Regular Research Article

Numerical Analysis of Hydrodynamic and Channel Discharge Impacts of Planned Coastal Reclamation in Eastern Surabaya

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Abstract: Coastal reclamation is widely implemented in major cities to support economic growth and infrastructure development. Surabaya plans to develop the Integrated Coastal Area of Surabaya Waterfront Land (SWL) in the Pamurbaya coastal zone through reclamation activities. The area includes river estuaries and fishponds. This makes it sensitive to changes in hydrodynamics, sediment transport, and channel discharge due to coastal morphological modifications. This study analyzes these changes using the Delft3D-FLOW model, coupled with Delft3D-WAVE through a nested grid approach. Tidal data from TPXO were validated against field observations at Wonorejo Station, showing satisfactory calibration (RMSE = 0.23 and MAPE = 11.75%). Simulation results indicate that maximum current velocity decreased from 0.375 m/s to 0.364 m/s after reclamation. Sediment transport was redistributed, with the largest positive depth change in Kali Kepiting (0.077 m) and the smallest in Kali Lebak Indah (0.17×10^{-3} m). Depth-averaged discharge decreased across channels by 1–69%. Reductions were largest in Kali Kepiting and Kali Bokor, while channels connected to the open sea, such as Kali Wonokromo, showed smaller decreases. These findings demonstrate that the impacts of reclamation are spatially variable and can affect the sustainability of fishpond operations. Mitigation measures, including periodic dredging and long-term monitoring, are recommended to maintain hydraulic connectivity and flow balance.

Keywords: Channel Discharge, Delft3D, Hydrodynamics, Numerical Modeling, Reclamation.

Plain Language Summary Coastal areas undergo various changes due to human activities, such as urban expansion and the development of other infrastructures. These activities, including land reclamation, can affect water flow, sediment transport, and tidal circulation. This study assesses the impact of the Surabaya Waterfront Land (SWL) reclamation plan in Pamurbaya on local coastal dynamics. Modeling results indicate that reclamation can alter current patterns, redistribute sediments, and reduce water flow in certain channels. These changes may affect the efficiency of tidal flushing and long-term water renewal. This, in turn, could impact community activities such as fishpond operations. To minimize the effects, periodic dredging is recommended to maintain the ideal water depth. The findings can support more sustainable coastal planning and management.

1. Introduction

Numerical modeling is one of the most widely used approaches for understanding coastal dynamics influenced by environmental changes. This method can produce results comparable to laboratory experiments when calibration and verification are properly conducted [1]. In addition to being time- and cost-efficient, numerical modeling allows the simulation of multiple scenarios for impact assessment [2]. In this study, numerical

modeling is employed to analyze changes in hydrodynamics and channel discharge in the eastern coastal area of Surabaya (Pamurbaya).

Surabaya is one of Indonesia's major cities, experiencing rapid population growth that drives the development of residential and other infrastructure [3], [4]. The city also holds a strategic role as part of the Gerbangkertosusila National Strategic Area (KSN), aimed at establishing a maritime and marine economic hub [5]. Consequently, coastal infrastructure development is crucial. One of the planned projects is the Integrated Coastal Area development of Surabaya Waterfront Land (SWL) through reclamation. This project has received regulatory approval under the Marine Spatial Utilization Permit (PKKPRL) from the Indonesian government.

Reclamation involves the development of coastal areas by increasing land through the filling of water bodies [6]. Globally, this practice has been widely applied in major cities, with the most extensive example in Shanghai, China, covering over 580 km² [7]. While reclamation is projected to provide substantial economic benefits, it may disrupt coastal ecosystems [8]. Therefore, its implementation must be carried out cautiously, considering all potential environmental impacts.

Numerous studies have demonstrated that reclamation affects hydrodynamics and sediment distribution. A 3D modeling study in the Bohai Sea revealed a 3.95% reduction in tidal prism and a decrease in suspended sediment flux (SSF) by up to −6%, although localized increases were observed in Bohai Bay and Laizhou Bay [9]. In Laizhou Bay, reclamation reduced cross-bay sediment transport by approximately 22% [10]. Research in Kendari Bay further confirmed that reclamation alters current direction and velocity, particularly in narrow channels, and affects sediment distribution patterns [11]. These findings underscore the relevance of numerical modeling for assessing reclamation impacts on hydrodynamics and flow discharge.

Studies have also demonstrated a significant reduction in the volume of water exchanged during tidal cycles as a result of reclamation activities. Research conducted in Sanmen Bay reported a 34.9% decrease in tidal prism due to reclamation between 1971 and 2020 [12]. The tidal prism is expected to continue declining if sedimentation persists. Tidal discharge and flood flow are closely correlated with the magnitude of the tidal prism, which has important implications for coastal environmental and ecological conditions [13].

