Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Study of Sedimentation Transport in Pinyuh River Estuary Mempawah District, West Kalimantan

Arfena Deah Lestari [1], Mochammad Meddy Danial [1,*], Stefanus Barlian Soeryamassoeka [2]

[1] Department of Ocean Engineering, Faculty of Engineering, Universitas Tanjungpura Pontianak, Indonesia
[2] Department of Civil Engineering, Faculty of Engineering, Universitas Tanjungpura Pontianak, Indonesia

ARTICLE INFO

Article history:
Received 6 April 2026
Received in revised form 20 May 2026
Accepted 5 July 2026
Available online 17 July 2026

Keywords:
Estuary; sediment transport; longshore transport sediment

ABSTRACT

The Pinyuh River Estuary is one of the access routes for fishing boats, located in Mempawah Regency, West Kalimantan. The estuary of this river experiences narrowing and shallowing due to sediment deposition, resulting in the fishing boats cannot pass through the estuary when the sea water is the lowest. This is caused by an inappropriate sea wall construction and hydro-oceanographic processes. The shipping channel for fishing boats becomes disturbed and experiencing obstacles such as grounding in the estuary. The bathymetric depth is only 0.2 meters in the estuary with the lowest tide. The current speed is measured by current meter and sediment samples are subjected to laboratory tests. The total transport of bottom sediment and floating sediment at the estuary is calculated using the LC Van Rijn method. The longshore transport sediment is analysed using CERC formula by knowing the refraction and breaking waves at the research location. The result shown that the shallowing of shipping channels due to the sedimentation is very significant. There are two options to solve this problem, i.e., dredging works and the coastal protection such as jetties.

1. Introduction

The estuary of the Pinyuh River is a shipping channel for fishing boats heading to the Natuna Sea. The estuary of this river is in Sungai Pinyuh sub-district, Mempawah district, West Kalimantan. This is the access point for fishing boats to enter and exit to the sea. However, this river estuary is experiencing shallowing due to very significant sedimentation at the river mouth and due to hydro-oceanographic processes. This can have an impact on the traffic flow of fishing boats, such as hull grounding at lowest tide.

A shipping channel must be free from obstacles that can disrupt the shipping channel so the traffic of ships can passing through the shipping channel and it can be sail smoothly [1]. Research conducted in 2021 on shipping channels at Pinyuh River Estuary shown that the depth of the river river estuary is only 0.2 meters on the left side [2]. The impact is fishing boats that passing through river estuaries

* *Corresponding author.*
E-mail address: meddydanial@civil.untan.ac.id

https://doi.org/10.37934/araset.61.5.203213

must be turned to the right of the estuary to avoid grounding at the lowest tide. One causes of shallowing the estuaries is due to the accumulation of sediment at the river estuary.

Estuaries are complex with many interacting dynamic environments processes [3]. Estuaries are a place for sediment traps [4,5,6,7]. They have a structure at three parts [6]: an outer portion is marine dominated with a net bedload towards the estuary, lower energy at central portion with bedload convergence and an inner portion, which is still influenced by marine but river dominated [4,6]. It is a complex process and related to mechanisms of the sediment load production, transport, and deposition. It is the effects of moving a water that carries cohesive or noncohesive particles and it resulting a flux from the particle source to the sink [8]. It because sediment covers most of the earth's surface and because its long-term movements affect the bottom of the waters [9] such as shallowing of the depth of the river estuary and other environmental impact like coastline changes and can effect to the coral reef [10].

For the analysis of sediment source and pathways not only in estuaries, but also a longshore and in rivers [4]. The longshore movement of sediment particles begins with a waves attack. After energy dissipation through shallow waters, it triggers a shore parallel movement of water that is strong enough to move particles along the shore [11,12]. This shore parallel movement of water induced by the momentum of breaking waves is also known as the longshore current and it constitutes a driving force of longshore sediment transport [11,13].

In 2020, a seawall was built at the the Pinyuh River Estuary which was not properly constructed. The seawall is formed from an arrangement of concrete cubes as seen in Fig 1 below.

Fig. 1. The condition of The Pinyuh River Estuary

Fig 1 shows the condition of the Pinyuh River estuary with the seawall building. This building was built with the aim to protecting the coastal of the Pinyuh River from abrasion. In fact, the problem that occurs on this coastal is quite massive sedimentation. The construction of this seawall increases a sediment rate. The increasing of sediment rate is caused by some infrastructures built both ocean and inland. Any modifications in either of these can impact on the coastal water body because of very dinamic complexes process in River Estuary [14]. It has caused serious implications to coastal stability in the region due to a reduction in riverine sediment discharge and the blockage of littoral sediment transit [11].

