# Analysis of Coastline Changes and Water Current Circulation Patterns in Batam City, Riau Islands Province

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**ABSTRACT**

Environmental damage is caused by coastal reclamation to advance the economic sector in Batam City. Reclamation can cause changes in the coastline of Batam City. This study aims to determine the extent of changes in the coastline that occurred in Batam City from 2003 to 2023 and to understand the pattern of ocean current circulation in Batam City before reclamation in 2003 and after reclamation in 2023. This study was conducted in January 2024. The method used for data analysis to observe changes in the coastline is the Digital Shoreline Analysis System. Numerical models available in the MIKE21 software to model water circulation in estuary beaches. The study results show that land additions dominated changes in the coastline of Batam City from 2003 to 2023. The sub-district with the most significant addition was Bengkong, with an addition of 816.58 m and an addition rate of 39.79 m/year, followed by Nongsa, with an addition of 279.05 m and an accretion rate of 13.59 m/year. The flow pattern during the ebb and flow before reclamation had a maximum speed of 0.27 m/s, while after reclamation, the maximum current speed increased to 0.33 m/s. It can be concluded that the progression of the coastline primarily drove the changes in Batam City's coastline from 2003 to 2023. Meanwhile, the increasing current speed can reach 0.33 m/s.

**Keywords:** Coastline, Reclamation, Current Pattern, Tides, Batam

## 1. INTRODUCTION

Coastline changes are one form of coastal area dynamics that occur continuously. Coastline changes in coastal areas include erosion (retreat) and beach additions (sedimentation or advance). Coastline changes caused by retreat or erosion occur due to ocean currents and ocean waves that continuously hit the shoreline and relatively flat beaches. In contrast, coastal advancement is caused by the accumulation of sediment from the mainland, which is deposited on the coast, primarily through river estuaries (Martuti, 2019). These coastline changes can be monitored multi-temporally using remote sensing satellite technology. Remote sensing technology is a technique or art based on electromagnetic waves. This technology produces images by building a relationship between the flux the satellite's sensor carries and the physical properties of the observed object on the Earth's surface. The image is analyzed to see changes in the coastline. By combining the results of multitemporal image analysis, the process of coastline change can be measured/observed in detail (Riyanti et al., 2017).

The strategic location and topography of Batam City make this area an attractive investment destination. Generally, investments entering Batam City are absorbed into various industrial sectors. The largest industries in Batam City are electronics assembly and related industries, as well as light and medium industries such as manufacturing and the shipyard. The rest are spread across other sectors, including property and tourism. Coastal development activities are mainly carried out along the coastline of Batam Island. The increasing number of developments in the coastal areas of Batam City has led to a deterioration in the current environmental conditions in Batam, resulting in increased environmental damage. This environmental damage is caused by the expansion of the area and land through the reclaiming of coastal areas to advance the economic sector in Batam City (Putra & Dedi, 2021). This activity (reclamation) can cause changes in the coastline in Batam City.

Reclamation is one of the efforts made to overcome the limited land. Reclamation can be interpreted as filling land on a large scale with water or coastal areas to create new land. Reclamation in this coastal area is expected to improve and utilize areas that are considered less productive. However, implementing reclamation can also affect the condition of the coastline. In relation to the reclamation, changes will occur in the coastline, which will, of course, also affect the current patterns around it. The current patterns will, of course, affect sediment transport, both in the form of bed load and suspended load. The next consequence is a change in sedimentation patterns that impact the shallowing of waters both inside and outside the anchorage pond (Widada, 2016).

Monitoring shoreline changes is a way to control coastal reclamation activities. One effort to obtain information about shoreline changes and current circulation patterns is the use of remote sensing technology.

## 2. RESEARCH METHOD

### Time and Place

This research was conducted from January 1, 2024, to January 15, 2024. The research location is in Batam City, Riau Islands Province. Satellite image data analysis was conducted at the Physical Oceanography Laboratory, Faculty of Fisheries and Marine Sciences, Universitas Riau. The research location is shown in Figure 1.


