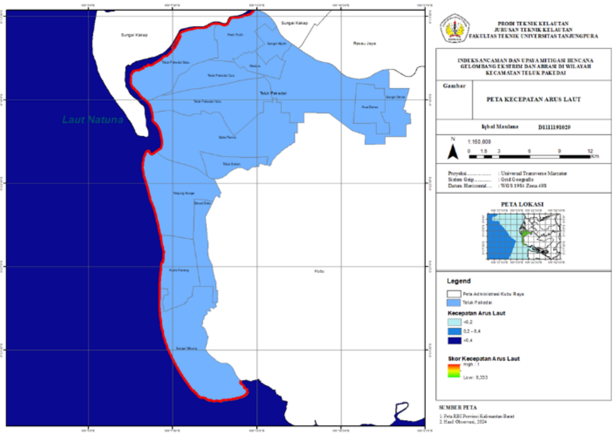

Figure 9. Flow Speed Map

3.1.4 Land Cover

The results of the GIS/ArcMap analysis show that this area is dominated by plantations, which change coastal land use patterns and reduce natural land areas such as mangrove forests. The dominance of plantations can change land use patterns in coastal areas, resulting in a reduction in natural land areas such as mangrove forests which usually function as buffers or coastal protectors. Apart from that, the existence of settlements also causes land conversion. The land cover map in Teluk Pakedai District shows the dominance of forests, plantations and fields.

Figure 10. Residential Areas In the Pakedai Bay coastal are

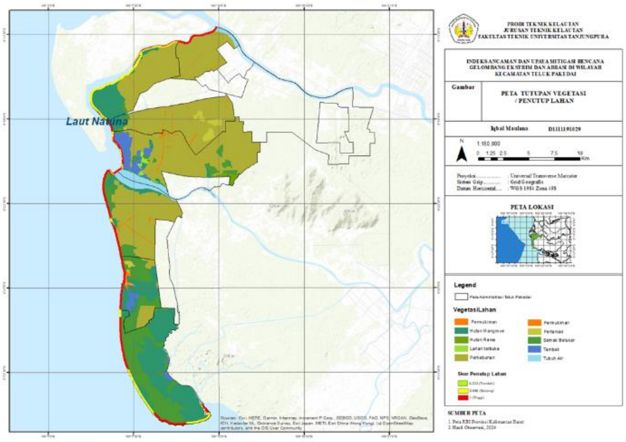

Figure 11. Map of land cover in Teluk Pakedai District

3.1.5 Beach Typology and Coastline Shapes

The assessment of the shape of the coastline is carried out visually based on its dominant shape. Coastlines that form a "U" shape are considered curvy, while those that curve almost straight are considered straight [10]. The shape of the coastline from satellite images varies depending on geological, geomorphological and environmental factors [11], in accordance with BNPB Perka No. 2 of 2012 in the preparation and scoring of extreme wave and abrasion hazards.

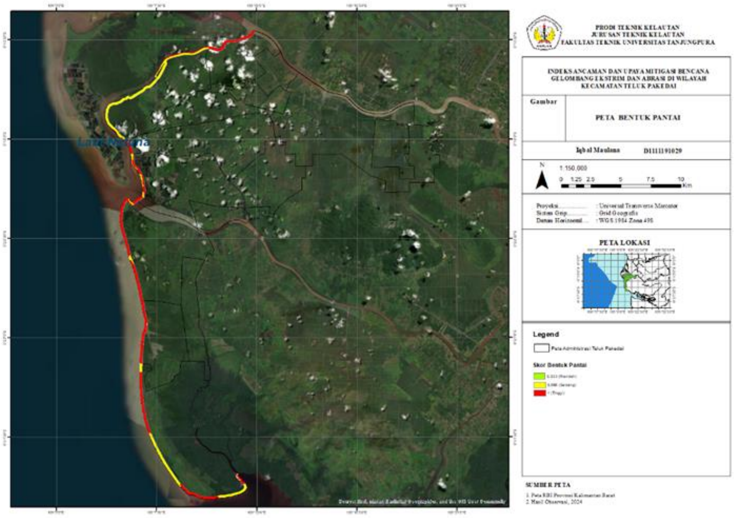

Figure 12. Beach Shape Score

From satellite imagery, the coastline in Teluk Pakedai District shows a curved and straight shape, with a score of medium to high, while the beach typology is muddy with a score of 1.