From the figure above it can also be seen that the shipping channel at the Pinyuh River estuary is very small for the entry and exit of fishing boats with a width of 45 m at estuary and towards the upstream river. The width of the river becomes narrower only 22 m [2]. To solve the sedimentation problem in this estuary, it is necessary to carry out the study of sediment transport both from the upstream and from the ocean .

2. Material and Method

2.1 Research Location

The location of this research is at Pinyuh River Estuary, Mempawah Regency, West Kalimantan. This estuary is located with coordinates 109°4'1.29"E-0°15'56.50"N. The research was conducted in April-December 2022. The location map in this research is indicated by an arrow, as shown in Fig 2 below.

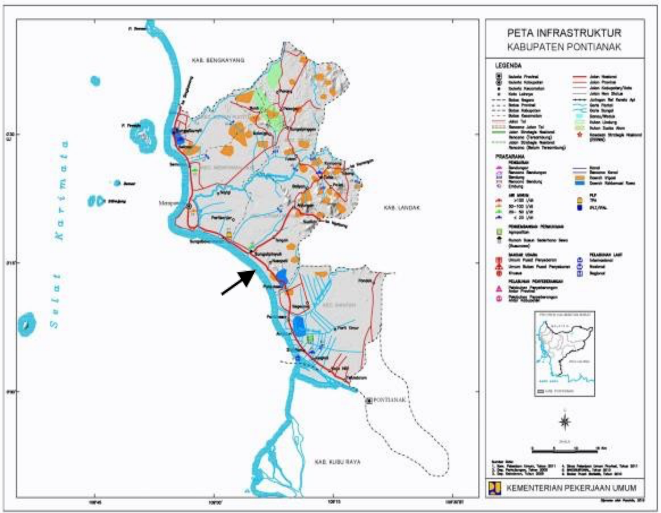

Fig. 2. Research location

The estuary of the Pinyuh River is one of the access points for fishing vessels to the fishing port where most of the people work as fishermen. Large sedimentation at the mouth of the estuary disrupts this shipping channel. It’s made a fishing boat should have to wait for high tide on the sea and take turns for entering the port so that the shipping channel could only be in one direction.

2.2 Method

The data used in this research are primary and secondary data. Secondary data is data obtained from several agencies such as wind data and bathymetry data. Wind data from 2012 – 2021, was downloaded from the website of the Indonesia Meteorology, Climatology and Geophysics Agency. Wind data is used to predict the height and period of significant waves at the research location. To obtain the significant wave height, the eq 1 and 2 is used [15].

$$H_s = 0{,}0016\left(\frac{gF}{{U_A}^2}\right)^{1/2}\left(\frac{{U_A}^2}{g}\right) \quad (1)$$

$$T_p = 0{,}2857\left(\frac{gF}{{U_A}^2}\right)^{1/3}\left(\frac{U_A}{g}\right) \quad (2)$$

$$P(H_s \leq Hsm) = 1 - \left(\frac{m-0{,}44}{N_t+0{,}12}\right) \quad (3)$$

$$P(H_s \leq Hsm) = 1 - \left(\frac{m-0{,}2-\frac{0{,}27}{\sqrt{k}}}{N_t+0{,}12+\frac{0{,}23}{\sqrt{k}}}\right) \quad (4)$$

where H_{sm} is wave height of the m order (m), m is wave height number (-), N_t is number of wave event, and k is time series data (year).

Refraction calculations are carried out to obtain the breaking wave height. It is calculated using the following equation [16].

$$\frac{d_b}{H_b} = \frac{1}{b-\left(\frac{aH_b}{gT^2}\right)} \quad (5)$$

where d_b is depth of breaking wave (m), H_b is the breaking wave height (m), g is gravitational acceleration (m/s^2), and T is wave period (s).