**Figure 1. Research location**

### Method

The method used in this study is a survey method that involves direct observations, conducted through measurements and sampling in the field. Purposive sampling determines sampling points. The data collected primarily consist of results from water quality measurements in the field and water samples analyzed in the laboratory, which were then analyzed descriptively. Then, I continued with data analysis.

### Procedures

### Image Processing

Image data input was collected in 2003, 2008, 2013, 2018, and 2023 for data processing. Data input for each image year includes the bands to be used, namely bands 1-8. The first image processing was downloaded from the USGS, namely images from 1988, 2004, and 2020. Geometric correction was performed by selecting the UTM zone and the research area. The UTM (Universal Transverse Mercator) system on Earth is divided into several zones, numbered 1-60, with meters as the unit of measurement. The Earth's coordinate system will be divided into two parts: above the equator, as the northern part, denoted by the symbol North (N), and the southern part of the equator, denoted by the symbol South (S). Geometric correction of Batam City uses the WGS 1984 UTM 48 North datum. Then, the data will be processed first using remote sensing software to obtain data on the area of mangrove forests and coastlines. This digitization stage involves converting from raster to vector form. This is done to facilitate the classification of coastlines. This process consists of creating a line that separates land and sea, forming a coastline that will be identified and analyzed.

### Calculation of Speed, Distance, and Coastline Prediction

This study utilized the Shoreline Analysis System (SAS) tool, integrated with GIS 10.4 software, to calculate the rate, distance, and prediction of shoreline change. Predictions are made to determine future changes in the shoreline. This prediction can be estimated in the next 10 or 20 years. The distance of shoreline change is calculated using the Net Shoreline Movement (NSM) method. The NSM method, where a positive (+) distance indicates the shoreline is advancing, and a negative (-) distance indicates the shoreline is retreating, which can be observed in. The DSAS method used to calculate the shoreline change rate is the End Point Rate (EPR). The EPR method calculates the shoreline change rate by dividing the distance between the oldest and current shorelines by the time shown. Data with a positive (+) value experiences advance, and data with a negative (-) value experiences Retreat (Syaharani & Triyatno, 2019).

**Flow Pattern Modeling**

Current velocity modeling is performed using a mathematical model that inputs secondary data, including bathymetry, coastline, tidal, and wind data. The hydrodynamic module in MIKE 21 HD is a general numerical model system for simulating water levels and flows in estuaries, bays, and beaches. This model can simulate two-dimensional, non-permanent flow in a single-layer fluid (vertically homogeneous) or three-dimensional flow. The MIKE 21 hydrodynamic module (MIKE 21 HD) is a fundamental component of the MIKE 21 flow model program.

**Data analysis**

**Coastline Change Analysis**

Analysis of the DSAS method with Net Shoreline Movement (NSM) will calculate the distance of the oldest and newest shoreline changes. Calculating the distance of shoreline changes is done over both long and short time periods. Measurement of the distance of shoreline changes over a long time is the calculation of the distance in the range of 2003-2023, while the measurement of the distance of short-term shoreline changes is carried out in the range of 2003-2008, 2008- 2013, 2013-2018, and 2018-2023. To ensure that the most significant and minor distances of change are obtained in areas experiencing shoreline changes in Batam City. The NSM statistical approach is illustrated in Figure 2.

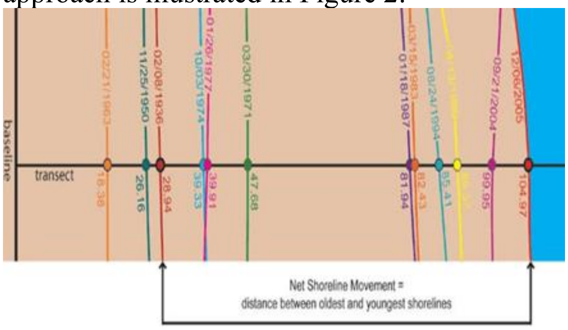


**Figure 2. The NSM statistical**

Analysis of the DSAS method, which involves calculating the End Point Rate (EPR), enables the determination of the rate of change of the coastline by dividing the distance between the oldest coastline and the newest coastline (Figure 3). This study utilizes EPR to analyze the rate of change of the shoreline through long-term and short-term monitoring from 2003 to 2023. The short-term coastline change rate was measured in the periods 2003-2008, 2008-2013, 2013-2018, and 2018-2023. Furthermore, the locations that show the smallest and largest Advance and Retreat rates in Batam City can be analyzed. The EPR statistical approach is illustrated in Figure 3.