The Pamurbaya area has already undergone significant morphological changes, dominated by sedimentation driven by the inflow of multiple rivers, estuaries, and channels transporting sediment to the coast [14]. Additionally, reclamation may alter flow discharge through estuaries by modifying current patterns and sediment distribution [15]. Meanwhile, existing community activities in the planned reclamation area are at risk of disruption. Flow discharge changes, particularly in areas with aquaculture in fishponds, could significantly affect these activities.

Coastal reclamation has become increasingly widespread, particularly in major cities worldwide [16]. Numerous studies have examined its impacts, typically highlighting changes in current patterns, tidal dynamics, and sediment transport. Some research has also addressed alterations in water exchange volumes in estuaries, bays, and lagoons. For instance, a Delft3D-based study in Bohai Bay demonstrated a reduction in local water exchange and modifications in residual current distribution due to impeded water mass transport caused by reclamation [17].

Similarly, river discharge studies using Delft3D, such as the Surma River in Bangladesh, revealed sharp discharge peaks in April, visualized through depth-averaged discharge [18]. However, studies linking reclamation to channel discharge variables directly affecting aquaculture operations remain limited.

Consequently, this study focuses on analyzing changes in hydrodynamics and flow discharge in channels connected to fishponds as the primary metric. Numerical modeling was conducted using Delft3D to assess the effects of reclamation in Pamurbaya. Simulation results are presented as spatial distributions, including depth-averaged discharge visualizations, to

identify variations in flow discharge. These findings are expected to provide a foundation for further studies on erosion and sedimentation trends, discharge changes, and the planning of future mitigation measures.

2. Materials and Methods

The city of Surabaya is geographically located between 112°36'–112°54' E and 7°09'– 7°21' S [3]. The Eastern Coast of Surabaya (Pamurbaya) is situated along the city's eastern shoreline, extending from the northern coastal area down to the Wonorejo River in the south. Several primary drainage channels and rivers also discharge into the Pamurbaya region. The planned development of the Surabaya Waterfront Land (SWL) is situated within this area, designed as a reclamation zone separated from the mainland, as illustrated in Figure 1.
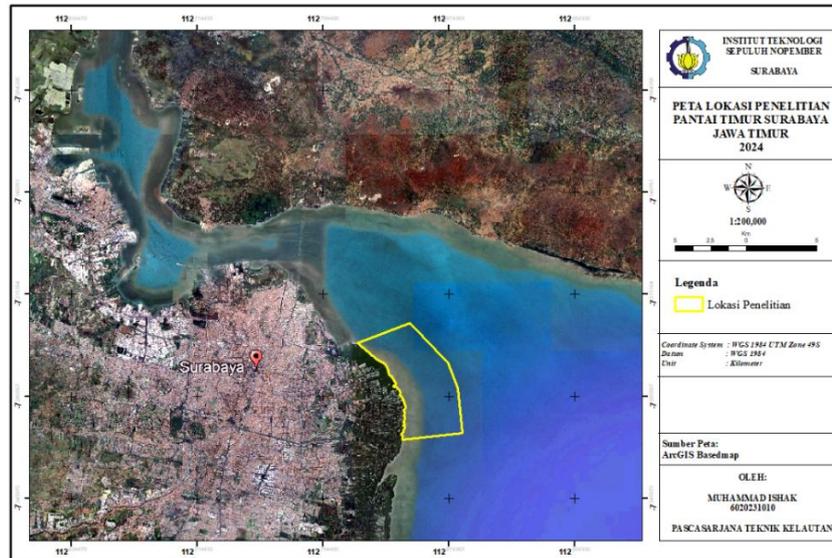

Figure 1. Research area

Numerical modeling was conducted to analyze changes in hydrodynamics and channel discharge. A nested grid approach was applied to balance the need for wide spatial coverage with sufficient local resolution. In the initial stage, a parent (coarse) grid was developed, covering the Madura Strait area up to the Pamurbaya region. The grid was constructed using the UTM Zone 49S coordinate system, with a spatial resolution ranging from approximately 139.57 m to 1621.42 m. The selected grid resolution was determined based on considerations of numerical stability and computational efficiency.

After the overall model shown in Figure 2 reached a stable condition and closely matched field observations, a detailed (nested) model with finer grid resolution was developed. This grid focused on the proposed reclamation area, simulated under two scenarios: the baseline condition and the reclamation condition.