The current speed is measured using a current meter at two locations. The sediment samples were taken from two different locations, at the river estuary and at the sea to determine total sediment from the river and from the sea. Bedload sediment samples are tested in the laboratory to determine the size and type of sediment, while suspended sediment samples are also tested to determine the Total Dissolve Solid (TDS) and Total Suspended Solid (TSS). Therefore, the sediment transport is calculated using the L.C Van Rijn equation for river estuaries as formulated by eq 6 and 7 [17].

$$Q_b = 0.053\ (\Delta g)^{0.5} {d_{50}}^{1,5} {D^*}^{-0,3} T^{2,1} \quad (6)$$

where Q_b is bedload sediment (m^3/s), Δ is relative weight (kg/m^3), g is gravity (m/s^2), d_{50} is median particle (m), D^* is dimensioonless particle parameter (-), and T is Transport Stage parameter (-).

$$Q_s = F.V.D.C_a \quad (7)$$

where Q_s is suspended load sediment (m^2/s), F is correlation factor (-), D^* is dimensioonless particle parameter (-), and C_a is reference consentration (kg/m^3)

Analysis of longshore sediment transport at the coastal area is using the CERC equation as formulated by the following equation [18].

$$I_l = KP_{ls} = K = \left(\frac{\rho g {H_b}^2}{8} C_b \sin\alpha_b \cos\alpha_b\right) \quad (8)$$

where I_l is longshore sediment transport rate (N/s), K is constant in original CERC Equation (-), P_{ls} is longshore energy flux at breaking wave condition (N/S), ρ is water density (kg/m^3), g is gravitational acceleration (m/s^2), H_b is breaking wave height (m), C_b is wave's group velocity at breaking condition (m/s), and α_b is angle between beach and incident wave crest.

3. Result and Analysis

3.1 Current Speed

In this study, current speeds were obtained through direct measurements by using current meters. The measurement results show that the average current speed at the research location is 0.29 m/s for the estuary rivers and 0.34 m/s for the coastal area. Based on the current speed results, which is very small, it is not significant to flush the sediment out of the estuary channel. Sediment tends to settle and accumulate because the weak currents lack the necessary energy to carry sediment particles downstream and out to the open sea.

3.2 Wind Data

The wind data is obtained from BMKG (Indonesia Meteorology, Climatology and Geophysics Agency) in Mempawah wind measurement station. The wind data is a recording data for 10 years starting from 2012 until 2021. Wind data is analyzed by grouping the data based on wind speeds and wind directions as shown in bellow table.

Table 1
Wind Speed Percentage Based on Wind Direction

Wind Speeds (m/s)	Wind Direction (%)								TOTAL
	N	NE	E	SE	S	SW	W	NW	
0 – 5	4.02	6.60	7.97	4.97	8.91	34.2	25.24	5.15	97.19
5 - 10	0.13	0.18	0.08	0	0.05	0.66	0.58	0.08	1.76
10 – 15	0.03	0.18	0.18	0.16	0.13	0.11	0.11	0.03	0.97
15 – 20	0	0	0	0	0	0.03	0.03	0	0.05
20 – 25	0	0	0	0.03	0	0.02	0	0	0.03
25 – 30	0	0	0	0	0	0.01	0	0	0
TOTAL	4.18	6.97	8.23	5.15	9.10	35.10	25.95	5.26	**100**

Table 1 shows the percentage of wind speed based on wind direction. From the table it can be seen that the wind blows from all directions with a wind speed of 0 - 5 m/s or is called a calm wind. Its about 97.19 %. And dominant direction of the wind is blows from southwest and west Direction. The percentage of wind speed based on wind direction can illustrated in a diagram namely wind rose diagram as shown in fig 3 bellow.

