

Determination of Coastal Vulnerability Level Based on CVI Method and GIS in Rupert Island, Riau Province

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ABSTRACT

The Rupert Island is one of the islands in Riau Province, Indonesia which generally consists of peat soil. Hence several coastal areas surrounded Rupert Island have been severely damaged due to the influence of the sea waves and tides. Meanwhile, the coastal area has been widely occupied by the local human business activities including residential areas, industrials, tourism areas and river catchment areas for fishing activities. Rupert Island is in fact, included in the National Tourism Strategic Area (KSPN) and it is also the outermost island in the territory of the Unitary State of the Republic of Indonesia bordering with Malaysia and Singapore. Hence, the conservation programs for these coastal areas become very important issues in the light of enforcing national sovereignty. This research was conducted to determine the level of vulnerability of the coast on Rupert Island abrasion using the Coastal Vulnerability Index (CVI) method and to generate a spatial map of the coastal areas on Rupert Island which are vulnerable to failure using the Geographical Information System (GIS) approach. The results obtained are that Rupert Island has low to very high coastal vulnerability index with the largest abrasion was occurred in the Pergam Village (with the coastline damage up to 3.5 m / year).

Keywords— Vulnerability, Coastal, Island, Rupert, CVI, GIS

1. INTRODUCTION

Each coastal area has a different level of vulnerability to environmental disturbances, both from natural factors and as a result of human activities. The Coastal Vulnerability Index (CVI) can be used to measure the extent to which the coast is vulnerable to damage. This level of vulnerability can be used as a reference for formulating various policies related to coastal area management and management plans [1].

Riau Province has a coastal area that has very high vulnerability. This area that has very high vulnerability is located in the Meranti Islands, Bengkalis and Rokan Hilir Regency [2-4].

Rupert Island is one of the islands in Bengkalis Regency which has a coastal area (Fig. 1). Peat soil which is generally characterized as soil in Rupert Island are vulnerable to abrasion due to the influence of the waves of seawater. Meanwhile, this coastal area is widely used for human activities, as a

residential area, industry, tourism and also a catchment area for fishermen [5-6].

In addition, Rupert Island is included in the National Tourism Strategic Area (KSPN). The determination of the location of the coast based on the national tourism strategic area refers to the Government Regulation of the Republic of Indonesia Number 50 of 2011 concerning the National Tourism Development Master Plan 2010-2025). The area in Riau province which is included in the national tourism strategic area in 50 national tourism destinations. The areas that are included in the strategic national tourism area are Rupert-Bengkalis Island and its surroundings [7].

Coastal vulnerability is a condition that describes a condition that is susceptible to coastal disasters such as abrasion and sedimentation. Abrasion that occurs continuously without any mitigation efforts will result in a reduction in the land area of an area. This is of course a serious problem considering the location of Rupert Island is the outer island of the Republic of Indonesia [8-9].

