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A GIS-Based Analysis of Coastal Abrasion Risk Potential

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Abstract

Coastal abrasion poses a significant threat to Indonesia, an archipelagic nation with one of the world's longest coastlines. The phenomenon is particularly severe in Napabalano District, Muna Regency, where dense settlements, economic activities, and declining mangrove ecosystems increase exposure to erosion hazards. This study aims to assess the risk of coastal abrasion in Napabalano District using a GIS-based approach aligned with the Indonesian National Disaster Management Authority (BNPB) framework. Primary data, including GPS coordinates, satellite imagery, and field surveys, were integrated with secondary data such as demographic statistics, oceanographic parameters, and historical records of abrasion events. Spatial analysis in ArcGIS was employed to evaluate vulnerability, capacity, hazard, and disaster risk indices. Results show that all villages in Napabalano District fall into the high-risk category, with Napabalano and Napalakura recording the highest risk values due to concentrated populations, limited mangrove protection, and inadequate disaster management capacity. Social and economic vulnerabilities, including high poverty ratios and dependence on coastal livelihoods, exacerbate exposure, while institutional capacity remains critically low, marked by weak early warning systems and limited community preparedness. Mitigation strategies proposed include mangrove rehabilitation, strict coastal zoning enforcement, community-based disaster preparedness programs, and the establishment of effective early warning systems. These findings highlight the urgent need for integrated, multi-stakeholder approaches to strengthen resilience against coastal abrasion. The study provides a strategic basis for local government and community planning in managing and reducing the impacts of coastal hazards in Napabalano District.

Introduction

Indonesia is a country with a long coastline, and is the second country with the longest coastline in the world after Canada (Yang et al., 2023; Afriansyah et al., 2022; Gulo & Koestoer, 2024). Where its territory is almost entirely surrounded by oceans with diverse coastlines. Coastal areas are important zones because they are basically composed of various ecosystems such as mangroves, coral reefs, seagrass, sandy beaches and others that are interconnected with each other (Masalu, 2008; Hasim, 2021; Isaac, 2024). Coastal areas are also transitional areas between terrestrial and marine ecosystems that are affected by changes on land and sea. Based on Law No. 27 of 2007 concerning the Management of Coastal Areas and Small Islands, the scope of regulation of Coastal Areas and Small Islands includes transitional areas between terrestrial and marine ecosystems that are affected by changes on land and sea, towards land

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covering the administrative areas of sub-districts and towards the sea as far as 12 nautical miles measured from the coastline at the highest tide towards the open sea and towards the archipelagic waters. Regulation of spatial use in the coastal land area is regulated in the applicable Regional Spatial Plan (RTRW) or Detailed Spatial Plan (RDTR). GESAMP (2015) defines coastal areas as land and water areas affected by biological and physical processes from both the sea and the land. This is broadly defined for the purposes of natural resource management. Therefore, the delineation of coastal areas can vary depending on administrative, ecological, and planning aspects (Liang et al., 2022; Guo et al., 2022; Yasin et al., 2023).

Indonesia's coastal areas include several coastal groups prone to abrasion, namely the west coast of Sumatra, the south coast of Java, the north and south coasts of the Nusa Tenggara island, the islands of Maluku, the north coast of Irian Jaya, and almost all of Sulawesi's coasts. Law No. 24 of 2007 defines abrasion as the process of coastal erosion by the destructive force of ocean waves and currents triggered by disruptions to the natural balance in the area. Coastal abrasion can be influenced by several factors, both natural and human-induced. These include coastal reclamation (in the form of settlements, ports, and industry). However, the primary causal factor is wave action on exposed beaches, influenced by wind, waves, tidal currents, sediment, and other events. Due to the interconnectedness of ecosystems, hydrological and oceanographic changes can also lead to abrasion in coastal areas (Cahyani et al., 2025; Frantzova et al., 2024; Rudianto et al., 2022).

Coastal abrasion can impact the surrounding environment, including the gradual loss of flora and fauna habitats (Canal et al., 2025; Jordan & Fröhle, 2022; Roy et al., 2023). If abrasion persists for a long period, the habitats of marine flora and fauna will gradually disappear. The loss of marine flora and fauna habitats also reduces marine resources, making it difficult for local residents to benefit from these resources (Moustafa et al., 2023; Saliu et al., 2023; Ullah et al., 2024). Furthermore, the gradual loss of marine flora and fauna habitats can damage marine ecosystems. Mangrove forests are damaged. Numerous studies have shown that mangrove forests can repel seawater, thus preventing abrasion (Asari et al., 2021; Chen et al., 2024; Astikasari et al., 2023). However, mangrove forests will be damaged or even destroyed if large-scale abrasion continues. Furthermore, when the storm season arrives, mangrove forests will have an increasingly difficult time holding back ocean waves. Shrinking coastlines or areas: if coastal areas continue to shrink, there will be fewer places for fishermen to park their boats, making it difficult to store boats on the shore (Suripeddi et al., 2025; Pollard et al., 2025; Chuang et al., 2021). Furthermore, the beauty of the coast can be diminished due to significant abrasion. In 2017, the Geospatial Information Agency (BIG) reported that Indonesia's total coastline is 99,093 kilometers. This is a very long line, but over time, the Indonesian coastline has begun to shrink (Yang et al., 2023; Phong et al., 2022; Dede et al., 2023). Shrinkage of the Indonesian coastline has already occurred in several locations, gradually reducing the coastline. This shrinking coastline is also accompanied by shrinking land area. This shrinking coastline can harm the environment, ecosystems, and coastal communities, preventing them from fully utilizing the coast. This shrinking coastline can be caused by both human activity and natural factors (Cahyaningsih et al., 2022; Day et al., 2021; Kang et al., 2023). A shrinking coastline indicates that the coast is increasingly jutting inland. This shrinkage is caused by coastal abrasion. Continuous coastal abrasion can also reduce the beauty of the beach itself by disrupting the natural balance. One factor contributing to the shrinking coastline is the decline in mangrove ecosystems. Mangroves are tropical trees that thrive in harsh conditions: mostly salty wood, coastal waters, and constant tidal action (Kumari & Rathore, 2021; Quadros et al., 2021; Kathiresan, 2021). Thanks to their ability to store vast amounts of carbon, mangroves are a key weapon in the fight against climate change, but they

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are threatened worldwide. By protecting mangrove forests, we can help safeguard the future of our planet (Asari et al., 2021; Indra Gumay, 2022; Jadin & Rousseau, 2022). According to Saparinto (2007), mangrove forests are forest vegetation that grows between the low tide line and can also grow on coral reefs and on dead coral flats topped with a thin layer of sand, mud, or muddy shores.

