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OCEANOGRAPHIC DYNAMICS AND THEIR EFFECTS ON SEDIMENTATION RATES IN THE MESJID RIVER ESTUARY, DUMAI

Ilham Ilahi[1]*, Mubarak[1], Nabila Afifah Azuga[1], Gita Purnama Sari[1], Vina Rahmadhani[1], Benny Heltonika[2]
[1]Department of Marine Science, Faculty of Fisheries and Marine, Universitas Riau, Pekanbaru, 28293 Indonesia
[2]Department of Aquaculture, Faculty of Fisheries and Marine, Universitas Riau, Pekanbaru, 28293 Indonesia
*ilhamilahi@lecturer.unri.ac.id

ABSTRACT

This study analyzes the oceanographic dynamics (bathymetry, tides, and shoreline changes) and their impact on sedimentation rates in the Mesjid River estuary, Dumai, Indonesia, which faces the Malacca Strait. The research was conducted from July to September 2025 at two stations using sediment traps, bathymetric surveys, and NDVI analysis for mangrove cover. The results show an estuarine depth ranging from 2.34, with significant shallowing at the river mouth. The tidal pattern is classified as mixed, with a semidiurnal predominance (Formzahl number = 0.43). Shoreline change analysis indicates that abrasion from ship-generated waves and mangrove degradation dominate. The average sedimentation rate reached 7.22 cm/year, with the highest accumulation observed at the estuary mouth due to current deceleration and sediment trapping by mangrove roots. Oceanographic dynamics and anthropogenic pressures amplify sedimentation in this tropical estuary.

Keywords: Oceanographic Dynamics, Sedimentation Rate, Mesjid River, Shoreline Change.

1. INTRODUCTION

Dumai City is located on the eastern coast of Sumatra Island in Riau Province, Indonesia, in a strategic position that directly faces the Rupat Strait and the Malacca Strait. The region has a relatively long coastline and is predominantly characterized by lowland areas with important coastal ecosystems, including mangrove forests and peat swamps. Its proximity to international shipping routes results in highly dynamic coastal waters, both in terms of physical oceanographic processes and economic activities.

Sustainable coastal zone management should be implemented through comprehensive planning, use, monitoring, and control of impacts from both human activities and oceanographic phenomena, particularly hydro-oceanographic factors that influence coastal environments[1].

Coastal areas are dynamic systems that continuously change due to interactions between terrestrial and marine processes. One of the primary processes shaping coastal morphology is sedimentation, which oceanographic dynamics such as ocean currents, tidal fluctuations, and wave energy strongly influence. Changes in the shoreline configuration within coastal regions are primarily driven by terrestrial factors, particularly sediment deposition transported by river flows and the presence of coastal vegetation. Water serves as the primary medium for transporting sediments through river systems[2].

One factor exacerbating the vulnerability of Dumai's coastal areas is changes in mangrove forest cover,

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particularly around the mangrove ecosystem at the Mesjid River Estuary in Dumai City. The Mesjid River Estuary, the primary pathway for sediment transport from land to sea, has also been affected by this issue. As an estuarine environment, the area is directly exposed to wave action and tidal currents and is also influenced by the frequent passage of vessels. The interaction between river discharge and marine hydrodynamics creates complex patterns of sediment deposition and erosion, particularly in locations not fully protected by mangrove vegetation.

Oceanographic dynamics, particularly currents and tides, are key factors controlling sedimentation rates in river estuaries. Nearshore current patterns are primarily governed by the propagation of waves approaching the coastline. During high tide, tidal energy drives seawater into the coastal zone, helping distribute sediments throughout the area. Conversely, during low tide, river discharge becomes more dominant, enabling the river flow to push seawater seaward. As a result, sediments are transported offshore and dispersed into adjacent marine waters, where they are subsequently deposited in the surrounding area[2].

Therefore, this study investigated the influence of oceanographic dynamics on sedimentation rates in the Mesjid River Estuary. This research is essential for providing reliable scientific data on the physical processes in the study area, which can serve as a scientific basis for developing effective coastal management and conservation policies in Dumai City.