The numerical model was constructed using Delft3D-FLOW, coupled with Delft3D-WAVE, to represent the interactions among currents, waves, and sediment transport. The open boundary conditions were defined based on global harmonic tidal constituents from TPXO, including the main components M2, S2, K1, and O1. The upstream boundaries were assigned as discharge boundaries varying as a function of time, while land boundaries were defined as closed boundaries, preventing flow across them. Additional input data such as salinity, temperature, and wind fields were included to achieve more realistic physical conditions. Sediment boundary conditions were also applied to simulate sediment transport dynamics physically and accurately.

Several datasets used in this study were obtained from field surveys referenced in the PKKPRL documentation. The field measurements were conducted between May and June 2024. The bathymetric data from the surveys were combined with national

bathymetry data (Batnas) around the Madura Strait, provided by the Geospatial Information Agency (BIG) [19]. The study area is a coastal zone with a maximum depth of approximately 15 m and a gentle seaward slope.
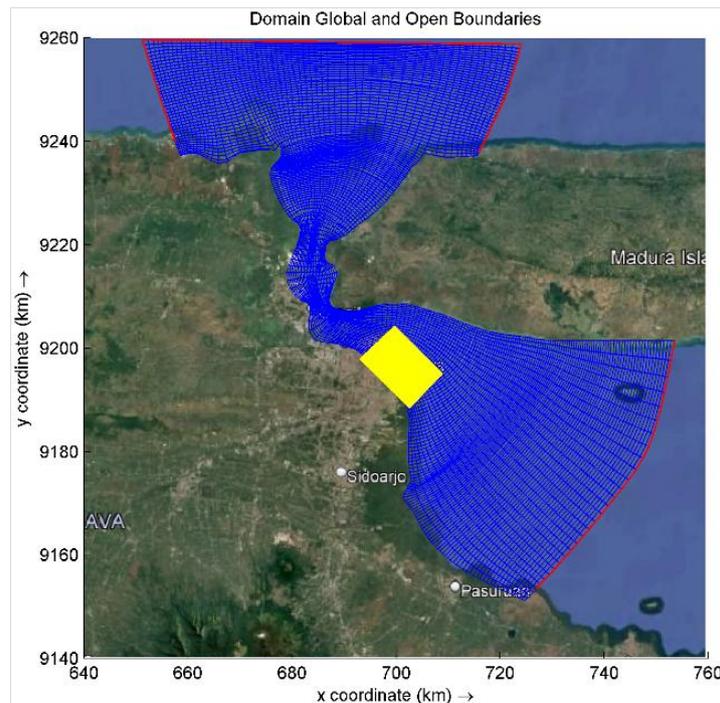

Figure 2. Overall model

Tidal data were collected from observations at the Wonorejo Station. The tidal type was determined based on the amplitudes of harmonic tidal components or the Formzahl number [20], as expressed in Equation (1).

$$F = \frac{K_1 + O_1}{M_2 + S_2} \qquad (1)$$

where: K_1 and O_1 are the amplitudes of the principal diurnal tidal components, while M_2 and S_2 represent the amplitudes of the principal semidiurnal tidal components.

Based on the observation data, the Formzahl number at Wonorejo Station was calculated to be 0.89, indicating that the tidal type at the site is mixed tide prevailing semidiurnal. This finding is consistent with previous research that analyzed tidal characteristics in Surabaya over a five-year period (2015–2020), which also identified the mixed–predominantly semidiurnal tidal type [21]. The tidal data from Wonorejo Station were used for model validation. The model simulations employed global harmonic tidal constituents from TPXO 7.2, obtained through the Delft Dashboard interface.

Additional supporting data included sediment grain size information obtained from laboratory testing of bottom sediment samples. The sediment material consisted mainly of sand and silt, with a median grain diameter (D_{50}) of 0.393 mm. Field measurements also provided discharge data for several primary drainage channels.

In addition to field observations, secondary datasets available from official online sources were also utilized. These included the 2022 shoreline data for mapping purposes, obtained from the Geospatial Information Agency (BIG) [19], and wave and wind data from the European Centre for Medium-Range Weather Forecasts (ECMWF) [22]. Temperature and salinity data sourced from the Copernicus Marine Service [23].

The hydrodynamic modeling in this study was performed using the Delft3D software suite, which has been widely applied in both international research and coastal engineering projects. Delft3D can simulate various physical

processes, including hydrodynamics, waves, sediment transport, and morphological evolution [24]. The formulation used includes the momentum equations, continuity equations, and transport equations for sediments or tracers carried by the flow.