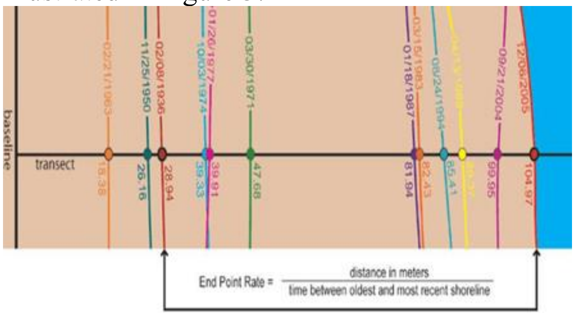


**Figure 3. The EPR statistical**

**Circulation Flow Analysis**

Hydrodynamic modeling is processed using the hydrodynamic module in MIKE 21, where several data sets are required, including tidal data, coastline data, wind data, and bathymetry data. These data will then serve as input for the current modelling. Open the MIKE 21 HD software, input the study area on the mesh boundary, fill in the time steps or how long the model simulation will be carried out, and input wind data on wind and wind data on each Boundary Condition. After that, the output is created. Fill in the parameters (current speed, direction, and surface elevation), rename them, and save the changes. Then run it. Then, after the run is complete, check the model that has been run. Activate the vector on the hydro results and observe the movement of the current and the direction of the arrow shown in the layout, which appears as a map.

## 3. RESULT AND DISCUSSION

**Tides**

Tides are the rising and falling of water at an observation point, accompanied by horizontal movement of the water mass. The tidal data used are measurements taken over 15 consecutive days with a 60-minute time interval. The tidal data will be used as input for boundary conditions during modelling to obtain current and sedimentation patterns and to calibrate seawater elevation data. The form of the tidal data graph is displayed in Figure 4.

**Changes in the Coastline of Batam City 2003-2023**

Observation of shoreline changes for 2003-2023: the red line shows the shoreline that occurred in 2003, while the black line shows the shoreline that occurred in 2023. The perpendicular line is a transect that arises between the two shorelines. The blue line shows accretion, while the green line shows abrasion. Visually, the dominant transect line is blue, and the dominant shoreline is experiencing accretion. The map of shoreline changes in Batam City from 2003 to 2023 is shown in Figure 5. Based on the results of the DSAS calculations, the period from 2003 to 2023 was dominated by accretion or land addition events. Land addition occurred in Nongsa District, amounting to 279.05 m, with a rate of change of 13.59 m/year. Nongsa District also experienced a not-too-high abrasion event of -19.4 meters, with an abrasion rate of -0.94 meters/year. The results of the DSAS calculations for the period 2003-2023 are presented in Table 1.