The social aspects of coastal erosion can be seen in changes in livelihoods, decreased incomes, behavioral changes, and the responsibilities of communities and governments (Sultana et al., 2023; Niu et al., 2023; Shidqi et al., 2025). According to Purba (2002), the social environment is defined as the area where various social interactions take place between various groups and their institutions, with established symbols, values, and norms related to the natural and built environment (spatial planning). Meanwhile, Carley and Bustelo, in Wulan (2012), explain that the scope of social aspects includes at least demographic, social, economic, institutional, psychological, and sociocultural aspects. Demographic impacts include changes in the workforce and population structure, employment opportunities, and population displacement and relocation. Socioeconomic impacts consist of changes in income, business opportunities, and employment patterns. Institutional impacts are increased demand for facilities such as housing, schools, and recreational facilities. Psychological and sociocultural impacts include social integration, social cohesion, and attachment to one's place of residence. In Indonesia, approximately 100 locations across 17 provinces and 68 coastlines have experienced abrasion that requires immediate attention and management (Disposaptono, 2015). The number of recorded abrasion disasters in Indonesia from 1815 to 2013 was 192. Indonesia is an archipelagic country with a fairly extensive territory and a long coastline. Furthermore, Indonesia also has a relatively large population, most of whom live in coastal areas. One of Indonesia's coastal areas is Napabalano District.

Astronomically, Napabalano District is located on the North coast of Muna Island and geographically, Napabalano District is located in the North of the equator extending from north to south between 5.00º - 6.25º South Latitude and 123.34º - 124.64º East Longitude. The northern part faces the Tampo Strait, the eastern part faces the Buton Strait, the southern part faces Lasalepa District, while the western part faces the Tiworo Strait. It has an area of 105.47 km² with a population of 12,473 people spread across 4 villages and 2 sub-districts. Napabalano District has 2 sub-districts which are coastal areas and directly face the Tampo Strait. It has a coastline length of ± 3 km. Potential threats to the Napabalano coastal area that often occur are abrasion, sea level rise and drought. Napabalano District is a center for rural economic growth, including the Tampo Market, Tampo Wooden Ship Port, Fish Auction Market, Raha Fuel Terminal, Jompi Jaya Sentosa Gas Station, and the Tampo-Torobulu Ferry Port. Based on the potential threat of coastal erosion and the large number of settlements concentrated in the coastal areas of Napabalano District, a coastal erosion risk assessment and mitigation efforts are needed in Napabalano District based on its disaster characteristics. According to BNPB Regulation No. 2 of 2021, disaster characteristics can be identified through a study and assessment of disaster risk in a region, taking into account several aspects, namely disaster threat, regional vulnerability, community vulnerability, and disaster management capacity. Based on this, a coastal erosion risk analysis study can be conducted in Napabalano District, and it is highly necessary as it serves as a guideline for coastal erosion prevention in Napabalano District.

Methods

This study relies on both primary and secondary data that are directly related to the research site in Napabalano District. Primary data are collected directly from the field, including GPS

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coordinate points, satellite imagery for coastline and land-use mapping, geological, topographic, and soil data, data on settlement density, and vegetation cover of mangrove forests. Secondary data are obtained from literature review and relevant government agencies. These include administrative maps of Napabalano District from the local government, oceanographic data on wave height and current velocity from BMKG, records of coastal abrasion events from BPBD Muna Regency, and demographic statistics such as population distribution, elderly population, density, poverty levels, number of fishermen, and disabled population from BPS Muna Regency. These datasets are aligned with the research problems and analytical framework to ensure comprehensive assessment.

Research Location and Time

The research site is located in Napabalano District, Muna Regency, which lies along the equatorial line between 5.00º–6.25º LS and 123.34º–124.64º BT. Administratively, Napabalano comprises two urban wards and four villages, covering an area of 105.47 km² with a population of 12,117 people. Its northern boundary faces Tampo Strait, the east borders Buton Strait, the west borders Tiworo Strait, while the south adjoins Lasalepa District. The research is scheduled from December 2024 to February 2025, synchronized with the Master's curriculum in Infrastructure and Environmental Engineering, Universitas Fajar, and adjusted to academic supervision milestones.

Research Materials

To support the research process, several instruments and materials are required. Field equipment includes a Global Positioning System (GPS) device, digital camera, and note-taking tools. For data processing, a high-specification laptop is used to perform spatial analysis with ArcGIS software. Supporting materials include satellite imagery maps at a scale of 1:50,000 and other thematic maps covering the entire Napabalano District.

Research Design

The study adopts a survey method with a descriptive analytical approach. Data collection involves field surveys, digitization of satellite imagery, and acquisition of oceanographic data such as tides, currents, and waves, alongside ecological observations of the coastal environment. Data processing is conducted using Microsoft Excel 2021 and ArcGIS 10.8 for spatial analysis. Analytical results are classified into three categories high, medium, and low allowing comparative assessment of disaster risk, vulnerability, capacity, and hazard levels. The analysis follows BNPB Regulation No. 1 and 2 of 2012, and results are presented in tabular and map forms. In terms of research variables: Independent variables consist of coastal abrasion potential and disaster hazards in Napabalano's coastal zone. Dependent variables are represented by vulnerability factors including social, economic, physical, and environmental aspects. Control variables are guided by BNPB Regulation No. 2 of 2012 concerning disaster risk assessment methodology.

Data Analysis

The data analysis in this study was carried out by processing both primary and secondary data using Microsoft Excel and transforming them into spatial formats with ArcGIS 10.4. One of the analytical techniques applied was the Normalized Difference Water Index (NDWI), which is useful for delineating water bodies and identifying coastal features. Following the framework outlined in the BNPB regulations, the analysis focused on four main indices. The first was the vulnerability index, which measured socio-economic, physical, and ecological conditions of the community, including indicators such as population density, the proportion of vulnerable

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groups, poverty levels, the number of fishermen, settlement density, and the extent of mangrove vegetation. Each indicator was weighted according to BNPB Regulation No. 2 of 2012, and the results were classified into low, medium, and high categories.

The second was the capacity index, which assessed institutional and community readiness to deal with disasters. This analysis examined the existence of regulations, disaster management institutions, disaster risk assessment documents, early warning systems, structural and non-structural mitigation efforts, as well as education and training related to disaster preparedness. The scoring system was based on BNPB Regulation No. 1 of 2012 but adapted to the local context of Napabalano. The third component was the hazard index, which considered both natural and environmental factors. It evaluated oceanographic parameters such as wave height and current velocity, ecological indicators such as the density of mangrove vegetation, and physical characteristics including coastline morphology and substrate type. These parameters were also weighted and classified into categories of low, medium, and high hazard levels.

The disaster risk index was calculated by integrating the results of vulnerability, capacity, and hazard analyses. This provided a comprehensive picture of the potential disaster risks in Napabalano's coastal areas. The classification of disaster risk levels was conducted based on scores, which were grouped into low, medium, and high risk using the formula and class intervals prescribed by BNPB. To complement the quantitative results, qualitative descriptive analysis was also employed. This included field observations, documentation, and interviews, which helped provide contextual insights into local conditions. The combination of these methods not only quantified the level of risk but also produced recommendations for disaster risk reduction. These recommendations emphasized structural measures such as seawalls and breakwaters, alongside non-structural approaches including mangrove rehabilitation, policy development, and strengthening community preparedness.