The momentum equations in the *X*-axis and *Y*-axis are expressed as follows:

$$\frac{\partial U}{\partial t} + U\frac{\partial U}{\partial x} + v\frac{\partial U}{\partial y} + \frac{w}{h}\frac{\partial U}{\partial \sigma} - fV = -\frac{1}{\rho^0}P_\chi + F_\chi + M_\chi + \frac{1}{h^2}\frac{\partial}{\partial \sigma}\left(v_V\frac{\partial u}{\partial \sigma}\right)$$

$$\frac{\partial V}{\partial t} + U\frac{\partial V}{\partial x} + v\frac{\partial V}{\partial y} + \frac{w}{h}\frac{\partial V}{\partial \sigma} - fU = -\frac{1}{\rho^0}P_y + F_y + M_y + \frac{1}{h^2}\frac{\partial}{\partial \sigma}\left(v_V\frac{\partial v}{\partial \sigma}\right) \qquad (2)$$

where the horizontal pressures P_x and P_y can be calculated using the Boussineq approximation. The depth-averaged continuity equation is expressed as:

$$\frac{\partial \zeta}{\partial t} + \frac{\partial [h\bar{U}]}{\partial x} + \frac{\partial [h\bar{V}]}{\partial y} = S \qquad (3)$$

where S_i represents the movement or exchange of seabed sediment.

The modeling results were then validated by comparing them with field observation data. In this study, the validation used the Root Mean Square Error (RMSE) method, a statistical metric used to measure the average squared difference between predicted values and actual conditions [26]. The RMSE formula is presented in Equation 5 [26].

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Mi - Oi)^2} \qquad (5)$$

where: *n* is the number of data points, M_i is the value predicted the model, and O_i is the value observed in the field.

3. Results

3.1. Model Calibration and Validation

To ensure the accuracy of the modeling results, calibration and validation were performed using sea level data measured at Wonorejo Station. The calibration process was onducted in stages by adjusting several key hydrodynamic parameters to achieve the best agreement. This process aimed to find the combination of parameters that best match the simulation results with the observational data. The hydrodynamic parameters used in the modeling are presented in Table 3.1.

where *S* represents the contribution per unit area resulting from the addition or removal of water mass.

The sediment transport equation is expressed as follows [25]:

$$\frac{\partial c_i}{\partial t} + \frac{\partial uc_i}{\partial x} + \frac{\partial vc_i}{\partial y} - \frac{\partial}{\partial x}\left(\varepsilon_{s,x,i}\frac{\partial c_i}{\partial x}\right) - \frac{\partial}{\partial y}\left(\varepsilon_{s,y,i}\frac{\partial c_i}{\partial y}\right) = Si \qquad (4)$$

Table 3.1. Configuration of Physical Model Parameters

Parameter	Value	Unit
Manning	0.03	
Time step (Δt)	0.1	[*min*]
Gravity	9.81	[m/s^2]
Water density	1025	[kg/m^3]
Saliniy	33.23	[*ppt*]
Temperature	30.33	[°C]
Horizontal eddy	10	[m^2/s]
viscosity	1	[m^2/s]
Horizontal eddy diffusivity		
Sediment concentration	0.131	[kg/m^3]
Grain size D$_{50}$	0.393	[mm]
Morphological scale factor	12	
Spin-up interval	1440	[min]
Number of layers	1	

Subsequently, astronomical phase correction was applied to the main tidal components. This step aimed to align the timing of peak tides between the model results and observations. As a result, an RMSE of 0.23 and Mean Absolute Percentage Error of 11.75% were obtained.
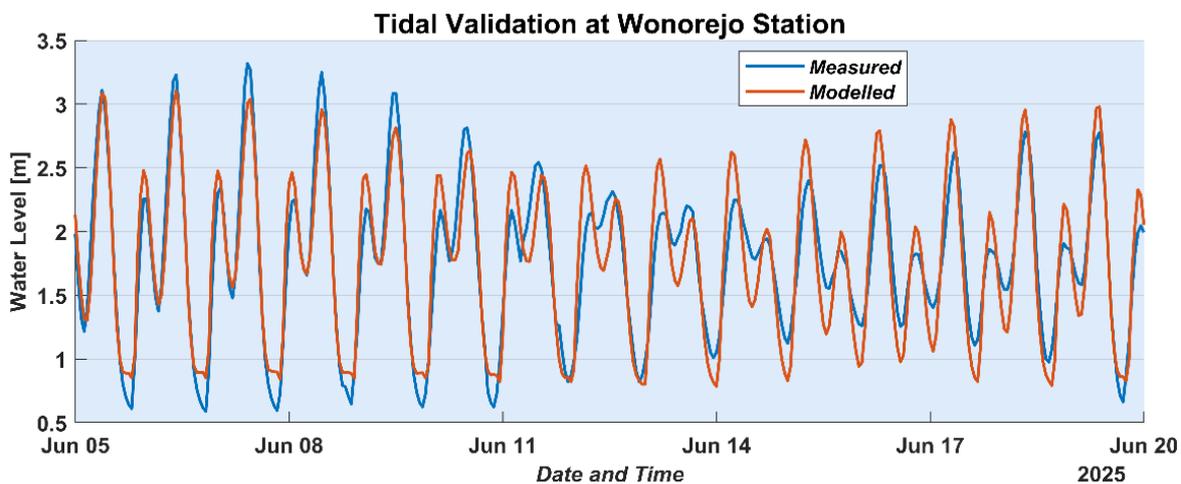
Figure 3. Tidal validation at Wonorejo Station

