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RESEARCH ARTICLE

The Preliminary Sedimentation Pattern Study in West Borneo NPP Potential Site

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Abstract. Coastal environmet dynamics study is one of the NPP site feseability studies that need to be conducted to understand the potential external risk in an NPP development. The Pantai Gosong area was the preferred potential site for the NPP development and was located in the coastal area. Therefore, external factors such as abrasion or sedimentation would influence the NPP site. This research studied the sedimentation pattern of the Pantai Gosong coastal area based on the landform analysis. The results showed that the landform in the Pantai Gosong area was classified as a highly eroded hill, lowly eroded footplain, natural levee-back swamp, beach ridge, alluvial plain, and coastal alluvial plain. The sedimentation process in the northern coastal area of Pantai Gosong that has lowly eroded footplain landform was more intense than in the southern part. The analysis was well correlated with the estimated sediment thickness from the microtremor method analysis that showed that the northern coastal area has higher sediment deposits with 12.7 to 21.7 m of thickness than the southern coastal area with 3.2 to 12.6 m thickness. The northern footplain in the Pantai Gosong coastal area was expected to have higher sedimentation than the southern part continuously.

1. Introduction Font size Minion Pro 10 bold

In 2019, The Indonesia National Nuclear Energy Agency (BATAN) was mandated to administer the National Priority Research Program (PRN) regarding Comercial-Scale Nuclear Power Plant (NPP) Prototype in West Borneo. In order to fulfill the mandate, BATAN carried out a potential site study in the West Borneo coast in 2020. Based on the study result, Pantai Gosong in Bengkayang Regency was the preferred potential site for comercial-scale NPP in West Borneo(A, Susiati, and Sunarko 2019).

NPP site feseability study needs to be conducted to determine the site characteristics for nuclear safety from external and internal hazard(BAPETEN 2018). One of the study aspects that need to be considered was the coastal environment characteristics of the potential NPP site, given that the Pantai Gosong area was located in the western coastline of West Borneo. The coastal environment dynamics that were affected by its natural process because a factor to be considered for NPP development(BAPETEN 2014).

The external factor in the coastal environment, such as abrasion or sedimentation, was the significant potential risk for the NPP safety. The abrasion process could cause the retreat process of the shoreline position, which would affect the site condition by destroying the coastal material. This process was generally caused by two main factors; intense sea waves and currents stronger than the shore material resistance and low sedimentation rate in the coastal sedimentation system that caused an imbalance between ingoing and outgoing coastal material(Susilawati and Mefianti 2018). Therefore, understanding the sedimentation pattern in the NPP site area was an important study for the NPP development input.

The sedimentary deposits in the coastal area might be generally formed by two processes; the redistribution of terrigenous clastic materials from fluvial activity or eroded rocks in the coastal area; and the production of bioclastic particles in the sea(Van Loon et al. 2017). The Pantai Gosong area was actively influenced by the fluvial activity from the nearby major river delta. Besides, the materials from the erosion process of the western hill area in the Pantai Gosong could also become the sedimentary deposit source. The preliminary sedimentation pattern could be studied based on the physical process in this area.

The physical erosion process in the onshore area could be studied by analyzing the landform. A landform is an area of any size separated from surrounding land based on its shape(DiPietro 2013). The erosion mechanism, transport, and deposition of the materials were influenced by the landform condition and the geomorphic agent, namely the ocean waves or the wind current.

The geology condition highly influenced the material characteristics of an area. Therefore, lithology information was also crucial for the morphology study in the landform analysis. The Pantai Gosong area comprises plutonic and volcanic igneous rocks, intrusive rocks, and alluvial deposits. The Semesa Island and the hill north-eastern of Pantai Gosong coast are composed of two kinds of rock formations, the Raya vulcanic (Klr) and the sintang intrusives (Toms). The Raya vulcanic are composed of altered andesite and dacite, while the sintang intrusives are composed of plutonic rocks such as diorite and granodiorite. Most of the study area was covered with quarternary surface sedimentary deposits, namely river and swamp deposits (Qa) and littoral deposits (Qc). Figure 1 shows the Pantai Gosong area's geology map referred from the regional geology map by Suwarna and Langford(Suwarna and Langford 1994).