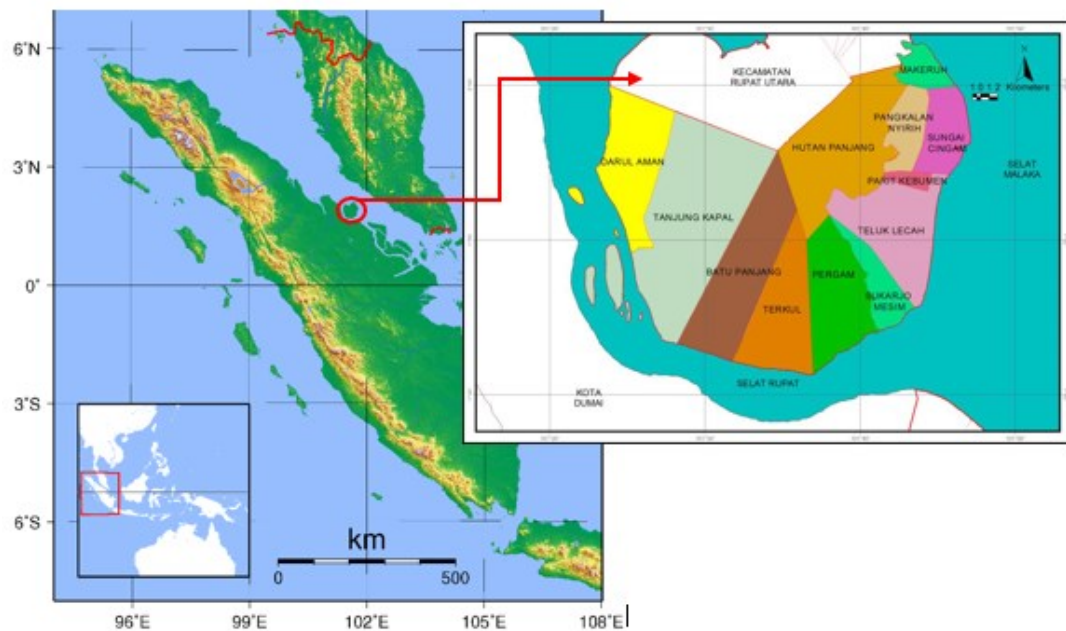


Fig. 1. Map of research locations

This research was conducted to identify the level of vulnerability of beaches on Rupat Island to coastal damage using the Coastal Vulnerability Index (CVI) method. Also, this study will map the coastal areas in Rupat Island that experience vulnerability using the Geographic Information System (GIS).

2. RESEARCH METHODOLOGY

2.1. Beach Vulnerability

Vulnerability or vulnerability has emerged as a central concept in understanding the consequences of natural disasters and for developing disaster risk management strategies. The general definition of vulnerability is the level of a system that is susceptible or unable to cope with disasters. Vulnerability is defined as the condition of a community or society that leads to or causes an inability to face a disaster. The level of vulnerability can be viewed from the physical, social, demographic and economic aspects. Physical vulnerability describes a physical condition that is prone to certain hazard factors [10].

Coastal vulnerability is a condition that describes the "susceptibility" (susceptibility) of a natural system as well as the social conditions of the coast (humans, groups or communities) to coastal disasters. In 1998, Arthurton from the British Geological Survey has proposed several recommendations, including actions to reduce coastal vulnerability as a means of mitigating natural marine and coastal disasters in coastal cities in the Pacific.

2.2. Coastal Vulnerability Index

Coastal Vulnerability Index (CVI) is determined by combining several risk parameters to produce an indicator.

This index is used to identify areas that are at risk of erosion, permanent inundation or temporary inundation [11-12].

Each input risk parameters are grouped based on risk classes 1, 2, 3, 4 and 5. These parameters are grouped based on the impact of the damage produced classified as very low, low, medium, high and very high, especially in coastal areas. After this process, each area in the coastal area will have a risk rating after considering the six parameters.

Table I. Coastal vulnerability levels

(CVI)	VULNERABILITY
0-25	Low
25-50	Medium
50-75	High
>75	Very high

In this study, the beach vulnerability index was determined based on the weighting of 10 coastal physical variables that refer to the research of Boruff, et al. (2005), and DKP (2004), namely: 1. Coastline (PP) changes (from calculations), 2. Visual Observation Damage (K), 3. Damage Length (PK), 4. Damage Width (LK), 5. Green Belt Width (SH), 6. Lithology (L), 7. Wave Height (H), 8. Tidal Distance (tidal range = PS), 9. Land Use (PL), and 10. Beach Slope (β). The detailed weighting physical variables are shown in Table II.

Based on the weighting of the ten coastal physical variables, the coastal vulnerability index (CVI) is calculated. According to Boruff (2005) to calculate the value of coastal vulnerability the following equation can be used:

$$CVI = \sqrt{\frac{\text{Multiplication of all variables}}{\text{Number of Variables}}} \quad (1)$$

The visual conditions of coastal damage at the study location were documented in this study. Some interviews were also conducted with several people who live in coastal areas. Satellite images data also analyzed to determine the magnitude of coastline changes from year to year.