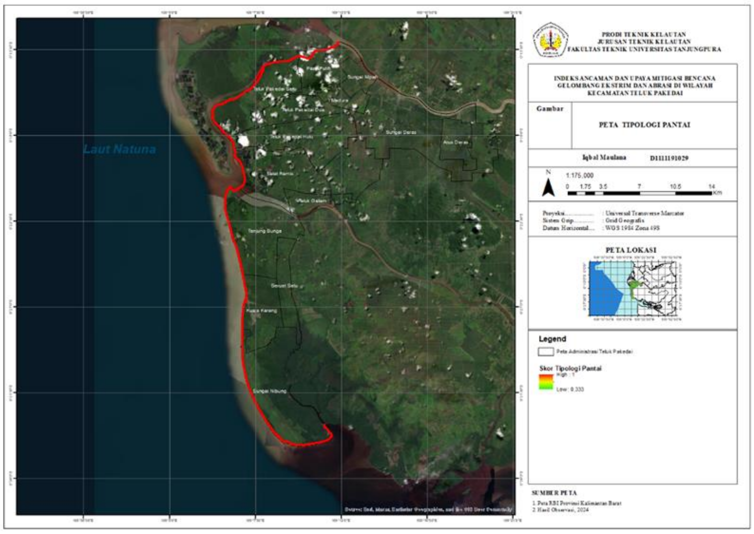

Figure 13. Beach Typology Score

3.2. Extreme Wave and Abrasion Hazard Index Assessment

3.2.1 Presentation of the Hazard Index Map for Extreme Waves and Abrasion

The hazard assessment aims to analyze the hazard index related to extreme waves and abrasion, which have a significant impact on the coastal environment and society [12]. Hazard maps are important for mitigating risk and increasing public awareness, using contrasting colors for easier understanding. The danger threat index is classified into low (0.333), medium (0.666), and high (1), with green, yellow, and red symbols. The map shows that Teluk Pakedai District has varying levels of danger, influenced by current speed, typology, beach shape and vegetation.

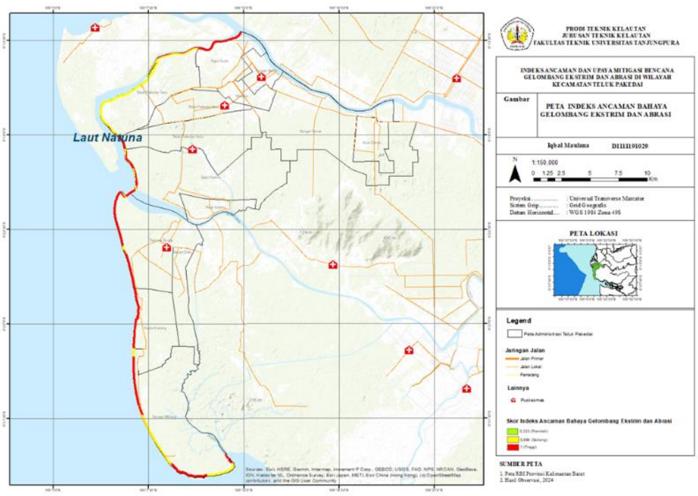

Figure 14. Hazard Index Map for Extreme Waves and Abrasion

3.2.2 Wide Hazard Classes for Extreme Wave and Abrasion Disasters

The Hazard Class Area and the Extreme Wave and Abrasion Hazard Map in Teluk Pakedai District show that out of 14 villages, 7 villages experience moderate to high levels of danger. The following is the broad Threat Index for Extreme Waves and Abrasion in the region.

Table 5. Extensive Hazard Classes and Hazard Maps of Extreme Waves and Abrasion

Village	Subdistrict	Regency	Types Of Danger	Danger				
				Danger Area (Ha)			Total Area	Class
				Low	Medium	High		
Kuala Karang	Teluk Pakedai	Kubu Raya	Extreme Waves And Abrasion	-	0,037	106,586	106,623	High
Selat Remis	Teluk Pakedai	Kubu Raya	Extreme Waves And Abrasion	-	15,602	167,536	183,138	High
Tanjung Bunga	Teluk Pakedai	Kubu Raya	Extreme Waves And Abrasion	-	15,917	176,781	192,698	High
Teluk Pakedai Hulu	Teluk Pakedai	Kubu Raya	Extreme Waves And Abrasion	-	0,023	22,937	22,960	High
Pasir Putih	Teluk Pakedai	Kubu Raya	Extreme Waves And Abrasion	-	0,011	86,845	86.856	High
Teluk Pakedai Satu	Teluk Pakedai	Kubu Raya	Extreme Waves And Abrasion	-	259,051	33,289	292,340	Currently
Sungai Nibung	Teluk Pakedai	Kubu Raya	Extreme Waves And Abrasion		167,536	188,943	356,479	High