Results and Discussion

The findings of this study go beyond the bare list of spatial analyses and quantitative typologies, these are the embodiment of the real life of a coastal community which has to contend with a fine line between land, means of living and natural processes. The lines of vulnerability in Napabalano District are not only written in maps or indices but also in the daily practices of life where households, institutions, and ecosystems have to work under the umbrella of frequent coastal erosion. The study attempts to conceptualise risk as a dynamic relationship between people and the environment by embedding the concept of demographic, environmental and institutional parameters in the BNPB paradigm. Both indicators therefore represent the numerical accuracy and social meaning, depicting how the geography and the community set-ups in the district intersect to create resilience and vulnerability in unequal measures.

This section is further than a data presentation in the approach to the findings in that it goes into the interlacing dynamics that define abrasion hazard exposition of the district. The spatial analyses, done using ArcGIS and field verification provide a multidimensional insight into the interactions between vulnerability, capacity, and hazard in the six villages. However, the meaning of these interactions can be understood in the form of social textures underlying them in their significance. Napabalano is not just a spot on a map; it is a system of interdependent settlements that are connected by common livelihoods, social relations and ecological relationships. Through this socio-environmental interrelatedness, the analysis offers depth to the readers who remember that vulnerability is not evenly distributed but rather mediated by access and opportunity as well as collective memory of previous disasters.

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The initial level of analysis is based on the dimension of social vulnerability, which is a gateway to the human roots of risk. Social vulnerability represents the combination of population density, age structure, gender balance, and poverty, as well as physical constraints, to determine vulnerability. In Napabalano and Tampo, the high densities of the population and housing get converted to high degrees of exposure whereby the environmental disturbances breed immediate effects on human beings. On the other hand, village of Pentiro which is sparsely populated seems to be safer as far as quantitative aspects are concerned but is socially weak as it is isolated and has little institutional coverage. These comparisons indicate that risk is not merely a matter of numerical plenty or geography but is created by the disequilibrium of abilities of communities to prepare, react and recuperate. The democratic and social setup of Napabalano District therefore discloses a stratified image of vulnerability whereby density, inequality and marginality are present in one coastal system.

Going into the economic world, the patterns are even more complicated. The coastal village livelihood systems of Napabalano are inseparably attached to natural resources which in turn are not stable at the presence of environmental change. The local economy is characterized by agriculture and small fisheries that both serve as the source of sustenance and at the same time, subject the household to the uncertainties that tend to be cyclical. The figures indicate that, Napabalano and Tampo have greater gross regional product values, but this may not necessarily lead to resilience. The economic power of the regions has a small foundation with mostly fishing and trade along the coast, which makes the societies highly susceptible to ecological shocks. Villages like Pentiro with little productive land and less circulation of capital face a different kind of vulnerability namely a vulnerability of scarcity and not exposure. The bigger image that can be formed is that of an economy that is integrated within environmental constraints, where prosperity and precarity are neighbors.

This relation is more accurately outlined by the analysis of physical vulnerability. The physical landscape of Napabalano District such as the residential structures, learning institutions, places of worship, and other social amenities depict a developmental trend that has evolved faster than the capacity to withstand natural disruptions. Napabalano Village which serves as the administrative nucleus, is where the greatest concentration of physical assets is concentrated and will therefore bear the greatest burden in case of abrasion. The very roads and buildings, which indicate development, are also the sources of liability with the waves washing up the beach and water seeping into human population. Tampo faces a similar predicament, whereby the hastened pace of growth and closeness to the coastline increases exposure without similar improvements in structural strength. The vulnerability that is experienced in smaller villages like in Pentiro or Langkumapo lies not in the abundance of resources, but rather in the weakness of the resources and limited access to resources of recovery. Therefore, the physical environment of the district is an uneven allocation of protection and destruction.

The environmental aspect adds a greater resonance of ecology to this trend, which stresses that the size of a coastline will not only depend on the artificial line of defence, but on the healthiness of the natural defenses as well. The ability to absorb shock and regenerate in coastal ecosystems is a collective result of mangrove forests, coral formations and sedimentary systems. In Napabalano, though, these environmental basics are at a loss. Empirical evidence shows that even though the villages like Napalakura and Pentiro still have relatively large areas of mangrove belts, Napabalanos mangrove cover has significantly declined. Such erosion has not only weakened the ecological barrier against waves, but it has also broken the fine balance between a marine productivity and the stability of the shoreline. The environmental product is, therefore, more susceptible to not only physical erosion but also ecological burn out, hence,

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

representing a graphical address of a long-term disproportion between anthropogenic extraction on the one hand and environmental renewal on the other.

The next point of analysis is the institutional capacity which places the human and ecological findings into the context of governance framework. The incompetence in capacity scores that were witnessed in all the villages is indicative of structural issues with the translation of national disaster management structures into localized action. Regulations, the structure of an organization are formally defined, but their enforcement is still in a fragmented and often reactive manner. The local communities do not often get or have the ability to sustain disaster education or support on early warning and the community can only rely on the ad hoc responses when they are in dire situations. Napabalano and Tampo have slightly better institutional profiles because of intermittent mitigation efforts; nevertheless, these are not sufficient to maintain preparedness. The lack of the integrated, participatory disaster management culture implies that resilience in the district is imaginatively designed as the operational goal but not the implemented practice that is part of the life in the community.

The hazard analysis also explains how the interaction between environmental exposure and institutional fragility is realized. Whilst the majority of coastal zones have quite homogenic wave and current patterns, Napabalano is characterized by open, linear coastline and reduced mangrove cover. Geomorphology of the area also causes direct waves to impact settlements and create constant erosional forces. Even though the other villages like Pentiro and Tampo are located in the low zones of hazard, they are exposed to the secondary effects because they are located near the active abrasion zones, which includes sediment redistribution and salinity intrusion. In this light, it is necessary to define hazard landscape of Napabalano not as the fixed category but as the dynamic process shaped by both natural forces and human carelessness.

It is when these social, economic, physical, environmental and institutional dimensions are regarded as a block that the resulting image is that of a district caught in between vulnerability and endurance. All the villages of Napabalano are classified as the high-risk category not due to the same threats, but due to the common structural weaknesses across all the villages that cut across locale specifics. The combination of high population density, economic concentration, and environmental degradation in Napabalano and Napalakura is what has resulted in vulnerable situations compounded. Langkumapo, located inland and not having direct exposure to the sea, is still connected to this coastal exposure system, both economically and in its institutional readiness. Risk in Napabalano does not occur as such a singular occurrence, but is present as a continuous state embedded in the social and ecological context of daily life.