Table II. The Weighting of coastal physical variables [13,14]

Weight	Variables									
	Coastline Changes (PP)	Visual observation of damage (K)	Length of Damage (PK)	Width of Damage (LK)	Green Belt Width (SH)	Lithology (L)	Wave Height (H)	Tidal Range (PS)	Land Use (PL)	Beach slope ($\tan \alpha$)
1	0 m/year	Visible symptoms of damage	< 0.5 km	0 m	> 1500 m	Rocks are frozen, sedimentary, compact and hard	< 0.5 m	< 0.5 m	Tackles, mangrove forests, vacant lots and swamps	0 – 2 %
2	(0 - 1) m/year	Seen scoured but still stable	0.5 – 2.0 km	1-10 m	(1000 – 1500)m	Sedimentary rock, fine-grained, soft	(0.5 – 1) m	(0.5 – 1) m	The domestic tourist areas and traditional ponds	2 – 5 %
3	(1 - 5) m/year	Scoured and there will be a collapse	2.0 – 5.0 km	10 – 50 m	(500 – 1000) m	Gravel and coarse sand	(1 – 1.5) m	(1 – 1.5) m	Rice fields and intensive ponds	5 – 10 %
4	(5 - 10) m/year	Scouring and collapsing but not yet harm to the facilities / infrastructure	5.0 – 10.0 km	50 - 100	(50 – 500) m	Fine sand, silt, soft clay	(1.5 – 2.0)m	(1.5 – 2.0)m	Settlements, ports, offices, schools, provincial roads	10 – 15 %
5	> 10 m/year	Scouring and ruins and potentially endangering the facilities /infrastructure	> 10 km	> 100 m	< 50 m	Fine sand, silt, clay, soft	> 2.0 m	> 2.0 m	Cultural preserve, tourist areas, industry, country roads and air defense facilities	> 15 %

2.3. Geographical Information Systems

GIS can be defined as a component consisting of hardware, software, geographic data and human resources that are treated to manage data and display it in an information system. The notion of managing here includes several processes, namely: retrieving, storing, repairing, updating, manipulating, integrating and analyzing. The difference between GIS and other information systems is its ability to combine spatial data and analyze data/information using a database management system. [13]

The analysis steps for the abrasion and accretion rates can be seen in the following chart diagram (Fig. 2):

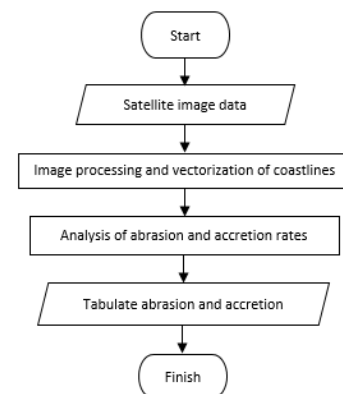


Fig. 2. Flowchart of Abrasion and Accretion Rate Analysis

From Fig. 2, the analysis of the rate of abrasion and accretion using the Digital Shoreline Analysis System (DSAS) v5.0 software tool can be obtained. Before being analyzed, the satellite image that has been processed according to the combination of memory channels is vectored

to obtain the coastline. This coastline vector is then used as a reference for changes in coastline per year (baseline). Furthermore, a transect line is made perpendicular to the baseline to divide the coastline with glands with an interval of 100 m. The rate of change in the coastline was analyzed using the End-Point Rate (EPR) statistical approach. This EPR method calculates the rate of change of the shoreline by dividing the distance between the shoreline of the oldest year and the shoreline of the latest year (net shoreline movement / NSM), as shown in Fig. 3. This method can be done using a minimum of two coastlines.