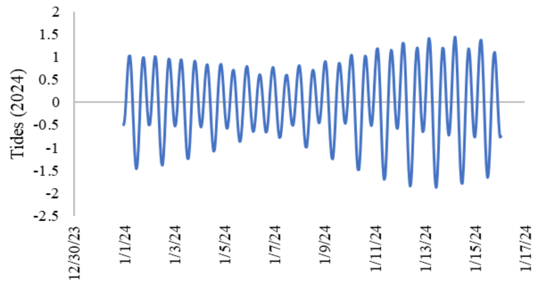


**Figure 4. Tidal graph 2024**


**Figure 5. Map of Batam City Coastline Change 2003-2023**

**Table 1. Calculation of DSAS 2003-2023**

| No | District | NSM (m) | EPR (m/year) | category |
|---|---|---|---|---|
| 1 | Batam Kota | 266,43 | 12,98 | Accretion |
| | | -38.07 | -1.85 | Abrasion |
| 2 | Batu Aji | 146,05 | 7,11 | Accretion |
| | | -42.58 | -2.08 | Abrasion |
| 3 | Batu Ampar | 167,74 | 8,17 | Accretion |
| | | -17.29 | -0.84 | Abrasion |
| 4 | Bengkong | 816,58 | 39,79 | Accretion |
| 5 | Lubuk Baja | 37,04 | 1,80 | Accretion |
| | | -34.82 | -1.69 | Abrasion |
| 6 | Nongsa | 279,05 | 13,59 | Accretion |
| | | -19.4 | -0.94 | Abrasion |
| 7 | Sagulung | 105,11 | 5,12 | Accretion |
| | | -20.4 | -0.99 | Abrasion |
| 8 | Sekupang | 91,21 | 4,45 | Accretion |
| | | -34.27 | -1.67 | Abrasion |
| 9 | Sungai Bedug | 251,76 | 12,26 | Accretion |

The occurrence of Maju in Nongsa District was attributed to the presence of companies along the coast, one of which was the Indo Matra Power Batam company, a private power generation company (independent power producer) (Figure 6). Bengkong District also experienced a relatively high coastline advance of 816.58 meters with a rate of change of 39.79 m/year, and the highest distance of change was 1,841.46 m. Lubuk Baja District experienced the lowest change in the coastline from 2003 to 2023. The accretion in Lubuk Baja District was 37.04 meters, with an accretion rate of 1.80 m/year. Meanwhile, the abrasion was -34.82 m, with a rate of -1.69 meters/year (Figure 7).

Observations conducted from 2003 to 2008 aimed to document changes in the coastline during the period of rapid development in Batam City's coastal areas. In Bengkong District, coastal reclamation began. This coastal reclamation was intended to create new land, increase economic value, and enhance productivity. From 2008 to 2013, all sub-districts in Batam City continued to experience predominantly accretion. This is likely due to the start of construction and development activities in coastal areas. Batu Aji District has the highest accretion rate because this area was built by many shipyard companies.

The accretion in Batu Aji District is used for industrial land adjacent to a shipyard. Accretion in Batu Ampar District is caused by oil and gas companies carrying out reclamation development to expand industrial land. They have a steam power plant (PLTU) in Batam, which supplies electricity to the Batam area and its surrounding areas. In Nongsa District, there is also PT SMOE Indonesia, a company that focuses on the oil and gas industry, particularly in providing turnkey solutions for offshore platforms, modules, jackets, and FPSOs (Floating Production Storage and Offloading). The housing built on reclaimed land in Bengkong District between 2013 and 2018 is projected to be luxurious, offering beautiful beach views. Batu Ampar District is experiencing relatively high accretion and abrasion due to land addition activities by oil and gas companies in this district. They provide engineering, procurement, construction, transportation, installation, and commissioning services. Between 2018 and 2023, abrasion and accretion occurred in Batu Ampar District and Nongsa District, primarily due to the activities of oil and gas companies in this coastal area. In Sungai Bedug District, abrasion occurred due to damage to the mangrove forest on the coast of Sungai Bedug District.