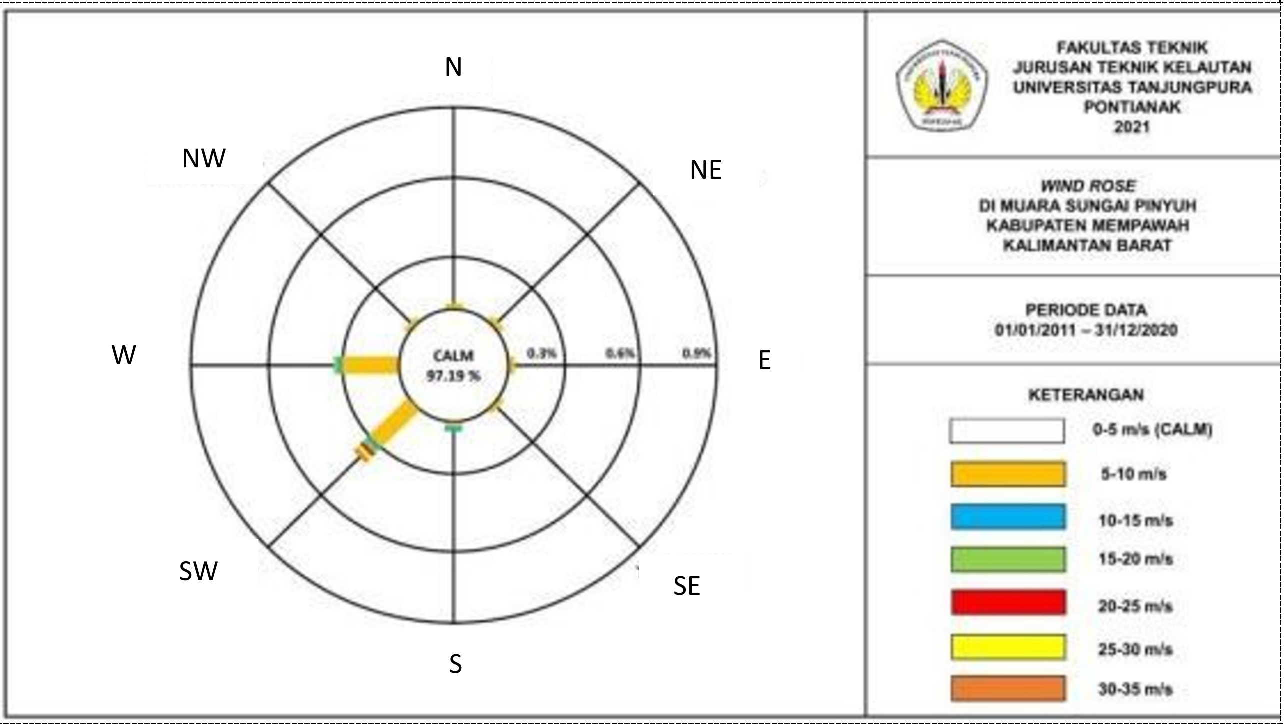

Fig. 3. Wind Rose Diagram

From Fig. 3, it is shown that the dominant direction of the wind and its speed can be represented as wind rose diagram. The largest wind speed blows from the southwest and west. From its figure, it can be seen that 35.10% of the wind speed blows from the southwest and 25.95% from the west direction. Wind causes waves to form on the surface of the water. The greater the wind's strength, the larger the waves that are created. The wave's direction depends on the primary direction from which the wind is blowing [19]. This phenomenon is utilized to construct of refraction diagrams.

3.3 Fetch

Fetch refers to the distance over a large stretch of water surface along which wind of nearly constant direction and speed blows, specifically in the direction of the wind itself [20]. Fetch are determined on the map according to the distance between the nearest islands and research location. Fetch is measured from the coastal area towards the west and southwest, corresponding to the direction of maximum wind speed. Fetch segments are created by drawing a line from the river estuary to the nearest island with an angle interval of 2^o so that the length of the line segment fetch at the research location is obtained. The calculated fetch length is shown in Table 2 below.

Table 2
Calculation of Fetch Length

Southwest				West			
α	Cos α	Distance (Xi) km	Xi Cos α	α	Cos α	Distance (Xi) km	Xi Cos α
22	0,9272	553	512,73	22	0,9272	37	34,31
20	0,9397	555	521,53	20	0,9397	37,6	35,33
18	0,9511	549	522,13	18	0,9511	548	521,18
16	0,9613	421	404,69	16	0,9613	547	525,81
14	0,9703	401	389,09	14	0,9703	508	492,91
12	0,9781	400	391,26	12	0,9781	230	224,97
10	0,9848	401	394,91	10	0,9848	217	213,70
8	0,9903	402	398,09	8	0,9903	214	211,92
6	0,9945	413	410,74	6	0,9945	495	492,29
4	0,9976	419	417,98	4	0,9976	540	538,68
2	0,9994	425	424,74	2	0,9994	502	501,69
0	1,0000	426	426,00	0	1,0000	114	114,00
2	0,9994	425	424,74	2	0,9994	204	203,88
3	0,9986	418	417,43	3	0,9986	458	457,37
6	0,9945	410	407,75	6	0,9945	517	514,17
8	0,9903	403	399,08	8	0,9903	520	514,94
10	0,9848	370	364,38	10	0,9848	52,5	51,70
12	0,9781	430	420,60	12	0,9781	447	437,23
14	0,9703	411	398,79	14	0,9703	528	512,32
16	0,9613	419	402,77	16	0,9613	516	496,01
18	0,9511	386	367,11	18	0,9511	530	504,06
20	0,9397	360	338,29	20	0,9397	551	517,77
22	0,9272	342	317,10	22	0,9272	488	452,47
TOTAL	22,389		9471,92	**TOTAL**	22,389		8568,71
Feff		**423,05**		**Feff**		**382,71**	

From Table 2, it can be seen that the effective fetch from the southwest and the west direction area were 423.05 km and 382.71 km, respectively.