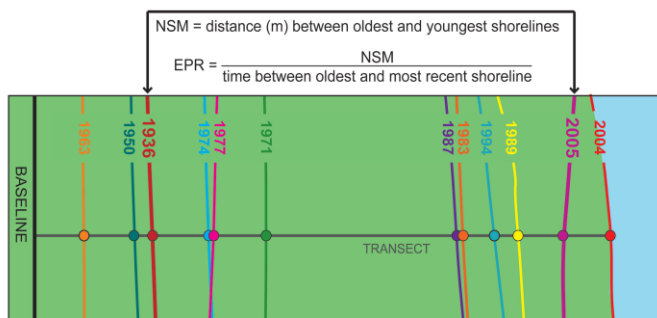


Fig. 3. End Point Rate Method

Meanwhile, to determine changes in land area that experienced abrasion and accretion, an overlapping process of data was carried out for each year in order to obtain the area of abrasion and accretion.

3. RESULT AND DISCUSSION

3.1. Coastal Vulnerability Based on CVI

From the results of field identification, the vulnerability of Rupert Island beach is obtained which can be seen in Table III.

Table III. Results of CVI in Research Study

No	Area	Total	Vulnerability
1	Pergam, Rupert	109.54	Very High
2	Tanjung Jaya, Rupert	80	Very High
3	Kedur, Rupert	50.6	High
4	Teluk Rhu, Rupert	48.99	Medium
5	Batu Panjang, Rupert	42.43	Medium
6	Tanjung Lapin, Rupert	34.64	Medium
7	Tanjung Punak, Rupert	28.28	Medium
8	Tanjung Kapal, Rupert	28.28	Medium
9	Makeruh, Rupert	12.65	Low

Coastal Vulnerability Index (CVI) in Rupert Island

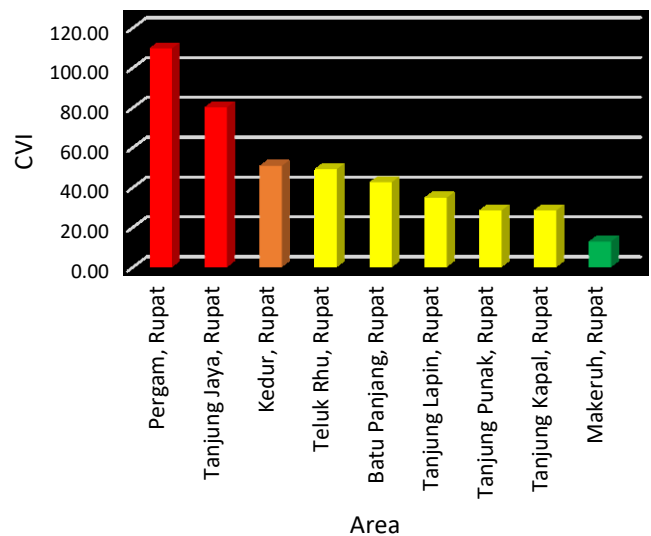


Fig. 4. Coastal Vulnerability Index (CVI) in Rupert Island

Table III and Fig. 4 show that Rupert Island has a vulnerability value from low to very high. The area with the highest coastal vulnerability was Pergam Village with a coastal vulnerability index value of 109.54 and the area with the lowest coastal vulnerability value was Makeruh village with a coastal vulnerability index value of 12.65. These results are a direct visual survey of the beach location as shown in Fig. 5.



Fig. 5. Existing Condition of Coastal in Rupert Island

3.2. Coastal Vulnerability Based on GIS

Coastal abrasion analysis uses two satellite image data with the following data:

Table IV. Satellite Image Data Used

No	Image Type	Memory Channels	Recording Time
1	Landsat 7 Enhanced Thematic Mapper Plus (ETM+) Level-1 Data Products	5, 4, 2	2000-04-26
2	Landsat 8 OLI (Operational Land Imager) and TIRS (Thermal Infrared Sensor) Level-1 Data Products	6, 5, 3	2020-02-05

The selected memory channel is a memory channel that provides a contrast difference between sea and land. This is useful for simplifying the process of interpreting coastlines from satellite imagery.