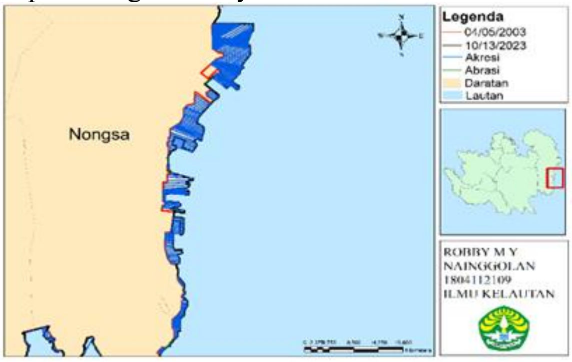


**Figure 6. Map of Coastline Changes in Nongsa District 2003-2023**

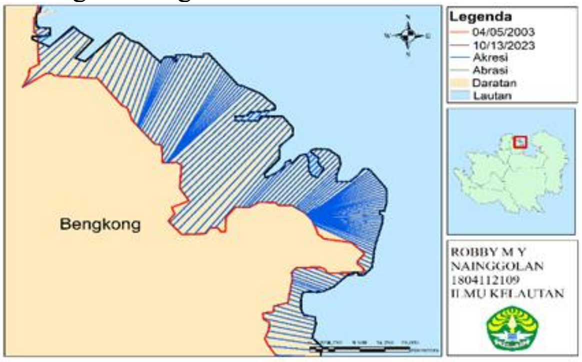


**Figure 7. Map of Coastline Changes in Bengkong District 2003-2023**

Roziqin & Gustin (2017) conducted a study on Coastline Change Mapping Using Remote Sensing Imagery on Batam Island, showing that the impact of coastline changes on Batam Island can be seen from the area of change when land was added and land was reduced. The total land area in each sub-district on Batam Island in 2009 was 42,419 Ha. After changes in the coastline, namely land reduction or erosion and land addition, the total area of each sub-district on Batam Island in 2013 was 42,284 Ha. Consequently, the coastline change resulted in a reduction of 135 Ha on Batam Island. The total area on Batam Island in 2016 was 42,903 Hectares. Based on the changes, there was an increase in land of 619 Ha on Batam Island.

The addition of land on Batam Island was significantly influenced by land use in the coastal areas of Batam Island, including port construction, resort activities, and marine tourism. Changes in the coastline of Batam City were primarily caused by human factors, specifically reclamation or land addition. The reclamation carried out by Batam City is a government program and policy aimed at boosting the local economy. This reclamation is intended for various sectors that can support economic growth, including the housing sector, the industrial sector, and the marine tourism sector.

**Circulation of Batam City Water Currents During High Tide**

Based on the results of the MIKE 21 current model simulation processing. The current is strong and evenly distributed in almost all upper water bodies, with speeds ranging from 0.08 to 0.20 m/s. The current in most of the bay waters (bottom centre of the image) shows a direction that tends to enter the bay, namely moving from the bottom right to the top left. The current speed varies, with some areas displaying longer arrows (indicating higher speeds), particularly at the mouth of the bay, which can reach 0.32 m/s. The current pattern map, before the development of reclamation (existing condition), is presented in Figure 8.

The tidal current circulation pattern on January 5, 2023, is characterized by a dominant current flow from north to south. There are areas with high current speeds in the middle area and the mouth of the bay, ranging from 0.26 m/s to 0.38 m/s. This image illustrates the dominance of currents flowing into the bay, from the bottom right to the top left, particularly in the middle and mouth of the bay. Figure 23, the tidal current circulation pattern on January 15, 2023, exhibits a similar pattern. At the mouth of the narrowing bay, the current arrow looks longer and denser, indicating a higher current speed that can reach a speed of 0.39 m/s. The speed increase at the bay's mouth shows that seawater is entering the bay basin with great intensity. The map of current patterns after reclamation is presented in Figure 9.