2. RESEARCH METHOD

Time and Place

This research was conducted from July to September 2025, at the Mesjid River Estuary, comprising two sampling stations. Station 1 was located within the Mesjid River channel, while Station 2 was situated at the mouth of the Mesjid River Estuary.

Procedures

Determination of Sampling Points

At each observation station, we collected samples from three points where sediment traps were deployed. The sediment traps were installed at each sampling point for 30 days, then retrieved for further analysis at the Physical Oceanography Laboratory, Department of Marine Science, Faculty of Fisheries and Marine Sciences, Universitas Riau.

Sediment Accumulation Sampling

The sediment traps used in this study were cylindrical and constructed by modifying PVC pipes with a diameter of 2 inches (5.08 cm) and a height of 30 cm. Figure 1 shows the sediment trap design.

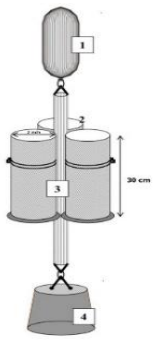

Figure 1. Sedimen trap[3]

Bathymetric Analysis

Bathymetric contour depth data for the Mesjid River Estuary were analyzed using Surfer 16 software. The results were then presented as a bathymetric contour map.

Mangrove Cover Change Analysis

Changes in mangrove cover within the Mesjid River Estuary were analyzed using ArcGIS software based on the Normalized Difference Vegetation Index (NDVI). The analysis utilized satellite data from 2014, 2019, and 2024. The results were presented as thematic maps.

Tidal Analysis

Tidal data were collected over a one-month observation period (July) and analyzed using the Admiralty method to determine the tidal harmonic constants and

tidal elevation characteristics of the study area.

Data Analysis

The collected data were compiled and presented as tables and maps. The findings were then interpreted and discussed descriptively, with reference to relevant scientific literature to support the analysis and interpretation of the research results.

3. RESULT AND DISCUSSION

Dumai City is located on the eastern coast of Sumatra Island, Riau Province, Indonesia, between 1°23′–1°24′ N and 101°23′–101°32′ E. The city directly faces the Rupat Strait and the Malacca Strait, one of the world's most strategic international shipping routes. Dumai has an extensive coastline bordering the Malacca Strait. Most of the region consists of lowland and coastal areas, with important ecosystems such as mangrove forests, peat swamps, and an extensive shoreline. These physical characteristics make Dumai particularly vulnerable to coastal erosion.

The Mesjid River Estuary, located within the coastal area of Dumai City, is highly vulnerable to coastal erosion. Several key factors influence this vulnerability. First, the predominance of muddy substrates makes the area highly susceptible to wave-driven erosion. In addition, because the Mesjid River Estuary directly faces the Malacca Strait, it is continuously exposed to ocean waves and tidal currents, which further intensify erosion.

Furthermore, between 2019 and 2024, the mangrove area increased by 22.49 ha, indicating ongoing mangrove rehabilitation and natural regeneration. Meanwhile, the Dumai City Government estimates that the average rate of coastal erosion is approximately 1 m year^{-1}. However, an academic study by Universitas Riau using Landsat satellite imagery and the Digital Shoreline Analysis System (DSAS) for the 1990–2020 period reported an average erosion rate of approximately −2.04 m year^{-1} along the Dumai coastline. As a result of this persistent shoreline retreat, the Mesjid River Estuary has experienced significant land loss, disrupting coastal communities' livelihoods, reducing productive land, and increasing the risk of damage to coastal infrastructure and residential areas.

Mangrove Forest Cover in the Mesjid River Estuary

Based on the interpretation and digitization of land cover maps for 2014, 2019, and 2024 in the Universitas Riau (UNRI) Purnama Campus area, Dumai, a notable temporal change in the mangrove ecosystem was observed. The analysis indicated that the mangrove forest covered approximately 22.62 ha in 2014. During this period, the mangrove distribution was relatively dense, continuous, and dominant along the coastal zone and adjacent waterways. These findings suggest that the mangrove ecosystem was in relatively good condition, with limited anthropogenic pressure at that time.