The sedimentation pattern from the landform analysis needs to be compared with current sedimentary deposits to ensure reasonable analysis results. Generally, the sediment thickness was determined by a geotechnical borehole. However, there were many methods to estimate the sedimentary deposit thickness for a preliminary study. In this paper, we used estimation from the microtremor methods. Microtremor is a geophysical method that uses the surface wave to analyze the properties of the surface geologic layer. The derived results from the methods could be used to calculate the sediment thickness. Many studies used the microtremor method to estimate the sediment thickness(Parolai, Bormann, and Milkereit 2002; Ryanto et al. 2020; Seht and Wohlenberg 1999). This study aimed to determine the sedimentation pattern and estimate the sediment thickness based on the landform analysis and microtremor measurement. The analysis was also correlated with the oceanographic data, namely the sea waves, ocean currents, and sediment transport in the study area.

2. The Methods

The research area was located in Pantai Gosong administratively in Sungai Raya Kepulauan District, Bengkayang Regency, West Borneo Province. The Pantai Gosong area was directly opposite Semesa Island, which was only about 1 km away. Semesa Island was one of the small islands in the Bengkayang Regency islands.

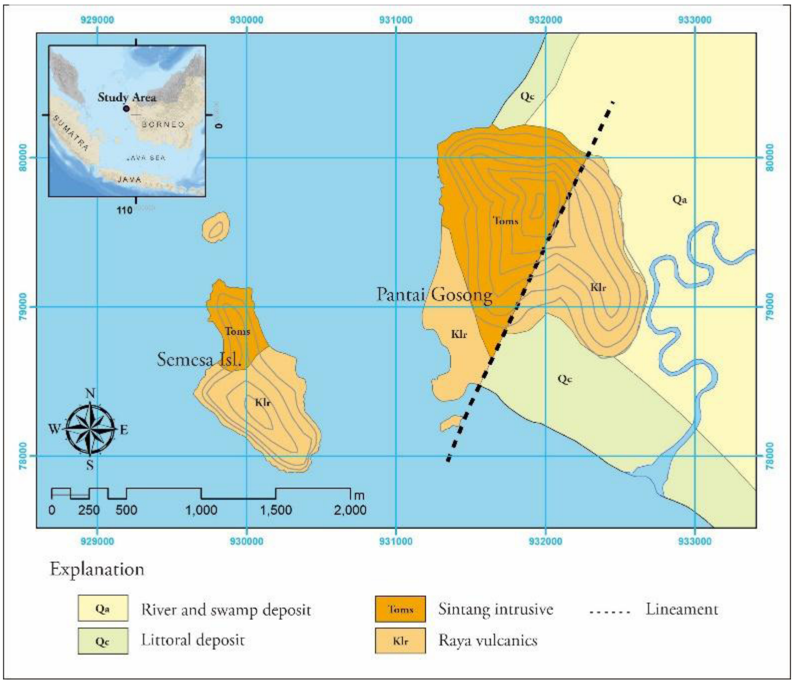

Figure 1. The Regional Geology Map of Pantai Gosong(Suwarna and Langford 1994)