Such combination of results proves that the disaster risk of the coastal areas cannot be understood through separate measurements or independent parameters. It has to be understood to be a dynamic interaction of people, place and policy. The trends revealed in Napabalano can be related to the way ecological exploitation, institutional incompetence, and socio-economic insecurity collectively contribute to the continued risk condition. It is important to note that the quantitative data of the further tables and spatial mappings are not to be considered as numerical values only, but as a reflection of the underlying ecological and social reality. They express the way communities are living at the land-sea interface and bargained survival amid vulnerability and adaptation to an environment that is ever-altering the circumstances of its existence.

Table 1. Social Vulnerability Based on Population Density in Napabalano District

Village/Urban Ward	Area (Km^2)	Population (People)	Density (People/Km^2)

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

Lambiku	20.46	1,379	67.40
Pentiro	35.03	650	18.56
Napabalano	11.67	4,624	396.23
Tampo	5.77	3,446	597.23
Napalakura	18.54	1,291	69.63
Langkumapo	14.00	1,083	77.36

The data show that Tampo and Napabalano have the highest population densities, with 597.23 and 396.23 people/km² respectively. These figures suggest that both areas are more exposed to disaster risks due to concentrated settlements, making evacuation and resource distribution more challenging. On the other hand, Pentiro records the lowest density at only 18.56 people/km², which indicates lower exposure but also potential isolation during emergencies.

Table 2. Social Vulnerability Based on Sex Ratio in Napabalano District

Village/Urban Ward	Area (Km²)	Population (People)	Sex Ratio
Lambiku	20.46	1,379	102.2
Pentiro	35.03	650	95.78
Napabalano	11.67	4,624	95.44
Tampo	5.77	3,446	101.4
Napalakura	18.54	1,291	107.56
Langkumapo	14.00	1,083	94.78

The sex ratio across the district ranges from 94.78 in Langkumapo to 107.56 in Napalakura. While most areas maintain a relatively balanced ratio, Napalakura shows a higher proportion of males, and Langkumapo a slightly higher proportion of females. Although the differences are not extreme, such imbalances may affect labor distribution and community roles during disaster preparedness and recovery.

Table 3. Social Vulnerability Based on Poverty Ratio in Napabalano District

Village/Urban Ward	Area (Km²)	Population (People)	Poverty Ratio
Lambiku	20.46	1,379	0.24
Pentiro	35.03	650	0.25
Napabalano	11.67	4,624	0.20
Tampo	5.77	3,446	0.23
Napalakura	18.54	1,291	0.30
Langkumapo	14.00	1,083	0.40

Poverty ratios vary significantly, with Langkumapo (0.40) and Napalakura (0.30) recording the highest values, indicating greater economic vulnerability in these villages. Poor households tend to have limited access to resources, making them more susceptible to the impacts of disasters. Conversely, Napabalano has the lowest poverty ratio (0.20), suggesting relatively stronger economic resilience despite its large population.

Table 4. Social Vulnerability Based on Disability Ratio in Napabalano District

Village/Urban Ward	Area (Km²)	Population (People)	Disability Ratio
Lambiku	20.46	1,379	0.06
Pentiro	35.03	650	0.05
Napabalano	11.67	4,624	0.08
Tampo	5.77	3,446	0.09
Napalakura	18.54	1,291	0.06

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Langkumapo	14.00	1,083	0.05

The disability ratio remains low across all villages, ranging from 0.05 to 0.09. Tampo (0.09) and Napabalano (0.08) record the highest values, meaning these areas may require more inclusive disaster planning to accommodate vulnerable groups. Although the ratios are numerically small, even a few households with disabled members can significantly increase community vulnerability during emergencies.

Table 5. Social Vulnerability Based on Age Dependency Ratio in Napabalano District

Village/Urban Ward	Area (Km²)	Population (People)	Dependency Ratio
Lambiku	20.46	1,379	16.15
Pentiro	35.03	650	15.15
Napabalano	11.67	4,624	18.52
Tampo	5.77	3,446	17.63
Napalakura	18.54	1,291	15.21
Langkumapo	14.00	1,083	14.24

The dependency ratio is highest in Napabalano (18.52) and Tampo (17.63), indicating a larger proportion of non-working-age individuals who depend on the working population. This places additional pressure on households during disasters, as fewer productive members are available to support recovery. Langkumapo has the lowest dependency ratio (14.24), suggesting a slightly stronger household capacity to cope with disasters.

Table 6. Social Vulnerability Analysis in Napabalano District

Village/Urban Ward	Population Density	Sex Ratio	Poverty Ratio	Disability Ratio	Dependency Ratio	Social Vulnerability Score	Class
Lambiku	1,379	102.2	0.24	0.06	16.15	2.2	Medium
Pentiro	650	95.78	0.25	0.05	15.15	1.6	Medium
Napabalano	4,624	95.44	0.20	0.08	18.52	2.2	Medium
Tampo	3,446	101.4	0.23	0.09	17.63	2.2	Medium
Napalakura	1,291	107.5	0.30	0.06	15.21	2.2	Medium
Langkumapo	1,083	94.78	0.40	0.05	14.24	2.2	Medium

The composite analysis shows that all villages fall into the medium vulnerability class, with scores ranging between 1.6 and 2.2. Pentiro records the lowest score (1.6), while the remaining villages are clustered at 2.2. This uniformity reflects that although socio-economic and demographic differences exist, the overall social vulnerability across Napabalano District remains moderate. It suggests systemic weaknesses that require attention, particularly in reducing poverty and strengthening resilience in high-density areas.

Table 7. Economic Vulnerability Based on Productive Land in Napabalano District

Village/Urban Ward	Productive Land Area (Ha)	Maize	Green Beans	Coconut	Cocoa	Kapok
Lambiku		2	0.5	30	0	1
Pentiro		3	0.5	21	0	1
Napabalano		2	0	15	1	0.5
Tampo		4	0	30	1	0.8
Napalakura		2.5	1	40	2	1
Langkumapo		1.8	1	35	2	2

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Productive land varies between villages, with Napalakura and Langkumapo showing the highest values in coconut and cocoa cultivation. These areas have stronger agricultural bases, which contribute to livelihoods but also create dependence on land use vulnerable to coastal abrasion. Napabalano, despite being the administrative center, has relatively limited productive land, which reflects lower agricultural resilience.

Table 8. Economic Vulnerability Based on GRDP in Napabalano District

Village/Urban Ward	Population (People)	GRDP (IDR)
Lambiku	1,379	57,393,980,000
Pentiro	650	27,053,000,000
Napabalano	4,624	192,450,880,000
Tampo	3,446	143,422,520,000
Napalakura	1,291	53,731,420,000
Langkumapo	1,083	45,074,460,000

Napabalano and Tampo record the highest GRDP values, reflecting greater economic activity compared to other villages. Pentiro has the lowest GRDP, which highlights its economic vulnerability. This disparity suggests that while some areas may have stronger economies, they are still highly dependent on limited sectors, leaving them exposed during disasters.