3.4 Significant Wave Height & Period

Significant wave height and period in this study obtained from corrected wind data using the eq 1 and 2. Significant wave height and waves period can be seen in Table 3.

Table 3
Significant Wave Height and Period

Year	Parameter	Direction	
		West	Southwest
2012	Hs (m)	1.37	1.3
	T (s)	4.82	4.12
2013	Hs (m)	1.35	1.28
	T (s)	4.78	4.09
2014	Hs (m)	0.84	1.37
	T (s)	4.16	4.16
2015	Hs (m)	1.49	1.42
	T (s)	4,91	4.18
2016	Hs (m)	1.35	1.28
	T (s)	4.81	4.07
2017	Hs (m)	1.47	1.41
	T (s)	4.89	4.17
2018	Hs (m)	1.31	0.75
	T (s)	4.76	3.48
2019	Hs (m)	1.37	1.29
	T (s)	4.82	4.05
2020	Hs (m)	1.21	1.13
	T (s)	4.63	3.90
2021	Hs (m)	1.27	1.19
	T (s)	4.7	3.96

From Table 1, it is evident that the highest wave height from the west occurred in 2015, measuring 1.49 meters with a period of 4.91 seconds. In contrast, the lowest wave height from the southwest was recorded in 2018, measuring 0.75 meters with a period of 3.48 seconds. Wave characteristics such as height and period are influenced by factors including wind speed, duration of wind, and fetch. Higher wind speeds, longer wind durations, and greater fetch at the research location contribute to the formation of larger waves.

These parameters play a critical role in shaping wave dynamics and subsequently affecting coastal processes such as sediment transport and erosion. Understanding the variability in wave conditions over time helps in assessing coastal vulnerability and designing appropriate mitigation strategies for coastal management and protection.

3.5 Wave Forecast with Return Period

Significant wave data was derived from 10 years of recorded wind speed data used for forecasting. Wave heights with a return period of 25 years were calculated using both the Fisher-Tippett type I method, which assumes extreme value distribution, and the Weibull method, known for its versatility in modeling wind and wave data. The resulting wave heights for the 25-year return period were averaged to provide a robust estimate of wave conditions under extreme events. Table

4 below displays these averaged wave heights, offering insights into potential high-wave scenarios critical for coastal planning and infrastructure design.

Table 4
The average of wave forecast with return period of 25 years

Direction	Fisher Tippett Type 1 Method	Weibull Method	Average	Periode
	Hsr (m)	Hsr (m)	Ho (m)	T (s)
West	1,3973	1.5684	1.3011	4.016
Shouthwest	1,2039	1.2982	1.4829	4.724

After obtaining significant wave height and wave period values to forecast the wave return period of 25 years, the analysis proceeds to calculate the refraction and wave breaking effects in the southwest and west directions at the research location. This calculation is carried out using equations 3 and 4, which are specific formulas likely related to wave refraction and breaking dynamics. These calculations are essential for understanding how waves behave as they approach the coast, influencing sediment transport patterns and coastal erosion in the study area.

3.6 Refraction and Breaking Waves

The process of wave refraction from the deep sea to the coast significantly influences the calculation of longshore sediment transport along the coast. According to calculations using equation 5, breaking waves were observed from the southwest direction at a depth of -19 meters, with a height of 3.1 meters and a breaking wave angle of 7 degrees. Similarly, from the west direction, breaking waves occurred at a depth of -18 meters, with a height of 3 meters and a breaking wave angle of 5.2 degrees.

The direction of wave propagation and refraction from the west and southwest can be visualized in Figures 4 and 5. These figures illustrate how waves bend and change direction as they approach the coast, influencing sediment movement along the shoreline. Understanding these dynamics is crucial for coastal management and engineering practices aimed at mitigating erosion and maintaining coastal stability.