By 2019, the mangrove forest area had slightly decreased to 22.18 ha. Although the reduction was relatively small in quantitative terms, the spatial analysis revealed increasing fragmentation of the mangrove ecosystem. The mangrove vegetation became divided into smaller patches and no longer formed the dense, continuous cover observed in 2014. This pattern indicates the onset of ecosystem degradation, likely driven by anthropogenic activities such as land conversion for plantations, the use of coastal areas for economic development, and possible exploitation of mangrove timber. Therefore, 2019 marks a period when anthropogenic pressures on the mangrove ecosystem became increasingly evident. The results of the analysis of mangrove forest cover in the Mesjid River Estuary are presented in Figure 2.

In 2024, mangrove forest cover increased to 22.92 ha. Although this numerical increase indicates a positive trend, a more detailed analysis reveals substantial changes in mangrove ecosystem quality and spatial distribution. The digitized land cover

map shows that a considerable portion of the area previously occupied by mangroves had been converted into plantations and shrubland. The remaining mangrove stands were generally confined to narrow strips along the coastline and riverbanks. These findings suggest that, despite the slight recovery in mangrove extent, the mangrove ecosystem's ecological condition in 2024 was less robust than in previous years because of reduced habitat connectivity and declines in ecological functions and carrying capacity.

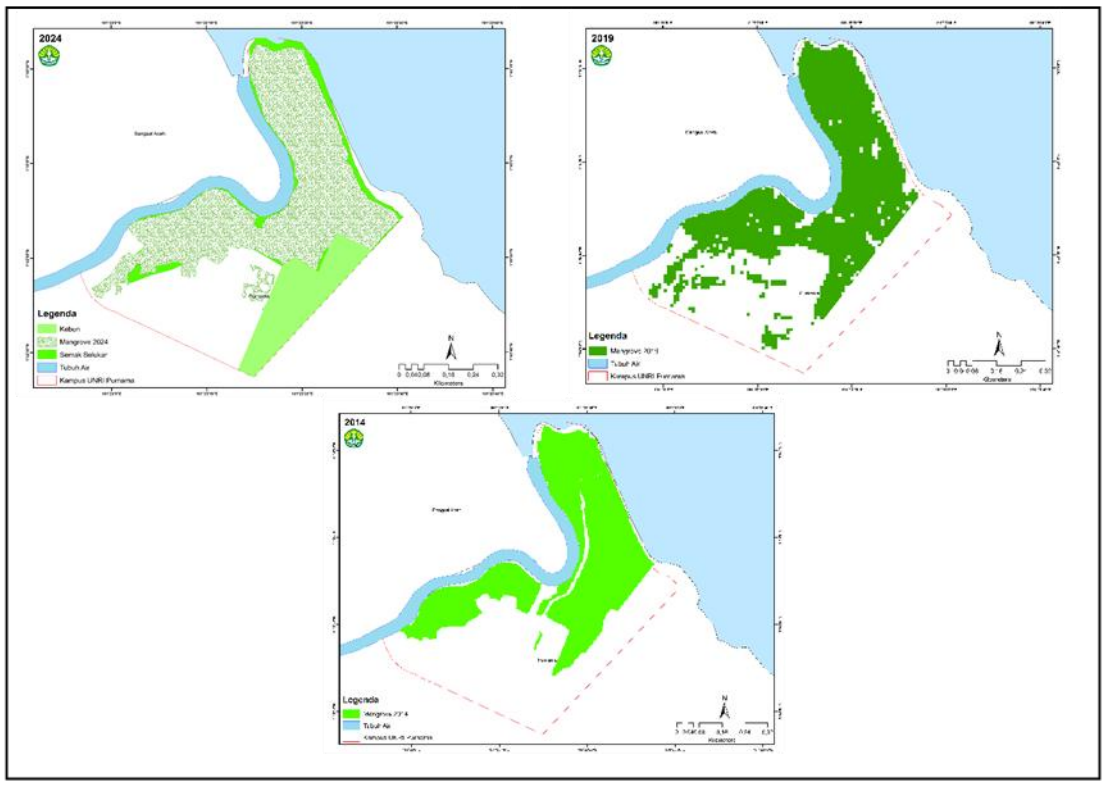

Figure 2. Mangrove cover map of (UNRI) Campus, Dumai, for the Period 2014–2024

From a temporal perspective, mangrove cover between 2014 and 2024 showed slight fluctuations but remained relatively stable in total area, ranging from 22 to 23 ha. However, the spatial distribution and ecological quality of the mangrove ecosystem warrant greater attention. The progressive land-use conversion observed throughout the study period indicates that the mangrove ecosystem surrounding the Universitas Riau (UNRI) Purnama