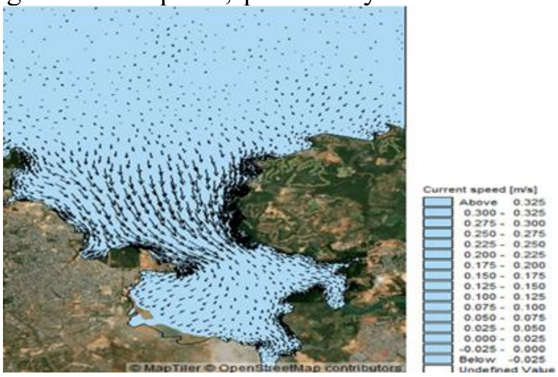


**Figure 8. Circulation pattern of Batam City water currents during high tide before reclamation**

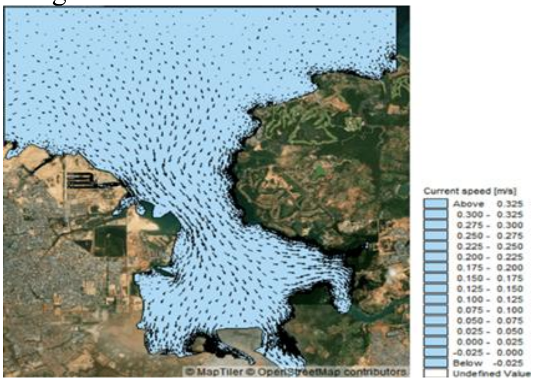


**Figure 9. Circulation pattern of Batam City water currents during high tide after reclamation**

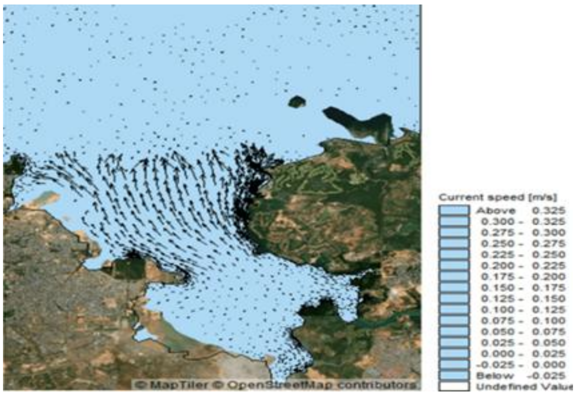


**Figure 10. Circulation pattern of Batam City water currents at low tide before reclamation**

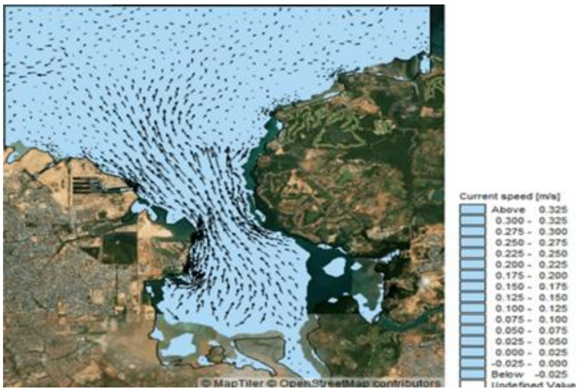


**Figure 11. Circulation pattern of Batam City water currents at low tide after reclamation**

The coastline before the reclamation showed a relatively open and wide water body, resembling a large bay or more open coastal waters. The coastline in the south and east appears more curved, forming a bay. The direction of the current moves relatively symmetrically from the south to the open sea in the north (natural open channel). With a speed ranging from 0.20 to 0.27 m/s. The current distribution exhibits a clear and consistent pattern, with currents generally flowing from the upper left (northwest) to the lower right (southeast) or directly to the south, particularly in the center of the water body (Figure 10).

The reclaimed 2023 coastline shows a body of water that narrows significantly in the middle, forming a strait or narrow channel. On both sides of this strait are protruding land masses, creating an apparent narrowing. The current exhibits intense and concentrated characteristics as it passes through the narrowed central part (strait/channel). The current arrows in the narrow area appear very dense and long, visually indicating that the current speed can reach a maximum of 0.33 m/s. Compared to the broader area around it, which ranges from 0.012 to 0.024 m/s. The narrowed land form guides and accelerates the current flow. The current may be weaker or more scattered in the broader area before and after the narrowing, but becomes very strong at the narrowest point (Figure 11).

Areas of consistently high current velocities are identified at bay mouths or narrow channels, which are the main link between the interior and open waters. This increase in velocity is the effect of narrowing the flow cross-section, where water must pass through a smaller path. Thus, its velocity increases to maintain a continuous flow rate. In larger areas of open water, current velocities tend to be slow. Current velocities are very low or even approaching stagnant conditions in some more sheltered areas, such as coves or depressions near the shoreline and zones far from the main channel. These zones reflect areas of less intensive water mass exchange.