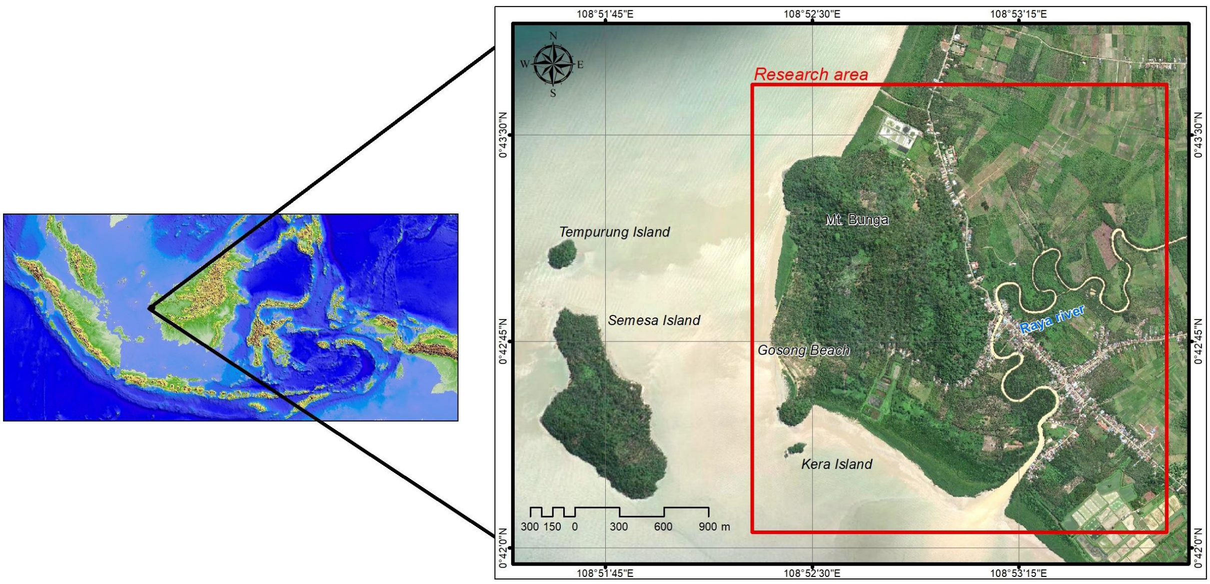

Figure 2. The Research Area

This research used secondary data to analyze the morphology condition. The secondary data used to analyze the area's morphology were the topography, lithology, and soil data. The topography data was derived from a digital elevation map (DEM) with 10 m spatial resolution. The morphometry analysis in the research area was carried out with this topography data. The lithology data was derived from the Singkawang regional geology map. The soil data from the Center for Research and Development of Agricultural Land Resources was used to support the morphography analysis. The spatial analysis of the secondary data was carried out using ArcGIS software with an analytical approach.

The landform analysis was conducted with an analytical approach from three aspects: morphology, morphochronology, and morphogenesis(Minár and Evans 2008). The morphology aspect concludes the size, shape, and elements of the landform based on the formation process. This aspect also concludes morphometry and morphography parameters identified from the slope map, derived from DEM data, and the river stream map of the research area. This aspect was analyzed based on Van Zuidam and van Zuidam-Cancelado(Listyani R.A. 2019).

The morphogenesis aspect analyzes the origin and development of a landform based on the geomorphologic energy that formed the landform and generated specific surface configuration, including the age, composing materials, or geologic structures. The morphochronology aspects analyze the landform sequence based on the geomorphology process that influenced the landform(Bachri et al. 2021). The sequence was indicated by the relative age associated with the process of weathering, soil formation, erosion, and sedimentation. The morphogenesis and morphochronology aspects were analyzed based on the composing materials, soil physical properties, geomorphologic energy from the regional geology map, the soil map, the slope map, and the river stream map of the research area.

The sediment thickness was estimated with the shear wave velocity profiles from the microtremor array data in the Pantai Gosong area (G5, and G6) that was previously published(Iswanto et al. 2020) and the natural soil frequency from 21 microtremor single station data that measured in three axial components. The natural soil frequency (f_0) value was calculated with the Horizontal to Vertical Spectral Ratio (HVSR) method by Nakamura(Nakamura 1989). The frequency of the maximum natural ratio between the horizontal and vertical components from the microtremor waves was considered the natural frequency of the surface soil. The ratio was calculated in the frequency domain with this equation :

$$\frac{H}{V} = \sqrt{(S_{NS}^2 + S_{EW}^2)/(2S_z^2)}$$

where H/V is the horizontal to vertical spectral ratio, S_{NS} is the spectrum from horizontal north-south component and S_{EW} is the spectrum from the horizontal earth-west component of the microtremor waves, and $2S_z$ is the spectrum from the vertical component.

The sediment thickness calculation was based on the quarter-wavelength approximation methods(Poggi, Edwards, and Fäh 2012). This method assumed that the shear wave velocity up to a certain depth corresponds to a quarter wavelength at the resonant frequency of interest. The sediment thickness could be calculated with this equation(Poggi et al. 2012) :

$$f_0 = \frac{v_s}{4h}$$

where f_0 is the resonant frequency of the soil, v_s is the shear wave velocity of the soil layer, and h is the thickness of the soil. This method was widely used to estimate the boundary between sediment and hard bedrocks.

Table 1. Landform Classification in Pantai Gosong Area.