Table 9. Economic Vulnerability Analysis in Napabalano District

Village/Urban Ward	Productive Land (IDR)	Score	GRDP (IDR)	Score	Economic Vulnerability	Class
Lambiku	500,000,000	1.8	57,393,980,000	1.2	3.0	High
Pentiro	380,000,000	1.8	27,053,000,000	1.2	3.0	High
Napabalano	275,500,000	1.8	192,450,880,000	1.2	3.0	High
Tampo	535,000,000	1.8	143,422,520,000	1.2	3.0	High
Napalakura	688,500,000	1.8	53,731,420,000	1.2	3.0	High
Langkumapo	618,000,000	1.8	45,074,460,000	1.2	3.0	High

The combined analysis of productive land and GRDP shows that all villages in Napabalano District fall into the high economic vulnerability class. This indicates that although some areas generate significant economic value, their dependence on agriculture and limited diversification of income sources make the entire district highly vulnerable to disaster impacts.

Table 10. Physical Vulnerability Based on Number of Buildings and Facilities in Napabalano District

Village/Urban Ward	Houses	Schools	Places of Worship	Government Buildings	Public Facilities
Lambiku	344	2	1	2	1
Pentiro	162	3	1	1	1
Napabalano	1,156	8	4	4	4
Tampo	862	8	4	2	1
Napalakura	323	3	2	1	1
Langkumapo	271	2	1	1	1

Napabalano and Tampo have the largest number of houses and public facilities, which indicates higher exposure to physical damage if disasters occur. Smaller villages like Pentiro and Langkumapo have fewer facilities, but limited infrastructure also reflects lower resilience in terms of public service availability after disasters.

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

Table 11. Physical Vulnerability Analysis in Napabalano District

Village/Urban Ward	House Score	School Score	Worship Score	Government Score	Public Facility Score	Physical Vulnerability	Class
Lambiku	1.2	0.6	0.6	0.9	0.6	12	High
Pentiro	1.2	0.6	0.6	0.9	0.6	12	High
Napabalano	1.2	0.9	0.9	0.9	0.9	15	High
Tampo	1.2	0.9	0.9	0.9	0.6	14	High
Napalakura	1.2	0.9	0.9	0.9	0.6	14	High
Langkumapo	1.2	0.6	0.6	0.9	0.6	12	High

All villages in Napabalano District are classified as high in physical vulnerability, with Napabalano (15) and Tampo (14) showing the highest values. This reflects a concentration of infrastructure that increases exposure to coastal abrasion impacts. Even villages with fewer facilities still fall into the high category due to limited resilience and service capacity.

Table 12. Environmental Vulnerability Based on Forest Areas in Napabalano District

Village/Urban Ward	Conservation Forest (Ha)	Production Forest (Ha)	Mangrove Forest (Ha)	Shrubs/APL (Ha)
Lambiku	0.00	135.97	456.67	842.58
Pentiro	0.00	683.03	605.53	512.82
Napabalano	10.36	159.87	36.51	257.38
Tampo	0.00	198.81	84.79	207.13
Napalakura	0.00	750.30	961.19	440.16
Langkumapo	0.00	1,829.77	49.41	803.00

Napalakura and Pentiro have the largest mangrove areas, which play a crucial role in reducing coastal abrasion risk. In contrast, Napabalano has the smallest mangrove coverage, making it more vulnerable to erosion. High proportions of shrubs and production forests in most villages suggest land use patterns that may reduce ecological protection against disasters.

Table 13. Environmental Vulnerability Analysis in Napabalano District

Village/Urban Ward	Conservation Score	Production Score	Mangrove Score	Shrub Score	Environmental Vulnerability	Class
Lambiku	0.4	1.2	0.3	0.3	2.20	Medium
Pentiro	0.4	1.2	0.3	0.3	2.20	Medium
Napabalano	0.4	1.2	0.2	0.3	2.10	Medium
Tampo	0.4	1.2	0.3	0.3	2.20	Medium
Napalakura	0.4	1.2	0.3	0.3	2.20	Medium
Langkumapo	0.4	1.2	0.2	0.3	2.10	Medium

All villages in Napabalano District are classified within the medium environmental vulnerability category, indicating that although the area benefits from certain ecological assets particularly mangrove forests that serve as natural barriers against coastal hazards these resources remain insufficiently robust or widespread to lower overall vulnerability levels. The mangroves contribute significantly to reducing shoreline erosion, moderating tidal impacts, and maintaining local biodiversity; however, degradation from unsustainable land conversion, aquaculture expansion, and limited reforestation efforts has weakened their ecological function. Villages such as Napabalano and Langkumapo, which scored slightly lower (2.10), reflect areas where environmental protection is less effective, likely due to higher exposure to coastal dynamics or inadequate conservation measures. This condition underscores the urgent

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

need for integrated environmental management strategies, including mangrove rehabilitation and community-based ecological monitoring, to enhance the district's resilience and move toward lower vulnerability classifications in the future.

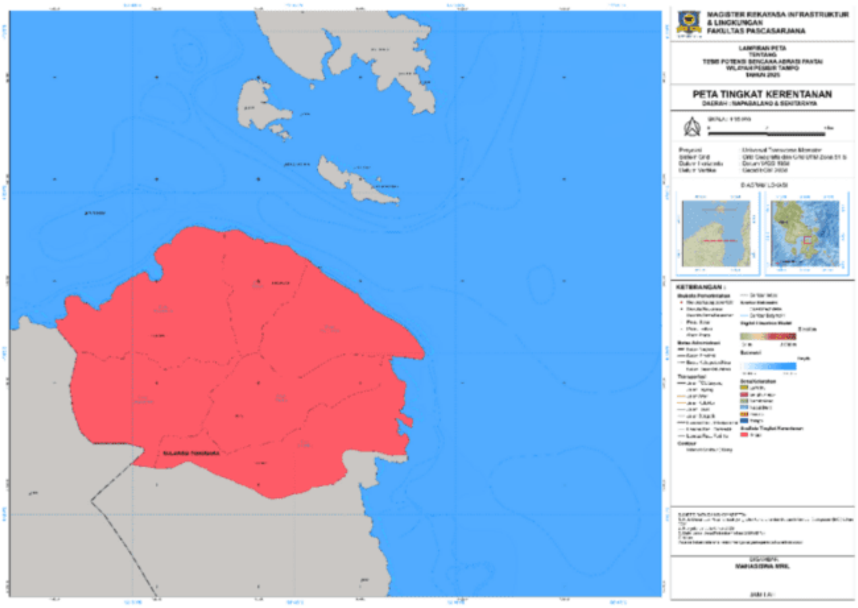

Figure 1. Map of coastal area vulnerability levels in Napabalano District

Table 14. Scoring of Capacity Parameters in Coastal Areas of Napabalano District

Village/Urban Ward	**Disaster Management Rules & Institutions**	**Risk Assessment Documents**	**Early Warning System**	**Structural & Non-Structural Mitigation**	**Disaster Education & Training**
Lambiku	2	1	1	1	1
Pentiro	2	1	1	1	1
Napabalano	2	1	1	2	1
Tampo	2	1	1	2	1
Napalakura	2	1	1	1	1
Langkumapo	2	1	1	1	1

The table shows that most villages/urban wards in Napabalano District scored poorly across all indicators. While regulations and institutions are formally established, there are significant weaknesses in disaster risk documentation, early warning systems, and community training. Only Napabalano and Tampo have implemented limited structural mitigation efforts, but this does not substantially improve their overall capacity.