Adha (2019) analyzed the current movement patterns of sediment grains in the Tering Bay reclamation area in Batam City, presenting results in the erosion and transport section. This section indicates that the strength of the current in these waters causes erosion. This is due to the strength of the seawater current, which ranges from 0.33 to 0.71 m/s. This relationship is evident between reclamation activities and hydro-oceanographic conditions in the waters of Tering Bay, Batam City. As seen in the August 2017 study, erosion occurred in the Tering Bay reclamation area, Batam City.

Siagian et al. (2013) also conducted a study on current patterns due to coastal reclamation planning in Makassar Waters, with the results showing a comparison of current speeds before and after coastal reclamation, which revealed a decrease in current speed. Specifically, the reduction in current speed was 7.52%. Based on these results, it is known that reclamation affects current speed even though the current speed does not change significantly. In other words, reclamation only has a minimal effect on changes in current speed. Current speed decreases or becomes low due to a reduction in current speed and is diverted by the presence of the coastal building.

## 4. CONCLUSION

Based on the study's results on coastline changes and modeling of Batam City's water current patterns, it can be concluded that the changes in the coastline that occurred in Batam City from 2003 to 2023 were dominated by the advancement of the coastline, resulting in an addition of land of 335,045.521 m². The sub-districts with the most significant additions of land were Bengkong Sub-district, at 816.58 m with an addition rate of 39.79 m/year, and Nongsa Sub-district, at 279.05 m with an addition rate of 13.59 m/year. The circulation pattern of the Tering Bay water current in Bengkong Sub-district, before and after reclamation, experienced changes that were not significant. The current direction pattern changed only around the reclamation area, causing a slight deflection of the current direction that was not too extreme. Meanwhile, the current speed increased in the bay face area due to the narrowing caused by reclamation. The current speed through the bay mouth area can reach 0.33 m/s.

## REFERENCES

Adha, F. (2019). *Analisis Pola Pergerakan Arus terhadap Distribusi Butiran Sedimen di Kawasan Reklamasi Teluk Tering di Kota Batam, Kepulauan Riau*. Universitas Brawijaya.

Martuti, N.K.T. (2019). Peran Kelompok Masyarakat dalam Rehabilitasi Ekosistem Mangrove di Pesisir Kota Semarang. *Jurnal Wilayah dan Lingkungan*, 6(2): 100-114.

Putra, E.E., & Dedi, E. (2021). Dampak Reklamasi di Kawasan Pesisir Pulau Batam terhadap Keberlangsungan Hidup Nelayan Sekitar. *Scientia Journal*: *Jurnal Ilmiah Mahasiswa,* 3(4): 1-10.

Riyanti, A.H., Suryanto, A., & Ain, C. (2018). Dinamika Perubahan Garis Pantai di Pesisir Desa Surodadi Kecamatan Sayung Dengan Menggunakan Citra Satelit. *Management of Aquatic Resources Journal (MAQUARES)*, *6*(4): 433-441.

Roziqin, A., & Gustin, O. (2017). Pemetaan Perubahan Garis Pantai Menggunakan Citra Penginderaan Jauh di Pulau Batam. *Prosiding Industrial Research Workshop and National Seminar*, 8:295-299.

Siagian, B.T., Helmi, M., & Sugianto, D.N. (2013). Kajian Pola Arus Akibat Perencanaan Reklamasi Pantai di Perairan Makassar. *Journal of Oceanography*, 2(1): 98-110.

Syaharani, L., & Triyatno, T. (2019). Analisis Perubahan Garis Pantai Kabupaten Padang Pariaman dan Kota Pariaman tahun 1988-2018 Menggunakan Digital Shoreline Analysis System (DSAS).

*Jurnal Buana*, 3(5): 1056-1067.

Widada, S. (2016). Prediksi Perubahan Arus Akibat Reklamasi pada Pangkal Breakwater Barat Pelabuhan Tanjung Emas Semarang dengan Pendekatan Model Matematik. *Jurnal Kelautan Tropis*, 18(3): 147-153