Landform	Composing materials	Geomorphic process	Topographic impression	Topographic expression		
				Relief	Slope (%)	Height difference (m)
Hill, highly eroded	Formation: Toms, Klr Soil: Ultisol, Materials:granite-andesite	Weathering, erosion, rockmass movement	Rolling-hilly-steep hilly	Moderate steep-very steep	15- >40	50-150
Footplain	Formation: Toms, Klr Soil: Ultisol, Materials:granite-andesite	Sedimentary deposition	Undulating	Almost flat-moderate	3-7	5-75
Beach Ridge	Formation: Qc Soil:Spodosol. Materials: clay, sand	Sedimentary deposition	Flat or almost flat	Flat-almost flat	0-2	<5
Natural Levee-back Swamp	Formation: Qa Soil: Entisol, Materials: clay. organic deposit	Sedimentary deposition	Undulating	Almost flat-moderate	3-8	2-25
Coastal Alluvial Plain	Formation: Qa Soil : Entisol, Materials: river clay and organic deposit	Sedimentation	Flat-Undulating	Flat-Almost flat-moderate	2-8	1-20
Alluvial Plain	Formation: Qa Soil: Spodosol, Materials: clay, sand	Sedimentary deposition	Flat-Undulating	Flat-Almost flat-moderate	2-7	1-15

Source: secondary data processing

3. Result and Discussion

The coastal characteristics were highly influenced by the geomorphologic energy in the onshore or offshore area and formed a specific coastal landform. Based on the secondary data processing, the landform of the research area could be identified and classified based on the characteristics and natural similarity, as shown in table 1. Spatially, these natural objects were shown as landform map as shown in figure 3.

The Pantai Gosong area was composed of marine, denudational, and fluvial landforms identified as beach ridge, highly eroded hill, lowly eroded footplain, and natural levee-back swamp (Figure 3). The main area of Pantai Gosong was the highly eroded hill that has intensively sustained vertical erosion and rockmass movement. The outcrop in the hill peak and some other areas in the steep, narrow valley with a steep slope resulted from these processes. The composing materials of this landform were the weathered material from old vulcanic intrusion rocks that have mechanically or chemically eroded. The geomorphological process produced smaller rock fragments and gravitational force, leading to the mass movement. The steep hilly topography with up to 150 m differences of elevation triggered the rock fragments movement to the area with lower elevation. The intensive materials deposition in the foothill formed footplains with flat topography. The marine activity was also intensively occurred in the western part of the hill that directly confronted the ocean. This condition would cause an extensive abrasion process in this area and form a rocky shore environtment(Tamura et al. 2019).

In contrast, the abrasion process in the footplain area with a gentle slope was less intense. The deposited soil materials in this footplain area have relatively good drainage and tend to have thick deposits. The topography expression of the highly eroded hill and the footplain landform is shown in Figure 4.

The beach ridge landform was formed in the southern part of the Pantai Gosong area, associated with a fluvial landform, namely the natural levee-back swamp. This landform has flat to gentle relief with elevation differences less than 5 m. The composing materials of this landform were litoral deposits developed in the quarternary age and produced quite thick deposits with mud, sand, and gravel texture. The topography impression and the materials showed that the active geomorphic process was dominated by material deposition from the Raya River transported by the river stream or the shallow sea waves. This geomorphic process produced a thick sandy sedimentary deposit. This sedimentary deposit was parallel with the coastline from the eastern part of the estuary to the western part that directly crossed the footplain.