Table 15. Scoring of Capacity Parameters in Coastal Areas of Napabalano District

Village/Urban Ward	**Indicator 1**	**Indicator 2**	**Indicator 3**	**Indicator 4**	**Indicator 5**	**Weighted Value**	**Class**
Lambiku	2	1	1	1	1	1.25	Low
Pentiro	2	1	1	1	1	1.25	Low
Napabalano	2	1	1	2	1	1.55	Low
Tampo	2	1	1	2	1	1.55	Low
Napalakura	2	1	1	1	1	1.25	Low
Langkumapo	2	1	1	1	1	1.25	Low

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

All villages/urban wards are classified as having low capacity. Napabalano and Tampo scored slightly higher (1.55) due to the presence of structural mitigation measures, but they remain within the low category. This indicates that disaster preparedness in the district is insufficient and largely reactive, rather than proactive.

Table 16. Capacity Level Classification

Range of Total Capacity Values	Class
1.0 – 1.66	Low
1.67 – 2.34	Medium
2.35 – 3.0	High

The classification system set by BNPB provides a framework for evaluating disaster management capacity. Villages in Napabalano District fall within the lowest range, reinforcing their limited ability to respond to coastal abrasion threats effectively.

Table 17. Capacity Levels of Coastal Areas in Napabalano District

Village/Urban Ward	Capacity Value (C Total)	Class
Lambiku	1.25	Low
Pentiro	1.25	Low
Napabalano	1.55	Low
Tampo	1.55	Low
Napalakura	1.25	Low
Langkumapo	1.25	Low

The final capacity index classification shows that all villages/urban wards in Napabalano District fall under the low category. This highlights a critical gap between institutional frameworks and their actual implementation at the community level. Without improvements in early warning systems, disaster education, and effective TRC deployment, the district will remain highly vulnerable to coastal abrasion hazards.

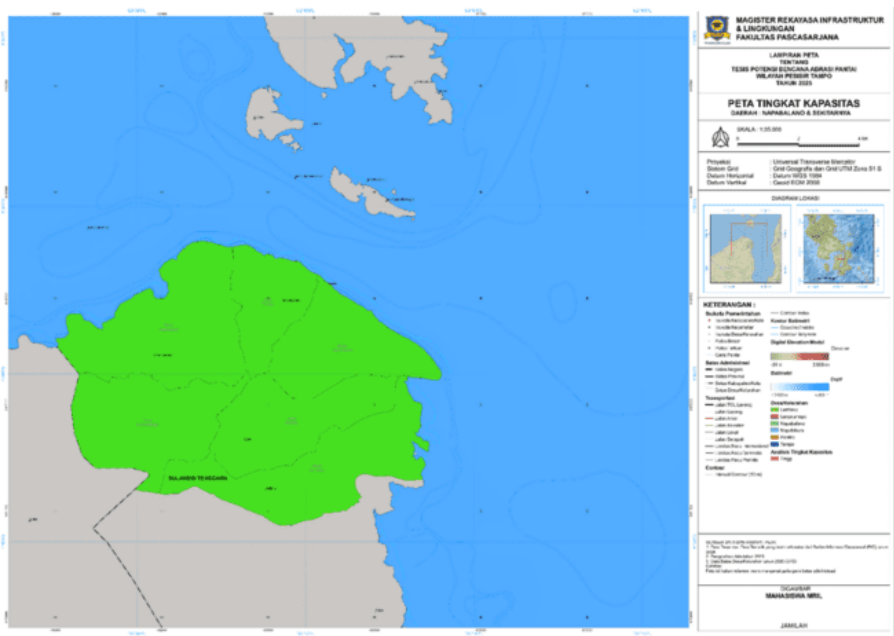

Figure 2. Map of the capacity level of the coastal area of Napabalano District

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

Table 18. Wave Height in the Coastal Areas of Napabalano District

Village/Urban Ward	Wave Height (m)
Lambiku	0.5 – 1
Pentiro	0.5 – 1
Napabalano	0.5 – 1
Tampo	0.5 – 1
Napalakura	0.5 – 1
Langkumapo	0.5 – 1

Wave height across all coastal villages/urban wards ranges between 0.5–1 meter. This uniformity is due to the relatively similar coastal and marine characteristics in Napabalano. Waves generally originate from the northeast, influenced by the Buton Strait – Tampo Strait waters. Since wave energy is a major driver of coastal abrasion, this consistent range indicates a moderate but persistent threat across the district.

Table 19. Current Speed in the Coastal Areas of Napabalano District

Village/Urban Ward	Current Speed (m/s)
Lambiku	0.05
Pentiro	0.05
Napabalano	0.05
Tampo	0.05
Napalakura	0.05
Langkumapo	0.00

Most villages (Lambiku, Pentiro, Napabalano, Tampo, and Napalakura) have a current speed of 0.05 m/s, indicating relatively low-energy water movement typical of shallow and sloping seabeds. Langkumapo shows 0 m/s, as it is geographically inland with no direct coastal frontage. These low current speeds reduce sediment dispersal but make coastal areas more vulnerable to accumulation and localized erosion when combined with wave action.