Based on Table 5, the villages experiencing a high hazard class are Kuala Karang Village with a hazard area of 106.623 hectares, Selat Remis Village with a hazard area of 183.138 hectares, Tanjung Bunga Village with a hazard area of 192.698 hectares, Teluk Pakedai Hulu Village with a hazard area of 22.960 hectares, Village Pasir Putih has a hazard area of 86.856 hectares, Sungai Nibung Village has a hazard area of 356.479 hectares, Teluk Pakedai Satu Village has a medium hazard class with an area of 292.340 hectares and while the other villages are not affected.

3.3. Extreme Wave and Abrasion Mitigation Planning for Teluk Pakedai District

Mitigation planning for extreme waves and abrasion in Teluk Pakedai District needs to involve strategic steps and community participation, including:

1. **Planting Mangrove Trees**: Reduces abrasion and strengthens coastlines through planting mangroves, which are effective in binding sediment and reducing wave strength. The combination of various types of vegetation can increase the stability of coastal ecosystems [13].

2. **Creation of Breakwaters**: Breakwaters function as physical barriers to reduce the impact of high waves. By absorbing wave energy, breakwaters protect beaches and infrastructure, and provide long-term protection against climate change [14].
3. **Increasing Community Knowledge**: Educating the community about the importance of protecting the coastal environment and how to deal with extreme waves is very important. Training can include mangrove planting and evacuation procedures, increasing disaster preparedness [15].
4. **Early Warning and Evacuation System**: Develop an early warning system to provide fast and accurate information to the community before a disaster. Evacuation plans should be prepared taking into account local needs, including evacuation routes and shelters [16]

These steps are expected to increase community resilience and protect the coastal environment from the impacts of extreme waves and abrasion

4. CONCLUSION

The conclusion of this research are: 1) This study assessed the impact of extreme wave and abrasion hazards in Teluk Pakedai District. From 2018–2023, significant erosion (16.93 Ha) and accretion (57.79 Ha) were recorded, particularly in Kuala Karang and Tanjung Bunga villages, respectively. These findings underscore the urgency of targeted mitigation practices. The implications extend beyond environmental concerns, as the observed erosion threatens local livelihoods, infrastructure, and biodiversity. By mapping hazards, this study provides critical data to inform coastal management strategies, such as zoning regulations and conservation efforts; 2) The results can be directly applied to guide local disaster mitigation measures. For example, mangrove restoration projects could stabilize erosion-prone areas, while constructing breakwaters may protect essential infrastructure. These efforts should be coupled with community education programs to foster local engagement in sustainable coastal practices; 3) The methodology employed, particularly the use of historical satellite data, is limited by the resolution and temporal gaps of available imagery. External factors such as illegal logging, unregulated coastal development, and climate variability could have influenced the results but were not explicitly accounted for. Future studies should integrate socioeconomic factors and longer-term climate models to provide a more holistic understanding of the hazards; and 4) This research contributes to the growing body of knowledge addressing coastal vulnerability in tropical regions. By bridging environmental data with actionable strategies, it highlights the need for collaborative efforts to mitigate the dual threats of natural hazards and anthropogenic pressures on coastal ecosystems; 5) recommendations for stakeholders (local government & planners, community groups, and researchers) such as implement an integrated coastal zone management plan that incorporates hazard maps for risk zoning and permits, participate in mangrove reforestation and adopt disaster preparedness practices, and conduct continuous monitoring using high-resolution spatial and temporal data to capture dynamic coastal changes.

DAFTAR PUSTAKA

[1] H. Yulianto, I. Iryani, S. Tinggi, I. Ekonomi, and Y. Makassar, “Green Lecture dan Penanaman Mangrove Di Kawasan Ekowisata Lantebung Green Lecture And Mangrove Planting In Lantebung Ecotourism Area,” vol. 1, no. 2, pp. 50–61, 2024, doi: 10.62383/bersama.v1i2.139.

[2] I. Nurmalia Permatasari, P. Sains Kebumian, and I. Teknologi Bandung, “Kajian Resiko, Dampak, Kerentanan dan Mitigasi Bencana Abrasi Dibeberapa Pesisir Indonesia (A literatur Review),” vol. 3, no. 1, 2021.