Campus has faced considerable environmental pressure. Although the total mangrove area remained relatively unchanged, increasing fragmentation and altered habitat structure suggest a decline in ecosystem integrity. The primary drivers of mangrove degradation in the coastal areas of Riau include land conversion for plantations (particularly oil palm), infrastructure development, mangrove timber harvesting, and the lack of sustained and effective rehabilitation programs.

Overall, although the mangrove area data indicate only minor fluctuations, the changes in distribution patterns and mangrove cover condition in the Universitas Riau (UNRI) Purnama Campus area, Dumai, reflect increasing ecological pressure. If this condition is not promptly addressed through well-planned conservation and rehabilitation measures, mangroves' essential functions as coastal protection against erosion, habitat providers for aquatic biota, and carbon sinks may be lost in the long term. Therefore, the results of this analysis can serve as an important basis for formulating policies on mangrove management and protection

within the campus area and its surrounding coastal environment.

Bathymetric Analysis of the Mesjid River Estuary

Based on the bathymetric survey conducted in the Universitas Riau (UNRI) Dumai Campus study area, and after correcting for tidal influences, water depth ranged from −2.3 to −7.4 m relative to mean sea level, as shown in Figure 3. The three-dimensional (3D) visualization clearly illustrates shoaling in the central part of the estuary, showing that bed elevation in this area is higher than that of the surrounding seabed. The 3D model indicates significant sediment accumulation along the central channel, corresponding to reduced flow velocity in this section. Furthermore, the cross-sectional profile shows variations in bed elevation, with the central portion appearing elevated while the left and right sides are comparatively deeper, confirming sediment deposition.

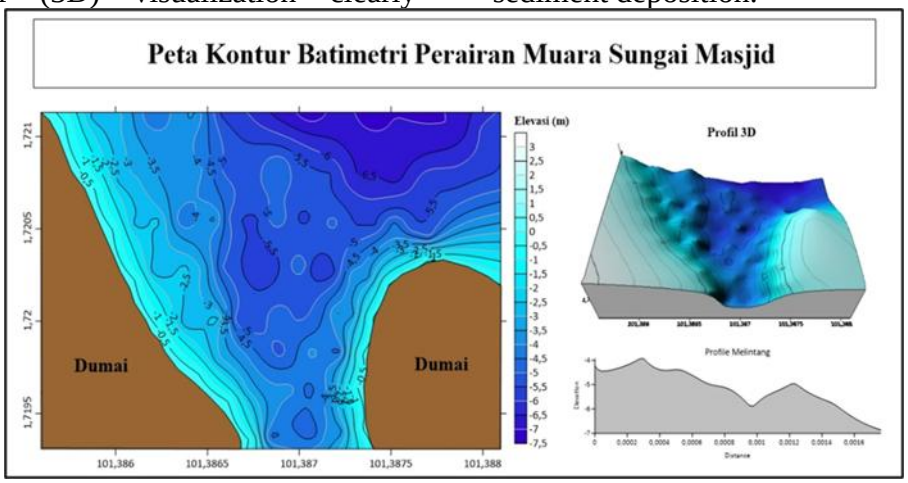

Figure 3. Bathymetric depth contours of the waters surrounding the (UNRI) Dumai Campus