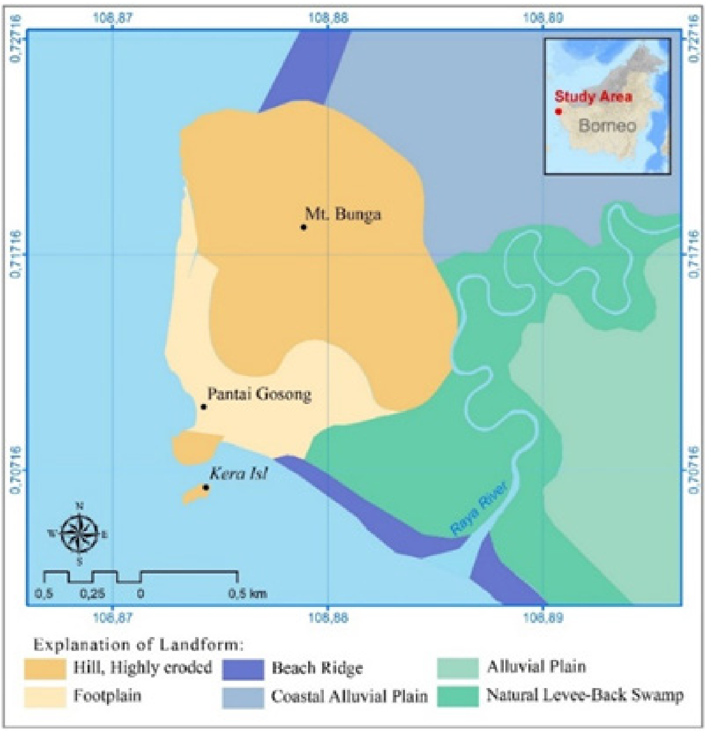

Figure 3. The Landform Map

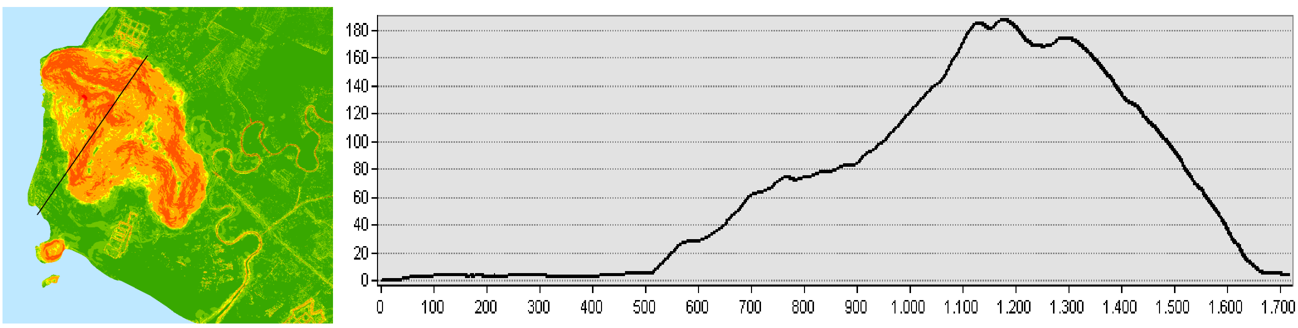

Figure 4. Topography Expression in Highly Eroded Hill and Footplain Landform

The landform in this area was a coastal plain covered with coconut farms and shrubs. The area still actively affected with deposition and sedimentation process was mostly covered with muddy mangrove forest.

The natural levee-back swamp landform in the research area was along the Raya River watershed and tended to be expanded in the estuary area. This landform has a gentle topographic impression with elevation differences ranging from 2 to 25 m, as shown in Figure 5. The area was composed of an abandoned natural levee that formed by the river stream. The stream was separated by swamps depression as an accumulation of rainwater or seasonal rivers. This condition generated the water inundation from the rain or river, which could stem the flow of small tributaries to enter the main river. The process caused the small tributaries to flow parallel with the main river, inundating and accumulating sedimentary materials to form a meandering pattern.

The swamps depression was also formed in the back of the beach ridge landform. The depression pattern was parallel with the coastline due to the deposition of river and sea waves materials. The process has continuously occurred, and the deposited materials became relatively thick, and the coastline was protruded forward. The materials were composed of alluvial and organic deposits, which formed in the quarternary age. The soil has a fine texture and low drainage. The natural levee-back swamp area was covered with shrubs, farms, ponds and partly used as a settlement.

In the Pantai Gosong area, the alluvial plain was a depositional body caused by the Raya river stream activity, which flowed from the Monterado highland area and debouched in the southern part of the Pantai Gosong area. This landform material was composed of alluvial and swamp deposits, which formed in the quarternary age. The soil data in this landform showed that the soil developed was relatively young and associated with a wet environment. The soil texture was loose sandy-clay with medium depth and fast soil drainage. This soil type development was caused by the high and stationary rainfall intensity, which made the soil highly resistant to erosion. However, The material deposition in this area was also intensely occurred. Most of the alluvial plain was affected by human activity. This area has a flat topography and tends to have fertile soil, making the nearby inhabitant farm. The area was mostly used as oil palm plantation, farmland, and also settlement.

The deposition process has occurred intensively because the landform topography was flat to gentle with 1 to 10 m elevation differences with shallow and wide valleys. The topography expression was similar to the coastal alluvial plain landform developed in the northern part of Pantai Gosong (Figure 6). The coastal alluvial plain was the coastal plain landform that has undergone advanced development and has shifted towards the land. The plains were covered with fluvio-marine materials with sandy-clay materials and had fast drainage with a medium thickness.

Based on the landform analysis, the sedimentary deposits pattern would be compared with the current sedimentary deposit thickness estimated with the microtremor method. The Pantai Gosong coast area was the preferred candidate area for the NPP plant location, and therefore, further sediment pattern analysis was focused on this area.