Figure 3 shows a comparison between the modeled and observed sea levels at Wonorejo Station during the period of June 6–20, 2024. In general, the fluctuation patterns of the model follow the observational trends, although the model does not fully capture the transitional characteristics of the tides in the field. This can be seen from the correspondence of rising and falling water levels.

3.2. Nested Grid

Nested grids were implemented to focus the modeling on the reclamation area. The grid resolution used ranged from approximately 32.68 m to 78.50 m using the UTM Zone 49 S projection. A finer grid resolution was applied to accurately resolve flow dynamics in areas requiring high precision around the planned reclamation site.

In the model details, six primary channel points were designated as observation locations, as shown in Figure 4 (a) and (b). These channels represent the main pathways for circulation between land and sea, and vice versa. The hydrodynamic model constructed using the fine grid subsequently served as the basis for analyzing changes in hydrodynamics and channel discharge.
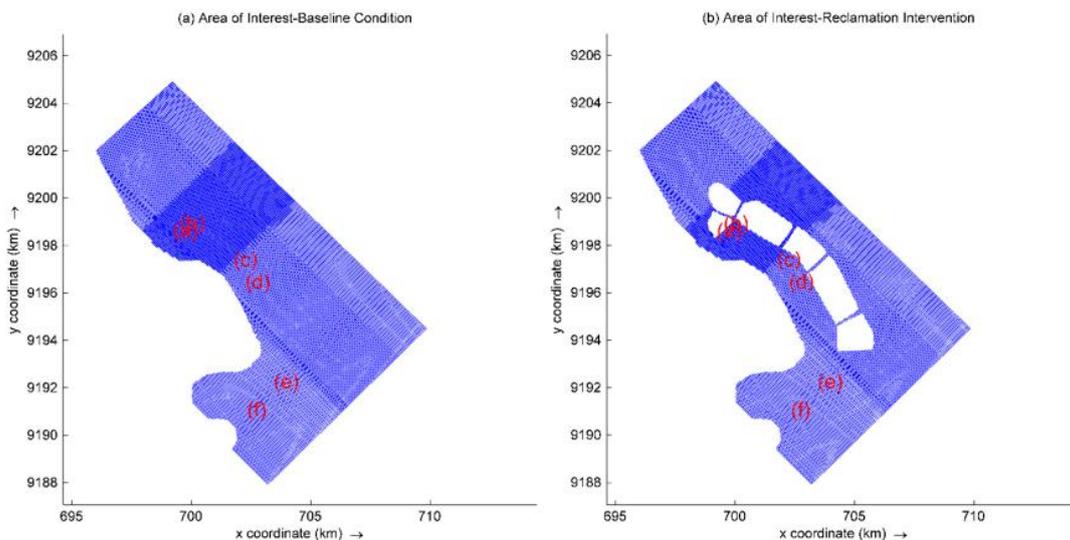

Figure 4. Detailed model scenario: (a) baseline condition; (b) reclamation intervention

The observation points used for analysis are listed in Table 3.2, with their locations corresponding to those shown in Figure 4.

Table 3.2. Observation Points

Code	Observation Location
(a)	Kali Lebak Indah
(b)	Kali Kepiting
(c)	Kali Dami
(d)	Kali Bokor
(e)	Kali Wonokromo
(f)	Kali Wonorejo

The modeling in the detailed model was conducted for two main conditions: high tide phase and ebb tide phase. Each condition was simulated for the existing scenario (baseline condition) and the post-reclamation scenario (reclamation intervention). The results were used to evaluate changes in current velocity, sediment transport, and discharge in the primary channels.