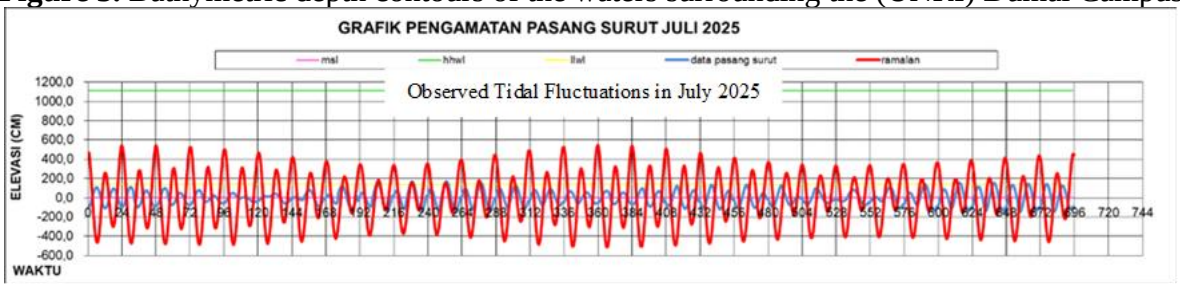

Figure 4. Tidal fluctuations in the Dumai Coastal Waters

Most sediment is not deposited on the bed of the Rupat Strait but is transported out of the strait by tidal currents flowing from the Malacca Strait through the Mesjid River Estuary into adjacent waters[4].

Tidal Characteristics

The tidal characteristics of the Mesjid River Estuary, Dumai City, are based on the analysis of tidal data collected during July 2025 (Figure 4). Based on harmonic analysis using the Admiralty method, the Formzahl number was calculated to be 0.43, indicating that the tidal regime in the Dumai coastal waters is classified as a mixed tide with a prevailing semidiurnal. The observed tidal elevations closely match the predicted tidal curve. The strong agreement between the observed and predicted tidal levels demonstrates the reliability of the harmonic analysis, indicating that the tidal data used in this study are sufficiently accurate to represent the tidal characteristics of the study area and support subsequent oceanographic analyses.

Shoreline Changes

The results of the shoreline change analysis for the Mesjid River Estuary during

the 2015–2025 period are presented in Figure 5.

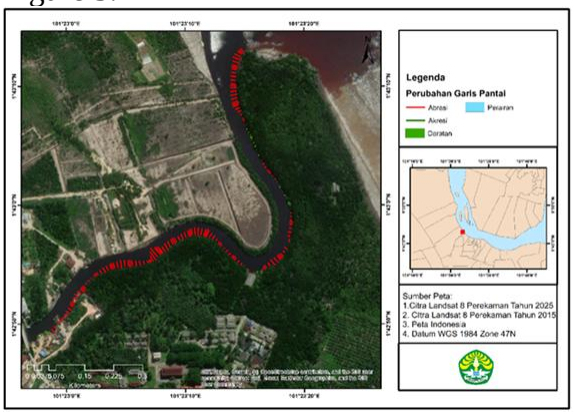

Figure 5. Shoreline changes in the Mesjid River Estuary

Based on the shoreline change analysis at the sampling site located in the Mesjid River Estuary, coastal erosion was found to be more dominant than accretion during the 2015–2025 period. This phenomenon is strongly influenced by anthropogenic activities, particularly intensive daily vessel traffic through the estuary. Ship-generated waves, especially those produced by vessels operating at moderate to high speeds, induce riverbank erosion by increasing wave energy that damages riparian vegetation and erodes unconsolidated bank sediments. Repeated wave impacts increase the erosive force on riverbanks, making sediments more susceptible to erosion. These findings indicate that navigation activities constitute one of the primary anthropogenic drivers of shoreline erosion in the vicinity of the Universitas Riau coastal area.

Ship traffic contributes significantly to the acceleration of shoreline erosion by increasing wave energy and disturbing the stability of bottom sediments within the estuary. Repeated vessel-generated waves promote the continuous detachment of sediment from riverbanks, particularly in areas with limited vegetation cover, thereby intensifying shoreline retreat.

However, shoreline erosion in the study area is not controlled solely by vessel-generated waves; tidal currents and fluvial dynamics also influence it. Tidal currents play an important role in estuaries, bay mouths, and semi-enclosed straits, where interactions between river discharge and tidal circulation govern sediment transport processes. Suspended sediment concentrations during the ebb tide are generally higher than those during the flood tide because river discharge becomes the dominant source of suspended sediments exported from the estuary[5].