In the analysis that has been done, apart from obtaining tabulated data, a map was also made to determine the distribution of areas experiencing abrasion and accretion. A map of the abrasion and accretion area on Rupert Island is presented in Fig. 3.

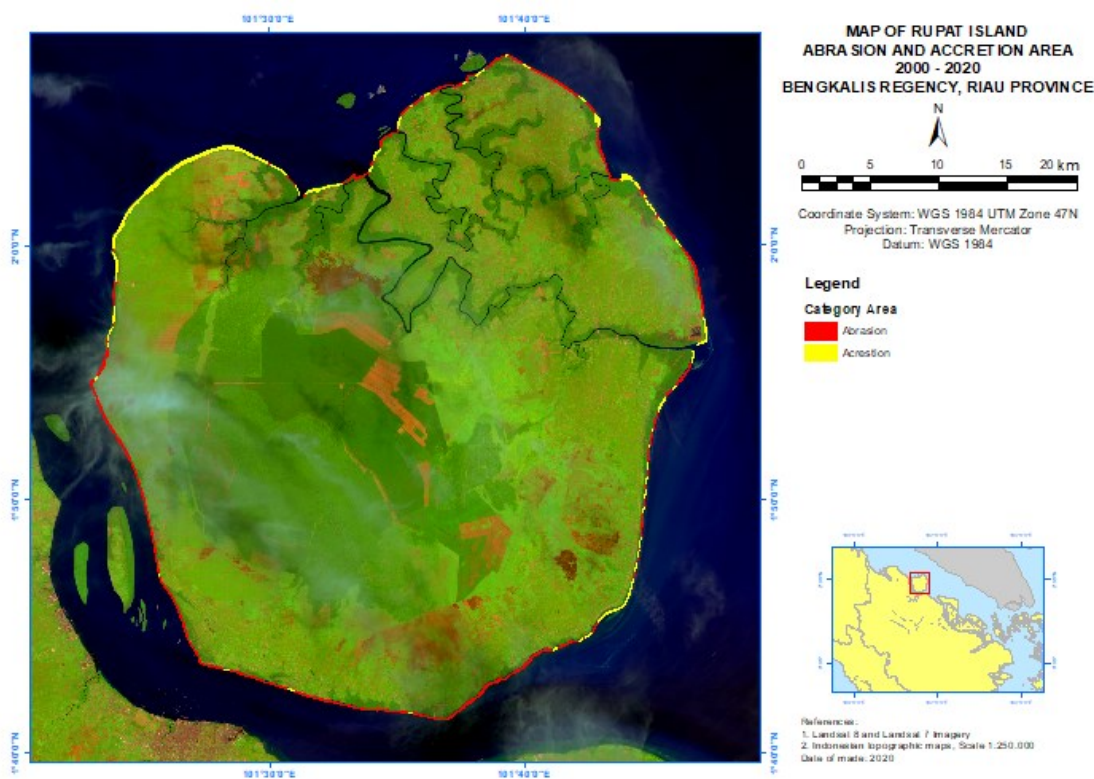


Fig. 6. Map of Rupert Island Abrasion and Accretion Area

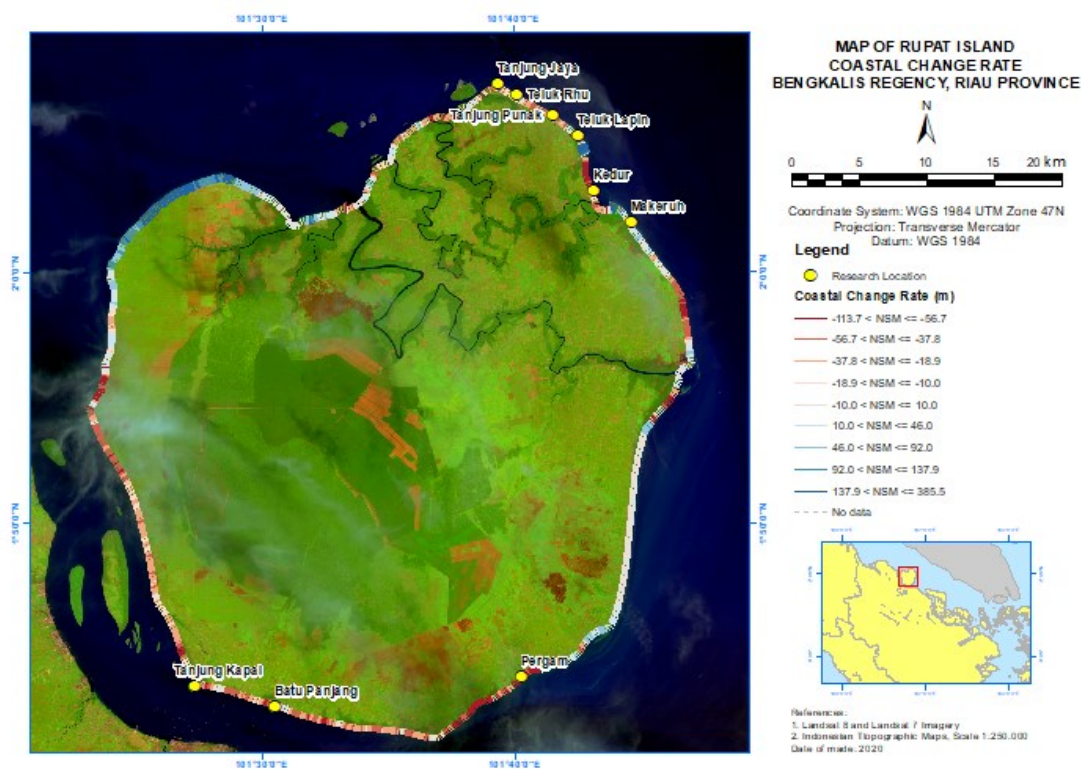


Fig. 7. Rupert Island Coastline Change Rate (EPR)

Based on Fig. 6, the distribution of areas experiencing abrasion is from the west coast to the north coast of Rupert Island. Meanwhile, the areas that experienced accretion were more focused on the northwest coast of Rupert Island. The area of the abrasion and accretion rates is presented in Table V:

Table V. Area of Abrasion and Accretion Rate of Pulau Rupert Beach, 2000 – 2020

Period	Abrasion		Accretion	
	Area (Ha)	Average (Ha/Year)	Area (Ha)	Average (Ha/Year)
April 2000 - February 2020	348.13	17.55	299.10	15.08

A map of the rate of change of the Rupert Island coastline is presented in Fig. 7. The locations studied are scattered from the southwest coast to the northeast coast.

The distribution of locations shows that most of them are in areas experiencing abrasion. The results of the analysis for areas experiencing accretion, shows that the highest EPR value of accretion is 19.49 m / year. However, it only happened over a short distance. Meanwhile, the accretion value between 0 - 5 m / year has a greater distribution along the coastline.

The EPR value for areas experiencing abrasion has different characteristics from accretion. The highest EPR value for abrasion is -5.75 m / year. However, the area of abrasion is mostly distributed along the coastline with a range of 0 to 5 m / year. The distribution of the EPR value can be seen in Fig. 8.