Based on the microtremor method estimation, the thickness of sediment layer deposit in the coastal area was ranged from 1.3 to 21.7 m, as shown in Figure 7. The area with a thin sedimentary deposit with less than 3.1 m of thickness was shown with blue color on the map. The thin sediment zone was in 2 areas: the foothill slope area in the west of the coast and the small hill area with intrusive rock outcrop in the south of the coast. The southern part of the coast has medium sedimentary deposits, shown with yellow color gradation with 3.2 to 12.6 m of deposit thickness. The northern part of the coast has thicker sedimentary deposits with 12.7 to 21.7 m of thickness and showed with red color in the map.

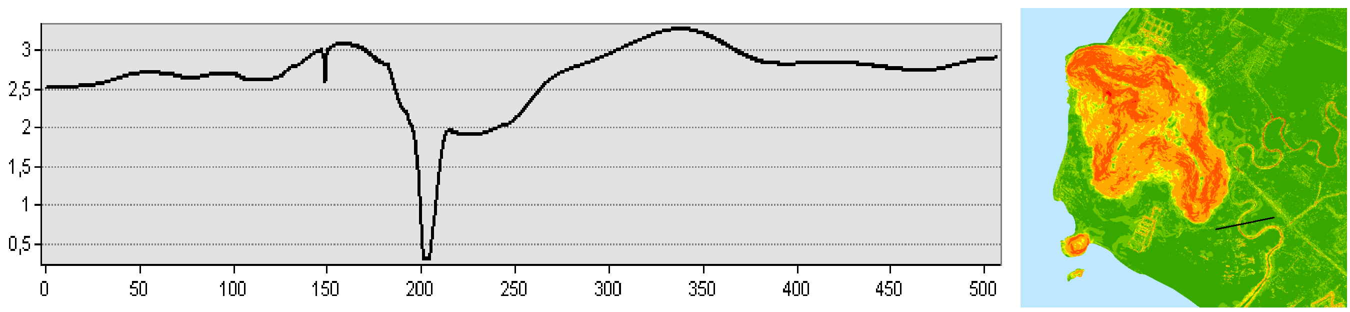

Figure 5. Topography Expression in the Natural Levee-back Swamp Landform

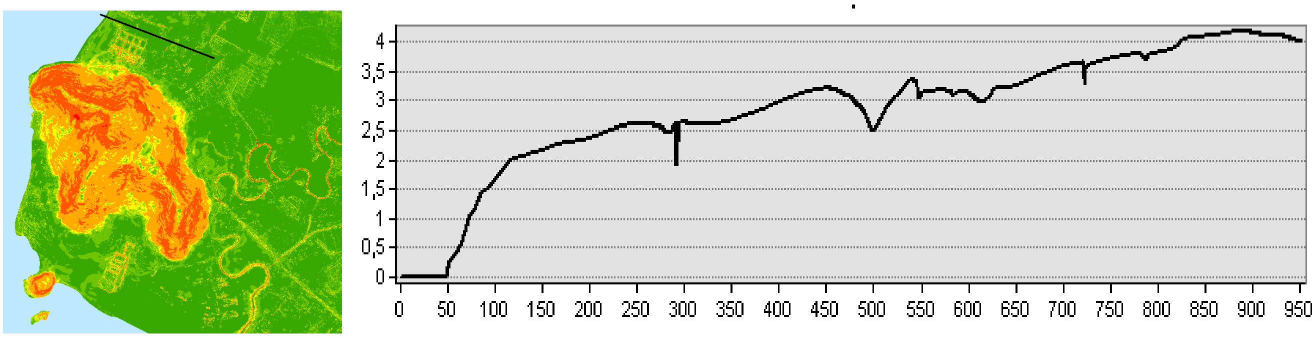

Figure 6. Topography Expression in the Coastal Alluvial Plain Landform

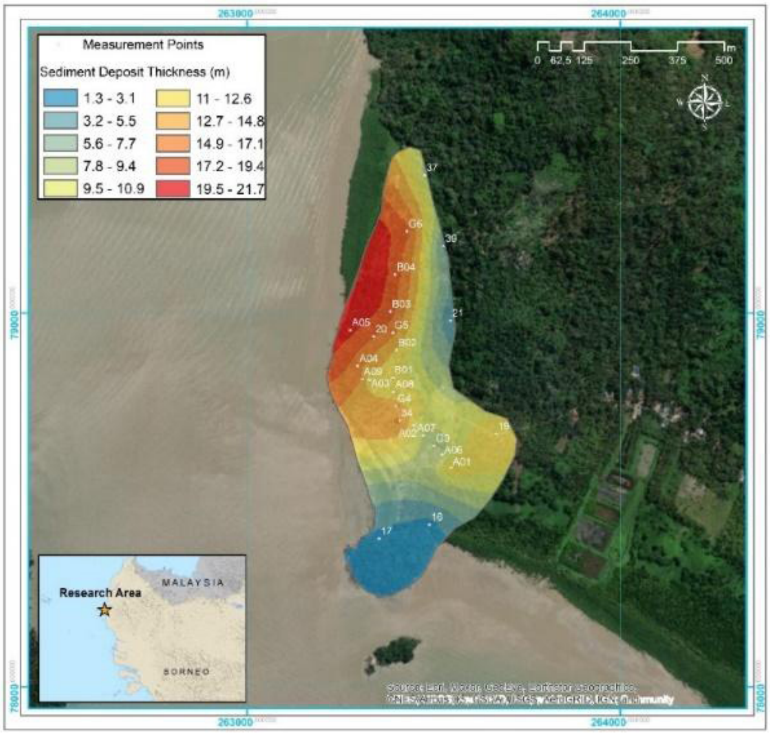

Figure 7. The Sediment Thickness Map From Microtremor Methods Estimation

The estimated sedimentary deposit thickness from the microtremor methods showed that the northern part of the coast tends to have thicker sedimentary deposits than the southern part. The results were in line with the sedimentary deposit pattern analysis based on the morphology in this area. The sedimentary deposition in the footplain area, the northern part of Pantai Gosong, was more intensive than in the southern part. This condition was caused by the intense material movement from the hill and continuously deposited in the footplain area. The gentle topography impression also supported the material deposition process. The southern part of the Pantai Gosong coast also has a continuous sedimentary deposit. However, this area's material's physical properties were more resistant to erosion, which made the sedimentary deposit thickness in this area thinner.

The microtremor estimated sedimentary thickness results showed a good correlation with sedimentary deposit patterns from the morphology analysis. The Pantai Gosong has different sedimentation levels for each of its areas. In the future, the northern coastal area was expected to continuously undergo more intense sedimentation from the materials produced by the erosion or the rockmass movement process in the hill area. The lithology and soil type in this area has a lower