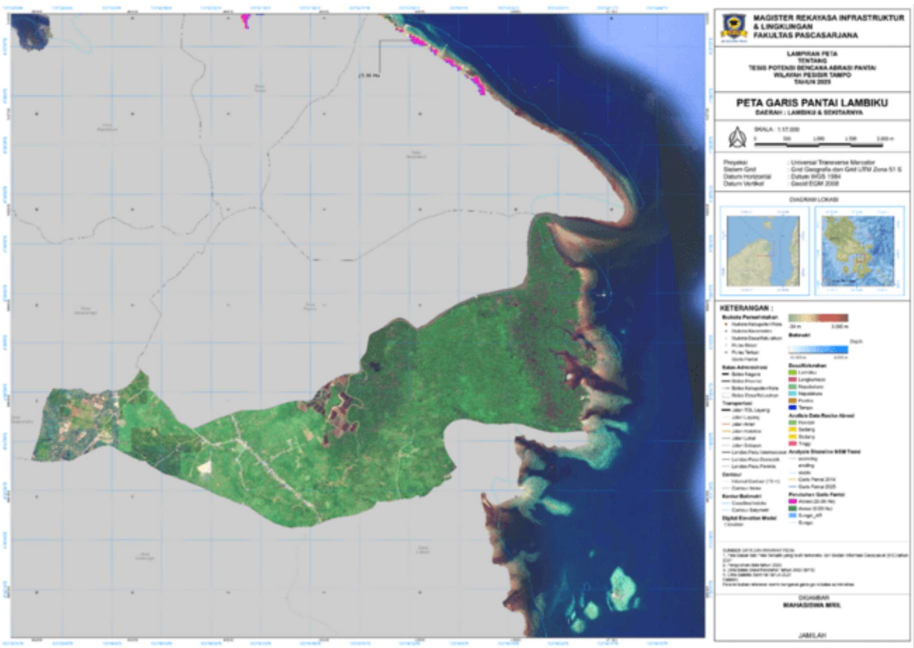

Figure 3. Shape of the Coastline of Lambiku Village, Napabalano District

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Based on field data, the beaches in Napabalano District are predominantly sandy, rocky, and open, some of which are covered by coastal structures and natural rock formations. The coastline of Napabalano District is extensively used for piers, residential areas, fishing facilities, and various government buildings.

Table 20. Hazard Index Analysis in Napabalano District

Village/Urban Ward	Wave Height	Current Speed (m/s)	Mangrove Vegetation	Coastline Shape	Coastal Characteristics	Total Value	Class
Lambiku	1	0.05	5	1	2	1.415	Low
Pentiro	1	0.05	5	1	2	1.415	Low
Napabalano	1	0.05	5	3	2	1.715	Medium
Tampo	1	0.05	5	2	2	1.565	Low
Napalakura	1	0.05	5	1	2	1.415	Low
Langkumapo	1	0.00	5	0	0	1.050	Low

Most villages fall into the low hazard category, with Napabalano the only one classified as medium hazard. This is due to its straight, open coastline and partial mangrove loss, which increase exposure to coastal abrasion. Tampo also shows elevated risk, though it remains in the low category, while Langkumapo scores lowest due to its non-coastal geography.

Table 21. Total Coastal Abrasion Hazard Values

Village/Urban Ward	Wave Height	Current Speed	Mangrove Vegetation	Coastline Shape	Coastal Characteristics	Total Value	Class
Lambiku	1	0.05	5	1	2	1.415	Low
Pentiro	1	0.05	5	1	2	1.415	Low
Napabalano	1	0.05	5	3	2	1.715	Medium
Tampo	1	0.05	5	2	2	1.565	Low
Napalakura	1	0.05	5	1	2	1.415	Low
Langkumapo	1	0.00	5	0	0	1.050	Low

Napabalano shows the highest hazard score (1.715), placing it in the medium hazard category. All other villages remain in the low category, though Tampo (1.565) is close to the medium threshold. Langkumapo, with no coastline, records the lowest hazard value.

Table 22. Hazard Level Classification

Hazard Index Range	Class
1.0 – 1.66	Low
1.67 – 2.34	Medium
2.35 – 3.0	High

This classification framework indicates that most Napabalano villages fall into the low hazard category, with only Napabalano itself entering the medium category due to its exposed coastal morphology and reduced mangrove coverage.

Table 23. Coastal Abrasion Hazard Levels in Napabalano District

Village/Urban Ward	Hazard Index (H. Total)	Category
Lambiku	1.415	Low
Pentiro	1.415	Low
Napabalano	1.715	Medium
Tampo	1.565	Low
Napalakura	1.415	Low
Langkumapo	1.050	Low

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

The final hazard assessment shows that Napabalano Village is the most threatened by coastal abrasion with a medium hazard classification, while all other villages remain low. This highlights Napabalano as the priority area for coastal protection and mitigation measures, especially given its combination of open coastline and reduced mangrove protection.

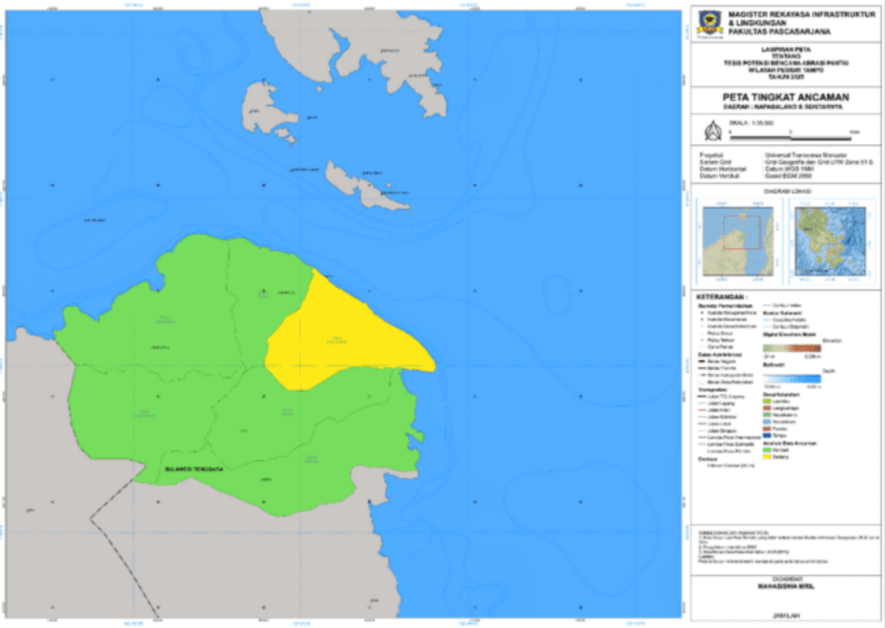

Figure 4. Map of Coastal Threat Levels in Napabalano District

Disaster risk analysis is a systematic process of identifying, analyzing, and evaluating the potential negative impacts of disaster threats in a region, taking into account the level of threat, vulnerability, and community capacity. The potential negative impacts are calculated based on the level of threat, vulnerability, and disaster management capacity of the region. The potential negative impacts can be assessed based on the potential number of people exposed to disasters, property losses, and environmental damage. To determine the value of disaster risk in a coastal area, it is necessary to know the threat value, vulnerability value, and capacity value that have been analyzed and their respective levels determined based on the data obtained.

Table 24. Results of Coastal Abrasion Disaster Risk Analysis in Napabalano District

Village/Urban Ward	Hazard (H)	Vulnerability (V)	Capacity (C)	Risk (R)
Lambiku	1.415	4.85	1.25	5.49
Pentiro	1.415	4.61	1.25	5.22
Napabalano	1.715	5.59	1.55	6.19
Tampo	1.565	5.35	1.55	5.40
Napalakura	1.415	5.35	1.25	6.06
Langkumapo	1.050	4.84	1.25	4.07

The results indicate that Napabalano (R = 6.19) and Napalakura (R = 6.06) face the highest disaster risks due to a combination of high vulnerability and relatively low capacity. Langkumapo, with no direct coastline, shows the lowest risk (R = 4.07) but is still within the high-risk category. This suggests that coastal abrasion is a severe threat across all villages, with variations in intensity influenced mainly by vulnerability and capacity differences.