[3] Z. Fadilla, P. Muhammad, Z. Penerbit, M. Zaini, and K. A. Lawang, “METODOLOGI PENELITIAN KUANTITATIF,” 2023. [Online]. Available: https://www.researchgate.net/publication/370561251

[4] D. Viv *et al.*, “Pemanfaatan Sumberdaya Lahan Pesisir Berbasis Daya Dukung Lingkungan Dalam Menghadapi Perubahan Iklim Global,” 2023.

[5] A. Octavian, M. Marsetio, A. Hilmawan, and R. Rahman, “Upaya Perlindungan Pesisir dan Pulau-Pulau Kecil Pemerintah Provinsi Sumatera Barat dari Ancaman Abrasi dan Perubahan Iklim,” *Jurnal Ilmu Lingkungan*, vol. 20, no. 2, pp. 302–315, Apr. 2022, doi: 10.14710/jil.20.2.302-315.

[6] A. Apriansyah, A. A. Kushadijayanto, and R. Risko, “Pengaruh Gelombang pada Perubahan Garis Pantai di Perairan Batu Burung Singkawang, Kalimantan Barat,” *POSITRON*, vol. 9, no. 1, p. 1, May 2019, doi: 10.26418/positron.v9i1.32632.

[7] M. Arif *et al.*, “PEMODELAN DAN ANALISIS PERUBAHAN GARIS PANTAI DI KABUPATEN SITUBONDO, JAWA TIMUR,” Malang, Jul. 2021. [Online]. Available: http://jfmr.ub.ac.id

[8] A. Isdianto, I. M. Asyari, M. F. Haykal, F. Adibah, M. J. Irsyad, and S. Supriyadi, “ANALISIS PERUBAHAN GARIS PANTAI DALAM MENDUKUNG KETAHANAN EKOSISTEM PESISIR,” *Jukung (Jurnal Teknik Lingkungan)*, vol. 6, no. 2, Sep. 2020, doi: 10.20527/jukung.v6i2.9260.

[9] I. Kadir and S. Winarto, “ANALISIS POTENSI BENCANA GELOMBANG LAUT EKSTRIM DAN ABRASI PANTAI DI WILAYAH PESISIR KABUPATEN PASANGKAYU, SULAWESI BARAT,” *BANDAR: JOURNAL OF CIVIL ENGINERING*, vol. 5, no. 1, May 2023.

[10] K. D. Priyono, *Geomorfologi Kebencanaan: Wilayah Pesisir dan Pengelolaanya*. Surakarta: Universitas Muhammadiyah Surakarta, 2022.

[11] A. Putranto and Jani, “PEMANFAATAN SISTEM INFORMASI GEOGRAFI UNTUK IDENTIFIKASI WILAYAH BERISIKO BENCANA TSUNAMI DI KAWASAN PESISIR PANTAI SINE, TULUNGAGUNG, JAWA TIMUR, INDONESIA (Utilisation of Geographic Information System to Identify Tsunami Disaster Risk Areas in the Coastal Area of Sine Beach, Tulungagung, East Java, Indonesia),” 2024.

[12] I. W. G. K. Arimjaya, “Kajian Bahaya Gelombang Ekstrem dan Abarasi Di Kawasan Pesisir METROPOLITAN SARBAGITA,” *GEOSPASIAL*, vol. 19, no. 3, pp. 10–15, Dec. 2022.

[13] Sumar, “Penanaman Mangrove Sebagai Upaya Pencegahan Abrasi di Pesisir Pantai Sabang Ruk Desa Pembaharuan,” Bangka Belitung, Mar. 2021.

[14] J. W. Ginting, I. Ayu Irawati Diah Ratna Putra, E. Meyrianso Simanjuntak, B. Litbang Pantai, P. K. Sumber Daya Air Jl Gilimanuk -Singaraja, and K. Buleleng -Bali, “MODEL FISIK REDAMAN ENERGI GELOMBANG DENGAN BREAKWATER TIANG PHYSICAL MODEL OF WAVE ENERGY REDUCTION BY USING PILE BREAKWATER,” 2019. [Online]. Available: http://jurnalth.pusair-pu.go.id

[15] T. Sukomardojo, M. Tabran, M. Al Muhtadin, I. A. Gymnastiar, H. Pasongli, and P. P. Surabaya, “Mendorong Perilaku Konservasi Lingkungan di Komunitas Pesisir: Pelajaran dari Inisiatif Berbasis Masyarakat,” 2023.

[16] K. D. Azizah and H. Sasdar, “PERAN KEBIJAKAN PEMBANGUNAN TERPADU DALAM MENGURANGI RESIKO BENCANA,” May 2024.