resistance level to erosion. The soil in this landform also has a low nutrient and a thin organic layer, which caused the soil fertility in this area to be relatively low. This condition also indicates that human activity would be lower in the northern coastal area, and the natural process would be undisturbed(Brandolini et al. 2020; Dibyosaputro 2015). However, the southern coastal area condition in Pantai Gosong was quite contrast compared to the northern area. This area has river deposits material with high drainage and erosion resistance levels, accelerating lateral erosion rather than material deposition. Besides, the higher fertility level and better soil drainage would increase the potential of human activity to establish farmland or settlement. This activity could disturb and alter the natural process of river material sedimentation.

The coastal dynamics process was highly affected by the sea waves activity that triggered the deposition or erosion process of materials. Based on the sea waves level data in Pantai Gosong, the sea waves reached the highest level of 1.26 m with a maximum period of 5.59 seconds. Meanwhile, the lowest sea wave level was 1.26 m with maximum period of 1.1 seconds [6]. The in situ sea waves monitoring showed that most of the waves were relatively small. The conformity of the calculated results and the in situ monitoring showed that the energy of the sea waves was relatively small. This condition made the sediment in the water was not possible to be transported by the sea waves energy [7][8]. The sea waves that propagated towards the onshore area would be broken and cause a parallel sea current, and has a major role in the sedimentation process [9][10]. The intense oceanic material deposition process between Pantai Gosong and Semesa Island caused the sea in this area to become shallower. Based on the bathymetry data in this area, the area has sea depth of -0.4 to 0.8 m, which was quite shallow (Figure 8). The area also has a flat seabed morphology with $-0,5^0$ to $-2,5^0$. The sedimentation process was also intensely occurred in the Sungai Raya estuary, in the south of Pantai Gosong. The bathymetry data showed a flat estuary bed relief that triggered the seawater to intrude the estuary, especially when the tide happened, which would hold the river stream. The sediment materials would be retained and cause the estuary silting.