3.3. Current Velocity Characteristics

The distribution of current velocity from the modeling results during the spring tide on June 6, 2024, is shown in Figure 5. Two scenarios were simulated: (a) baseline conditions and (b) with reclamation intervention. Before reclamation, the maximum current velocity reached 0.375 m/s. The current vectors indicate a dominant flow from the sea toward the land, representing natural circulation following the coastal morphology. After reclamation, noticeable changes in current characteristics were observed. The addition of new land in the reclamation area led to a redistribution of current velocity, with a decrease in the maximum velocity to 0.364 m/s.
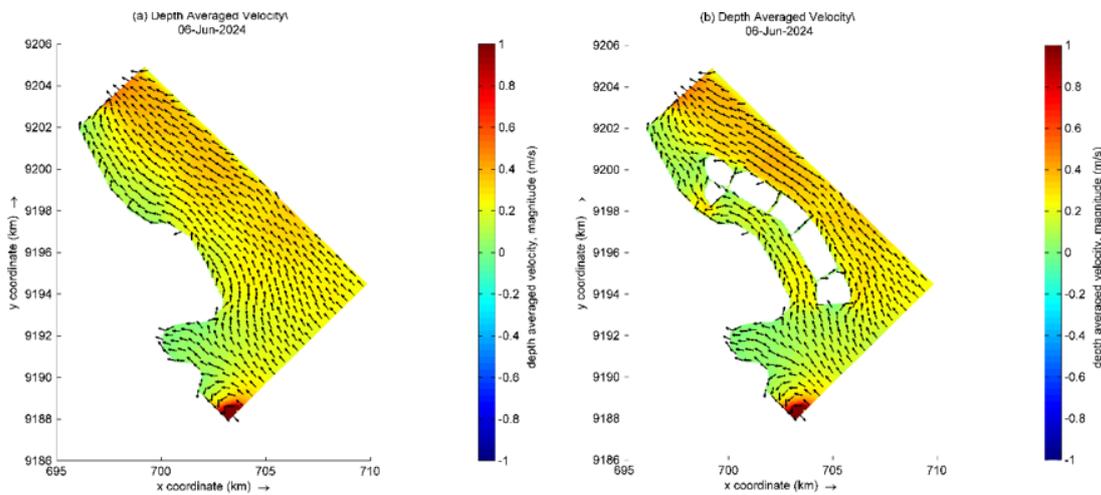

Figure 5. Spatial pattern of velocity during high tide phase
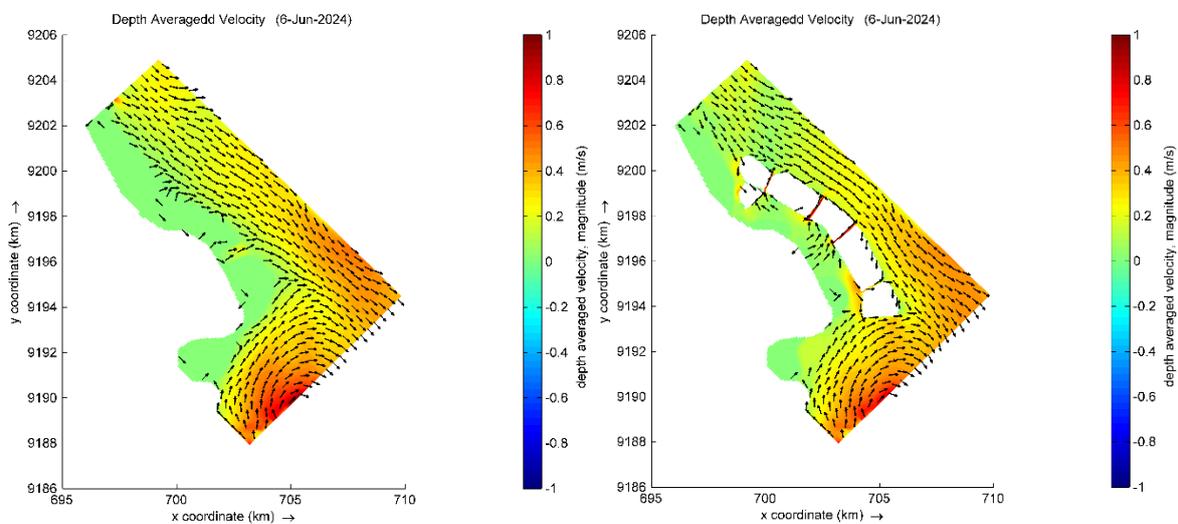

Figure 6. Spatial pattern of velocity during ebb phase

Subsequently, the visualization during the ebb tide is presented in Figure 6. Based on the results, the planned reclamation in Pamurbaya also leads to a decrease in current velocity during the ebb phase. In the pre-reclamation conditions, the velocity distribution ranged from 0 to 0.36 m/s. After reclamation, velocities ranged from 0.022 to 0.324 m/s, indicating a slight weakening of the maximum currents compared to the pre-reclamation condition.