Table 25. Disaster Risk Levels of Villages/Urban Wards in Napabalano District

Village/Urban Ward	Risk Value	Category

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

Lambiku	5.49	High
Pentiro	5.22	High
Napabalano	6.19	High
Tampo	5.40	High
Napalakura	6.06	High
Langkumapo	4.07	High

All six villages/urban wards in Napabalano District fall into the high-risk category. Among them, Napabalano and Napalakura are the most at risk, while Langkumapo records the lowest value but remains high risk. This means that no community is safe from abrasion, and comprehensive mitigation efforts are needed across the entire district.

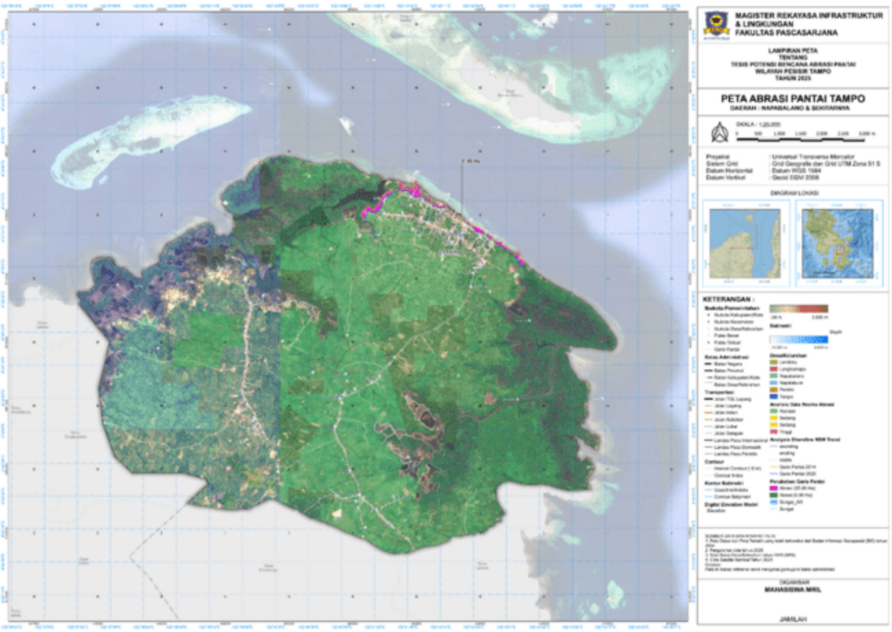

Figure 5. Coastal Abrasion Disaster Risk Map of Napabalano District

Disaster risk reduction is a systematic process of identifying, assessing, and understanding the risks of disasters or undesirable events, with the goal of formulating strategies and actions to mitigate their impacts. A disaster risk analysis of an area can provide insight into developing risk reduction policy programs for potential disaster impacts. Based on the analysis, the coastal areas in Napabalano District, particularly Tampo and Napabalano Villages, have been impacted by abrasion. Therefore, the author can provide the following recommendations for reducing the risk of coastal abrasion in Napabalano District:

Recommendations for Reducing and Preventing Disaster Risk

Efforts to reduce and prevent the high risk of coastal abrasion disasters in Napabalano District must be carried out comprehensively through the development of a Coastal Disaster Management Plan (RPB), as mandated by Law No. 24 of 2007. The preparation of the RPB is a continuation of the disaster risk assessment process and serves as a strategic document containing interrelated programs aimed at reducing risks in coastal areas with a high level of vulnerability and exposure. The first strategy focuses on reducing the vulnerability of at-risk groups, particularly poor fishermen and communities living directly along the coast, who have limited knowledge of disaster threats. Vulnerability reduction can be achieved through outreach and training programs that raise awareness of abrasion hazards, such as extreme wave events, and provide practical knowledge on disaster preparedness. These activities can involve

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

local stakeholders, including government agencies and universities, to ensure that vulnerable groups are better informed and prepared.

In addition to reducing vulnerability, another key strategy is strengthening community capacity. This involves cultivating a culture of disaster preparedness among coastal populations by providing education on self-rescue techniques and disaster risk reduction practices. Capacity-building initiatives also extend to local stakeholders and private actors who play important roles in the coastal economy, encouraging them to avoid development or settlement in zones highly prone to abrasion. Equally important is the establishment of an early warning system (EWS) that functions to provide timely information to communities and local authorities regarding potential disaster events. A well-designed EWS helps minimize loss of life and property by giving coastal residents advance notice to evacuate or take protective measures. Such a system should be developed collaboratively between the community and local government, with the Regional Disaster Management Agency (BPBD) of Muna Regency and Napabalano District taking the lead in its implementation.

Parallel to these measures, disaster risk reduction outreach activities must be continuously carried out to ensure information is widely disseminated to coastal communities. These activities may include installing information boards in high-risk areas, publishing and broadcasting early warning messages in print and electronic media, and conducting evacuation drills. Furthermore, partnerships between the Muna Regency Government, universities, and relevant agencies can generate scientific studies that strengthen understanding of abrasion dynamics and improve mitigation planning.

Finally, long-term sustainability requires a strong emphasis on disaster risk prevention. Preventive actions can be implemented by rehabilitating degraded coastal ecosystems, especially mangrove forests, which serve as natural barriers against wave energy and shoreline retreat. The rehabilitation of coastal ecosystems should be supported by strict enforcement of coastal zoning regulations, ensuring that coastal boundaries are protected and that land use in sensitive areas is effectively controlled. These preventive measures, carried out by the Public Works and Spatial Planning (PUPR) agency in collaboration with communities, will not only restore ecological resilience but also provide lasting protection for coastal settlements.

Taken together, these strategies vulnerability reduction, capacity strengthening, early warning systems, risk reduction outreach, and ecological rehabilitation form an integrated framework for managing and preventing abrasion disaster risks in Napabalano District. Through coordinated efforts between local government, communities, and supporting institutions, it is possible to mitigate the adverse impacts of coastal abrasion and build long-term resilience in the region.

Conclusion

The coastal area of Napabalano District is classified as high, with the capacity index for all coastal areas in Napabalano District being low, and the threat level for coastal abrasion in the coastal area of Napabalano District being low to moderate. The risk of coastal abrasion in the coastal area of Napabalano District is classified as high. Recommendations for reducing the risk of coastal abrasion in the high category include restoring or rehabilitating mangrove vegetation along the coast of Napabalano District. Prevention recommendations include improving the quality of the coastal environment and protecting coastal ecosystems.

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