The oceanographic data showed a sedimentation process along the coast in the west side of foothill plain or the beach ridge associated with the Sungai Raya estuary. The sediment accumulation in the waters of Pantai Gosong area and Sungai Raya estuary was predicted to occur continuously. The sediment materials would be supplied by the river deposit, cliff erosion, sediment transport along the coast, or perpendicular with the coast. The sediments in both of these areas were estimated to be developed further and could trigger coastline shifting. Based on the calculation, the sediment accumulation in the Sungai Raya estuary was estimated to be developed at

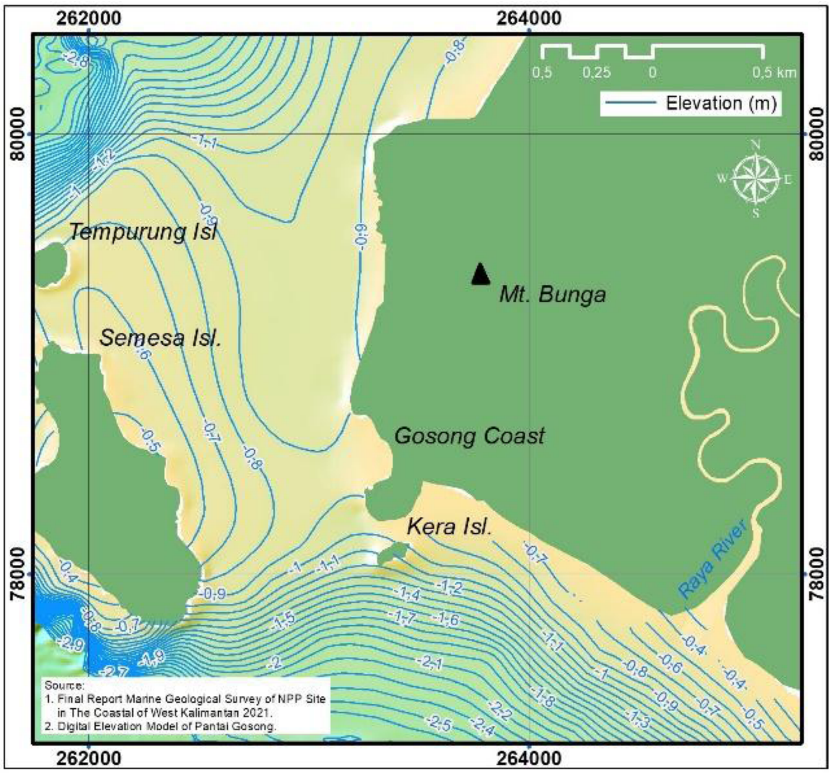

Figure 8. Bathymetry in Pantai Gosong area.

a rate of 611,798.9 m3/yrs with sediment transport direction to the northwest area following the sea current flow parallel with the coast at the maximum tide. Whereas in the coast at the northern foothill plain of Pantai Gosong, the sediment accumulation was estimated to be developed at a rate of 717,365.96 m3/yrs with the parallel current direction along the coast southeast area directed to Pantai Gosong bay.

The levee-back swamp, alluvial plain, and southern foothill plain were estimated to have a similar geomorphic process. In spite of these areas having deposition and sedimentation processes from hill materials or transport materials from the river, erosion was also intensely occurred. This condition was confirmed with active human activity that transformed the land to be farmland, settlement, road development, open land, and others. The land use transformation could reduce the sedimentation rate due to the vegetation's exposed land cover, which triggers the increase of surface runoff [11]. The levee-back swamp area is the river material deposition with high drainage and erosion resistance level, and this condition could accelerate the lateral erosion process rather than the deposition. In addition, a fairly good soil fertility level with good soil drainage could encourage human activity to open farmland or settlement, which could happen in a short timeframe. These human activities could disrupt natural processes such as river material sedimentation.

4. Conclusion

Based on the morphology, morphochronology, and morphogenesis study in the Pantai Gosong area, the landform was classified as a highly eroded hill, lowly eroded footplain, natural levee-back swamp, beach ridge, alluvial plain, and coastal alluvial plain. The landform was formed by denudation, fluvial, and marine process. The sedimentation process in the northern coastal area of Pantai Gosong that has lowly eroded footplain landform was more intense than the southern part. The analysis was correlated with the quantitative analysis from the microtremor methods. The northern footplain in the Pantai Gosong coastal area was expected to have higher sedimentation intensity than the southern part continuously. The condition was caused by the differences in composing materials, soil type characteristics, and human activity.

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