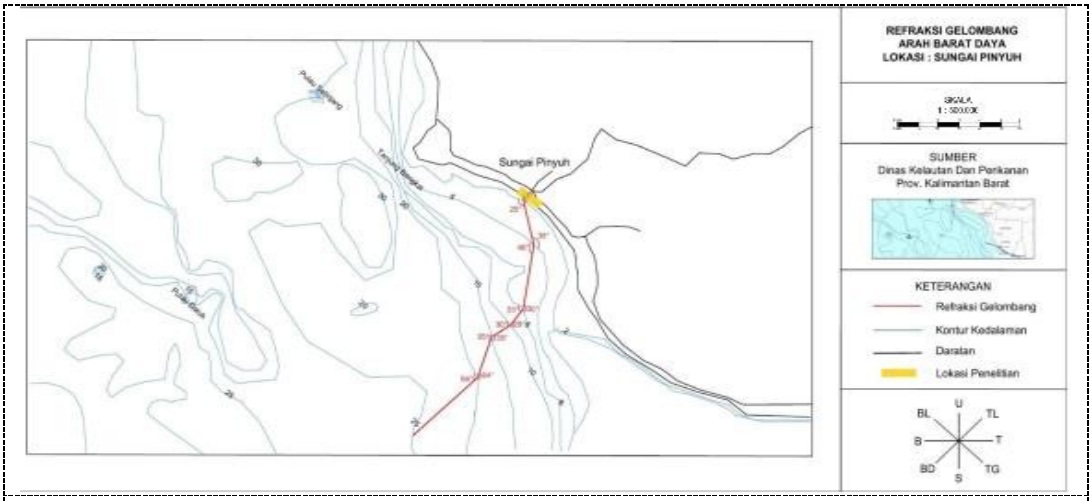

Fig. 4. Wave propagation from the Southwest direction due to refraction

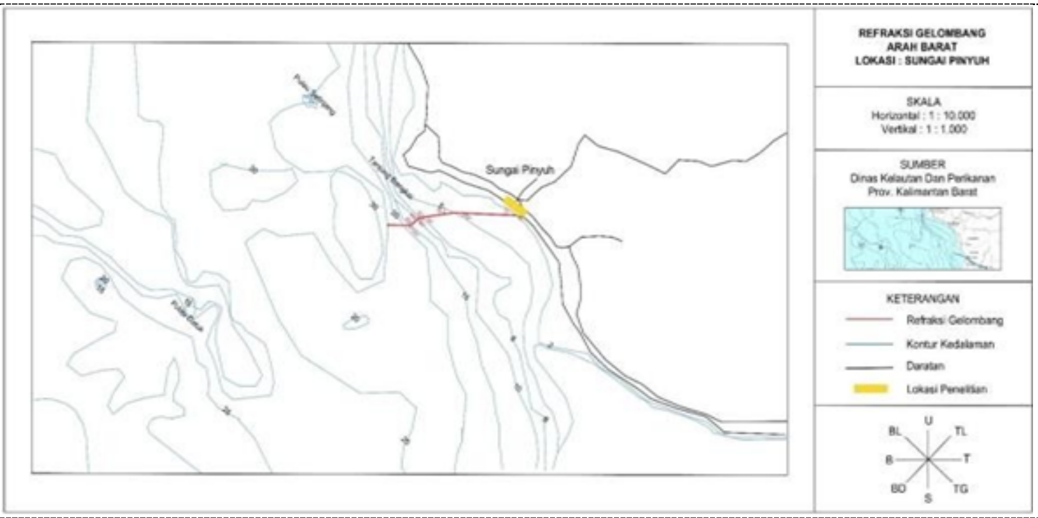

Fig. 5. Wave propagation from the West direction due to refraction

Figures 4 and 5 illustrate the transformation of waves from deep water to shallow water, a phenomenon known as wave refraction. Waves propagate towards the study area due to variations in bathymetric contours. The wave direction alters upon encountering shallower depths [16].

3.7 Sediment Samples

In this study, sediment samples were collected directly from two locations: the Pinyuh River estuary and Pinyuh beach. These samples included bedload sediment, bottom sediment, and suspended sediment, which were analyzed in the soil mechanics laboratory. Bedload sediments were tested to classify sediment types, revealing a predominance of coarse silt at both the Pinyuh River estuary and coastal area.

Suspended sediment samples were also gathered from the same locations. Laboratory analyses indicated that the total suspended sediment concentration was 178 mg/liter in the estuary and 420 mg/liter on the coastal area. Additionally, total solid sediment concentrations were measured at 1345.70 mg/liter in the estuary and 12,486 mg/liter on the coast.