The Mesjid River Estuary serves as the principal pathway for sediment transport from terrestrial to marine environments. When river discharge interacts with incoming marine waves, the resulting hydrodynamic energy erodes weakly consolidated sediments along the riverbanks. This high erosion rate has consequently led to shoreline retreat in the coastal zone, likely exacerbated by the degradation or absence of mangrove vegetation that would otherwise act as a natural buffer against wave attack. Mangrove forests play a crucial physical role in dissipating wave energy, stabilizing coastal sediments, and trapping suspended particles, thereby facilitating shoreline stabilization and promoting the natural expansion of mangrove habitats[6].

Sedimentation Rate in the Mesjid River Estuary

Sedimentation rates in the Mesjid River Estuary ranged from 3.54 to 8.89 cm year^{-1}, averaging 7.22 cm year^{-1}. At Station 1 (S1), sedimentation rates varied between 3.54 and 7.81 cm year^{-1}, corresponding to sediment volumes ranging from 147.5 to 325 mL. In contrast, Station 2 (S2**)** exhibited higher sedimentation rates, ranging from 8.41 to 8.89 cm year^{-1}, with sediment volumes between 350 and 370 mL. Overall, the average sedimentation rate of 7.22 cm year^{-1} indicates relatively high sediment accumulation within the study area. The results of the sedimentation rate analysis are presented in Table 3.

The observed differences in sedimentation rates between Stations 1 and 2 are closely associated with variations in flow dynamics along the river channel. At

Station 1, current velocities were relatively higher because the station is located within a straighter and narrower section of the river, where flow energy remains sufficient to transport suspended sediments downstream. Consequently, a considerable proportion of suspended material remained in transport rather than being deposited. In contrast, Station 2 is situated within a meandering section of the estuary that is partially sheltered by mangrove vegetation along the riverbanks.

Table 3. Sediment accumulation rate in the Masjid River Estuary

Stasiun	Volume Sedimentation (mL)	Accumulation Rate (mL/cm^3/day)	Sedimentation Rate (cm/year)
S1.T1	147,5	0,010	3,54
S1.T2	256	0,017	6,15
S1.T3	325	0,021	7,81
S2.T1	355	0,023	8,53
S2.T2	370	0,024	8,89
S2.T3	350	0,023	8,41
Averange			7,22

These geomorphological characteristics reduce current velocity, thereby enhancing sediment deposition. Spatially, the upper and middle reaches of the estuary exhibited the highest sedimentation rates, reflecting the decline in current velocity that promotes the settling of suspended particles. This finding is consistent with the typical characteristics of upper estuarine environments, where sediment accumulation is primarily controlled by the combined effects of tidal forcing and reduced fluvial energy[7].

Mangrove vegetation along the Mesjid River also plays a significant role in controlling sediment deposition. The complex root systems of mangroves reduce water velocity and effectively trap suspended particles, thereby increasing sediment accumulation in areas adjacent to mangrove stands. In addition, anthropogenic activities along the coastline influence sediment composition by supplying poorly sorted terrestrial materials to the estuarine environment. Because mangrove ecosystems dominate the study area, the predominance of fine-grained sediments provides favorable conditions for mangrove establishment and growth, as muddy substrates generally contain relatively high nutrient concentrations. The abundance of muddy sediments also indicates an active depositional environment with high sedimentation rates. These sediments are primarily derived from upstream river catchments, where terrestrial materials are transported downstream before being deposited within the estuary. Furthermore, high shoreline erosion contributes additional sediment inputs, further enhancing sediment accumulation in the study area[8].

4. CONCLUSION

A mixed-tide, prevailing semidiurnal regime strongly influences oceanographic dynamics in the Mesjid River Estuary and weakens currents at the estuary mouth, which promote sediment accumulation. The average sedimentation rate at the study site was 7.22 cm year^{-1}, with the highest sediment accumulation occurring in areas characterized by low current velocities and protected by mangrove vegetation. Shoreline changes in the study area are predominantly characterized by coastal erosion, driven by a combination of natural factors (currents and waves) and anthropogenic influences, particularly vessel-generated waves and mangrove forest degradation.

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