3.4. Sedimen Transport

The numerical modeling results demonstrate the influence of reclamation on sediment transport patterns and distribution within the study area. The spatial modeling results are presented in Figure 7. It illustrates the cumulative erosion and sedimentation distribution under both baseline and post-reclamation conditions. Before reclamation, erosion and sedimentation processes occurred more evenly and were aligned with the direction of the natural tidal currents. Following the addition of reclaimed land, the spatial distribution of sediments shifted. Tidal flows and sediment materials followed new pathways formed due to morphological changes in the reclamation area.
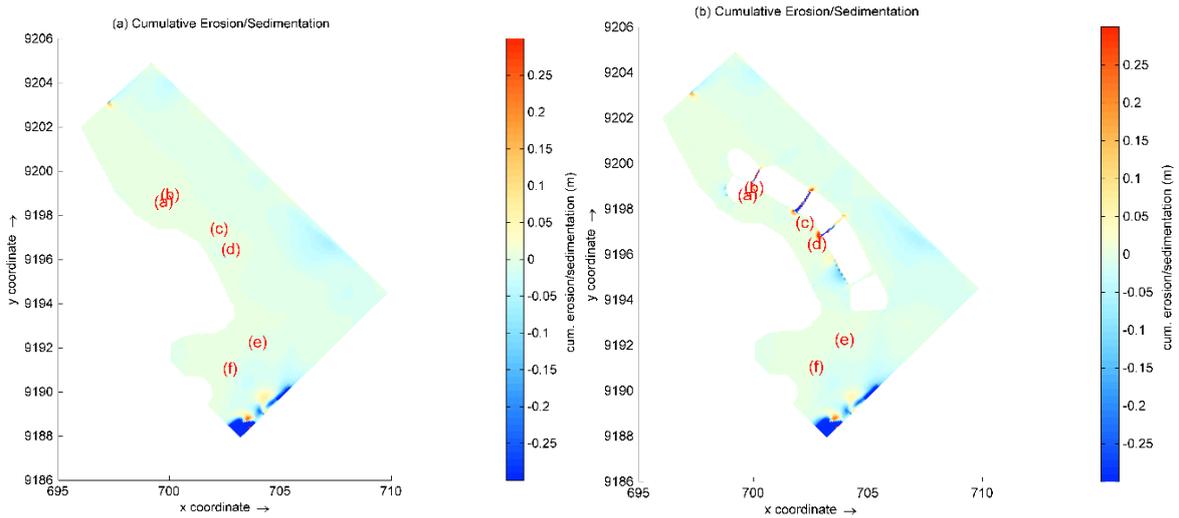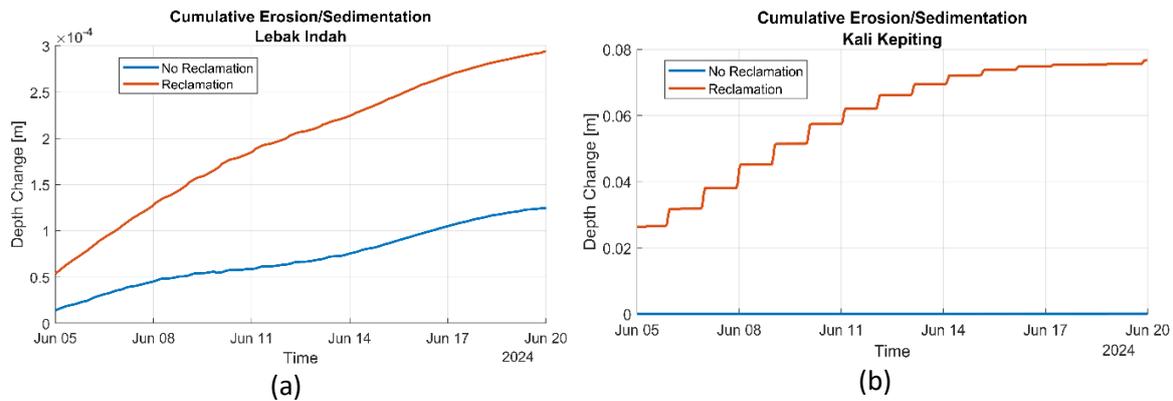