4. Discussion

Wave refraction from deep sea to coast plays a pivotal role in determining the transport of sediment along coastal areas. Wave refraction from the southwest and west propagates into the mouth of Sungai Pinyuh, creating variation of current speed that generated from breaking wave and causing sedimentation issues in the river mouth of Sungai Pinyuh. This process occurs as waves bend and change direction when they encounter shallow waters near the estuary, leading to the accumulation of sediment in the river mouth. Moreover, the refraction intensifies the sedimentation problem by continuously depositing materials carried from upstream and coastal areas. This sediment buildup can obstruct the navigation channels, impacting maritime activities and increasing the risk of flooding.

The current velocity from the upstream is slower than from the sea, causing sediment tends to settle and accumulate because the weak currents lack the necessary energy to carry sediment particles downstream and out to the open sea. This sedimentation can exacerbate the narrowing and shallowing of the estuary channel, which poses risks to navigation and increases the likelihood of flooding.

Sediment transport at the Pinyuh River Estuary is assessed using the L.C Van Rijn equations (eq. 6 and 7). The calculations indicate that the total sediment bedload (Qb) amounts to 3,791 m^3/day or 1,383,715 m^3/year, while suspended sediment (Qs) in the estuary is estimated at 4,229 m^3/day or 1,543,585 m^3/year. Additionally, longshore sediment transport along the coastal area is evaluated using the CERC equation (eq. 8), revealing rates of 6,120 m^3/day and 2,233.8 m^3/year from the southwest direction, and 4,162 m^3/day and 1,519.13 m^3/year from the west.

These findings highlight significant sedimentation issues at the Pinyuh River Estuary and along the coastal areas. In the estuary, wave action increases bottom stress and enhances sediment suspension, while upstream soil erosion contributes to sediment transport towards the estuary through water bodies.

The accumulation of sediment at the Pinyuh River Estuary poses numerous challenges, notably the gradual narrowing and shallowing of the shipping channel to just 22 meters wide and 0.2 meters deep at low tide [2]. This situation is hazardous for fishermen navigating the ship along the estuary, particularly at night, as ships risk grounding or colliding without appropriate solutions.

Based on the analysis, two recommended solutions, namely conventional and coastal engineering method are proposed to address these sedimentation issues: a) conventional method involve periodic sediment dredging along the left side of the river estuary, covering 5-10 meters, with an estimated total volume of 80,000 m^3. Additionally, the dredged material can be repurposed for reclamation or beach restoration projects facing erosion challenges; b) Coastal engineering method, including implementation of coastal protection measures such as jetties at banks of tidal inlets and estuary, to mitigate shallowing issues. These structures effectively trap longshore sediment and prevent channel siltation [17].

These solutions aim to manage sedimentation effectively at the Pinyuh River Estuary, ensuring safe and navigable conditions for maritime activities while supporting coastal conservation efforts.

5. Conclusions

Sediment transport at the Pinyuh River Estuary is significant, with calculations indicating large volumes of both bedload and suspended sediment. This sedimentation causes the estuary's shipping channel to narrow and shallow, posing hazards to navigation. Based on the conducted research, it is evident that the narrow and shallow shipping channel at the Pinyuh River Estuary is primarily attributed to significant sedimentation originating from both the sea and upstream areas, compounded by inadequate coastal structure construction. Any alterations made to the coastal or inland areas can affect the dynamics of the estuarine water body due to its highly complex processes. Two potential solutions to address these issues are dredging activities and the construction of coastal structures like jetties.

Acknowledgment

This research paper is part of the Research of Engineering Faculty and was funded by **DIPA** (Daftar Isian Pelaksanaan Anggaran) of Tanjungpura University.

References

[1] The World Association for Waterborne Transport Infrastructure. 2014. Harbour Approach Channels Design Guidelines. PIANC REPORT N° 121, Bruxelles Belgique. https://files.pca-cpa.org/pcadocs/ua-ru/04.%20UA%20Rejoinder%20Memorial/01.%20Exhibits/UA-88.pdf

[2] Febliana, M., A. D. Lestari, and J. Meirany. 2021. "Alur Pelayaran Di Muara Sungai Pinyuh Kabupaten Mempawah Kalimantan Barat." JeLAST: Jurnal Teknik Kelautan, PWK, Sipil, Tambang 8, no. 3. https://dx.doi.org/10.26418/jelast.v8i3.51474