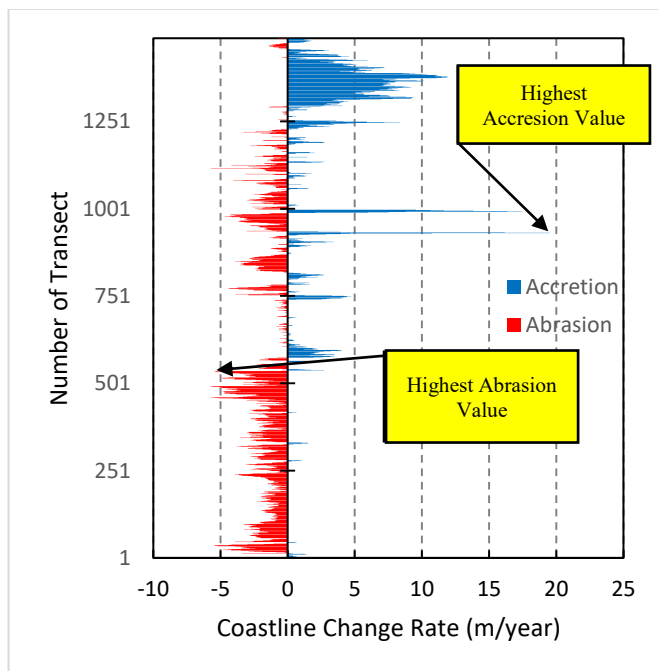


Fig. 8. Distribution of EPR Coastline Change Rate

There are 9 locations of survey points. the average EPR value of the analysis results from the location under review is presented. Pergam experienced the highest abrasion, namely - 3.557 m / year and only Teluk Rhu which experienced accretion of 0.213 m / year. In Fig. 9, the distribution of the rate of change of the coastline has been presented by showing the review location in No. transect. The coastal areas of Tanjung Kapal, Batu Panjang and Pergam have a significant distribution of abrasion compared to other review locations.

Table VI. Average Abrasion and Accretion Rates

No	Village	No. Transect	EPR (m/year)	Information
1	Tanjung Jaya	1071	-1.248	Abrasion
2	Teluk Rhu	1057	0.213	Accretion
3	Tanjung Punak	1027	-2.318	Abrasion
4	Teluk Lapin	1004	-1.834	Abrasion
5	Kedur	963	-2.440	Abrasion
6	Makeruh	920	-0.637	Abrasion
7	Pergam	519	-3.557	Abrasion
8	Batu Panjang	323	-2.093	Abrasion
9	Tanjung Kapal	263	-1.395	Abrasion

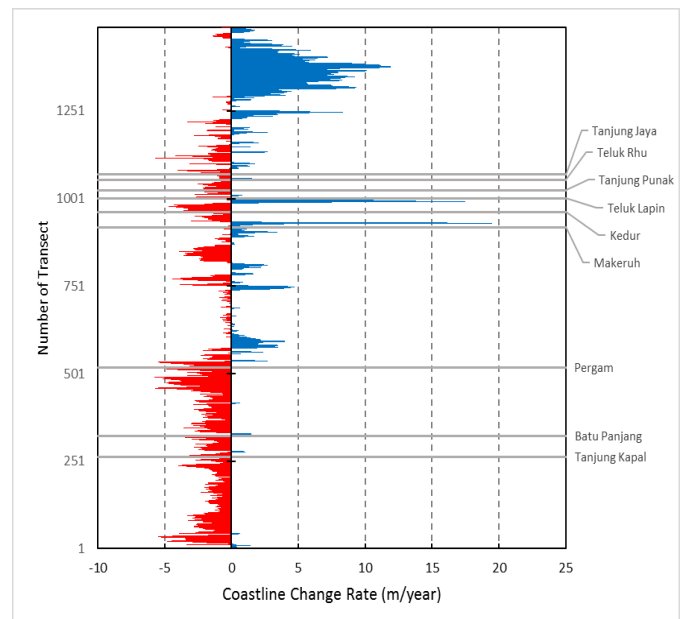


Fig. 9. Distribution of EPR Coastline Change Rate in Village Area in Rupert Island

4. CONCLUSION

From the analysis, it is concluded Pergam Village in Rupert Island experienced the highest abrasion process (3.557 m / year) with the coastal vulnerability index value was 109.54 which belongs to a very high vulnerability value. If allowed to continue, this situation will have implications for the reduction of land area in Rupert Island which is the outermost island in Indonesia.

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