[3] City of Launceston on behalf of the Launceston Flood Authority (LFA). 2019. Kanamaluka/Tamar River Estuary Sediment Raking Program Review. https://www.launceston.tas.gov.au/files/assets/public/document-resources/agenda-and-minutes/agendas/2019/17-october-2019/council-agenda-agenda-item-18.1-attachment-1-kanamaluka-tamar-river-estuary-sediment-raking-program-review-17-october-2019.pdf

[4] B, Friederike, et al. 2023. Change of Sediment Transport Direction Within The Rio Jaguaribe Estuary, NE Brazil, by Means Of Clay Mineralogical Analyses. Estuarine, Coastal and Shelf Science 287, July: 108323. https://doi.org/10.1016/j.ecss.2023.108323

[5] Boyd, R., R. W. Dalrymple, and B. A. Zaitlin. 1992. Classification Of Clastic Coastal Depositional Environments Sediment. Sedimentary Geology 80, October: 139–150. https://doi.org/10.1016/0037-0738(92)90037-R

[6] Dalrymple, R. W., and K. Choi. 2007. Morphologic and Facies Trends Through The Fluvial Marine Transition In Tide-Dominated Depositional Systems: A Schematic Framework For Environmental And Sequence-Stratigraphic Interpretation. Earth-Science Reviews 81, April: 135–174. https://doi.org/10.1016/j.earscirev.2006.10.002

[7] Muskanfola., M, R, Febrianto., S, and Ayuningrum, D. 2023. Hydrodynamic Characteristics and Sediment Distribution Patterns in Wulan Delta Estuary, Demak, Indonesia. Makara Journal of Technology 27, April: 11−16. https://doi.org/10.7454/mst.v27i1.1615

[8] Miall, A. D. 1996. The Geology of Fluvial Deposits: Sedimentary Facies, Basin Analysis, and Petroleum Geology. Springer: Berlin.

[9] Perry, C., and K. Taylor. 2007. Environmental Sedimentology. Blackwell Publishing: Oxford.

[10] Risk., M, J, and Edinger., E.N. 2011. Impacts of Sediment on Coral Reefs. http://dx.doi.org/10.1007/978-90-481-2639-2_25

[11] Kwami Serge Foga Agbetossou, et al. 2023. Field Measurements of Longshore Sediment Transport along Denu Beach, Volta Region, Ghana. Journal of Marine Science and Engineering 11: 1576. **https://doi.org/10.3390/jmse11081576**

[12] O'grady, J., A. Babanin, and K. McInnes. 2019. Downscaling Future Longshore Sediment Transport in South Eastern Australia. J. Mar. Sci. Eng. 7 : 289. https://doi.org/10.3390/jmse7090289

[13] Ostrowski, R. 2016. On Uncertainties in Determination of Sediment Transport Rates in Coastal Regions. Archives of Hydro-Engineering and Environtal Mechanics, December, 63: 265–280. https://doi.org/10.1515/heem-2016-0017

[14] Joseph., S, G, Rodolf., S, and Debora, L. 2019. Assessment of Sedimentation in a Coastal Lagoon: Chantuto Panzacola, Mexico, Journal of Coastal Research 92, July: 145-156. http://dx.doi.org/10.2112/SI92-017.1

[15] Coastal Engineering Research Center (CERC). 1984. Shore Protection Manual. (Vol. 1). US Army Corps of Engineers: Washington D.C.

[16] B, Triadmodjo. 1990. Teknik Pantai. Beta Offshet: Yogyakarta.

[17] Van Rijn, L. C. 1989. Handbook sediment transport by currents and waves. Delft Hydraulics Laboratory: The Netherlands.

[18] Bertule, M., Appelquist, L. R., Spensley, J., Trærup, S. L. M., & Naswa, P. (2018). Climate change adaptation technologies for water: A practitioner's guide to adaptation technologies for increased water sector resilience. UNEP DTU Partnership. https://backend.orbit.dtu.dk/ws/portalfiles/portal/145967791/CC_Adaptation_technologies_for_water_red.pdf

[19] Ardhuin., F, and Orfila, A. 2018. Wind Waves. New Frontiers In Operational Oceanography, August 1. https://doi:10.17125/gov2018.ch14.

[20] I. W. Geer. 1996. Glossary of Weather and Climate: With Related Oceanic and Hydrologic Terms. Boston, MA, USA: American Meteorological Soc.