Figure 7. Cumulative erosion and sedimentation patterns in the reclamation area

To understand the spatial response of sediments to reclamation interventions, an analysis was conducted around the mouths of the primary channels. Each location exhibited showed different morphological responses depending on its relative position to the main currents and the reclamation area. The analysis was carried out by comparing cumulative erosion and sedimentation graphs, as shown in Figure 8.
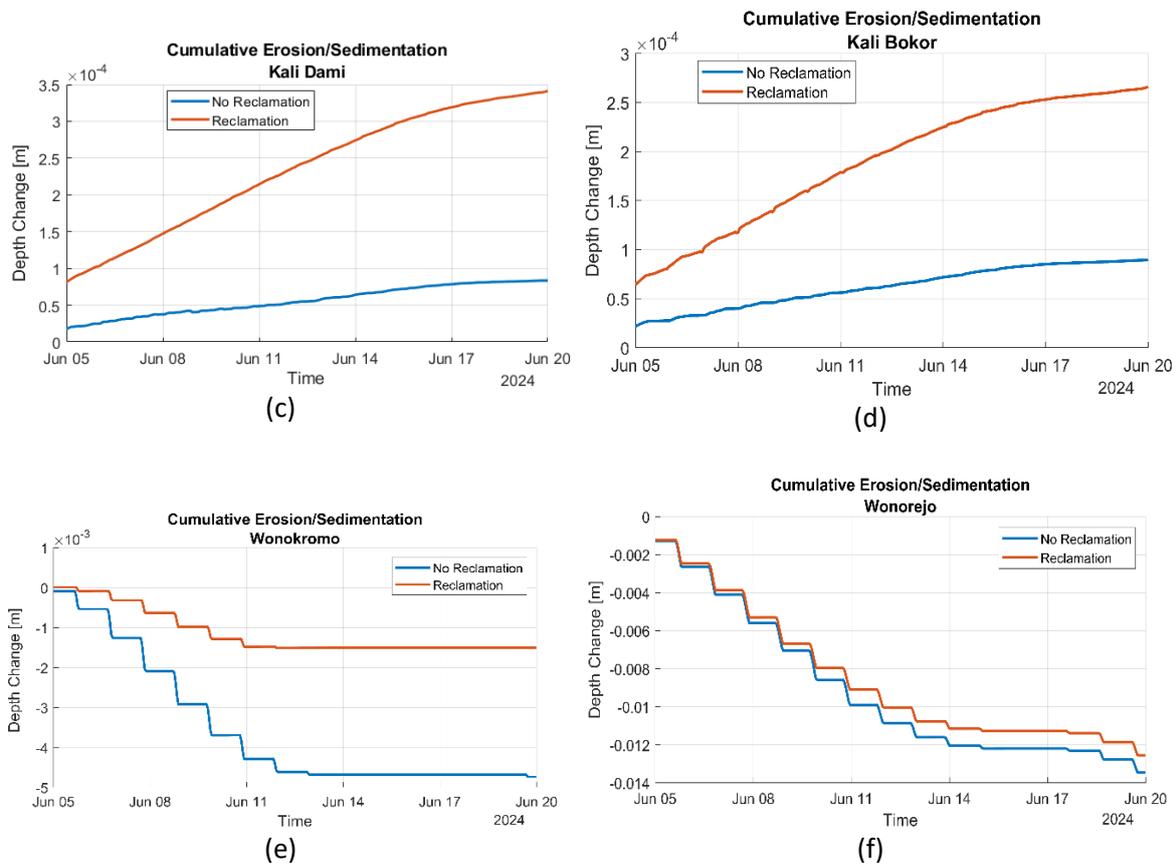
Figure 8. Cumulative erosion-sedimentation at observation point

The graph shows that without reclamation, the sediment transport patterns are quite varied. In the Kali Kepiting area, sediment conditions remain stable without significant depth changes. Other locations, such as Lebak Indah, Kali Dami, and Kali Bokor, experience consistent increases in sedimentation over time. In contrast, erosion occurs in Kali Wonokromo and Wonorejo.

After reclamation intervention, sedimentation occurs across all locations. The rate of depth change varies across each channel. The smallest change in depth is observed in Kali Lebak Indah, with a sediment thickness increase of 0.17×10^{-3} m. Meanwhile, a more significant change occurs in Kali Kepiting, with a sediment thickness increase of 0.077 m. Other observation points also show sedimentation with respective thicknesses of: Kali Dami 0.26×10^{-3} m, Kali Bokor 0.18×10^{-3} m, Wonokromo 0.323×10^{-2} m, and Wonorejo 0.907×10^{-3} m.

Overall, reclamation alters the natural balance between sediment inflow and outflow.

Moreover, the morphological changes due to reclamation may cause long-term sediment redistribution. This redistribution could potentially affect coastal stability and the depth of surrounding waters.
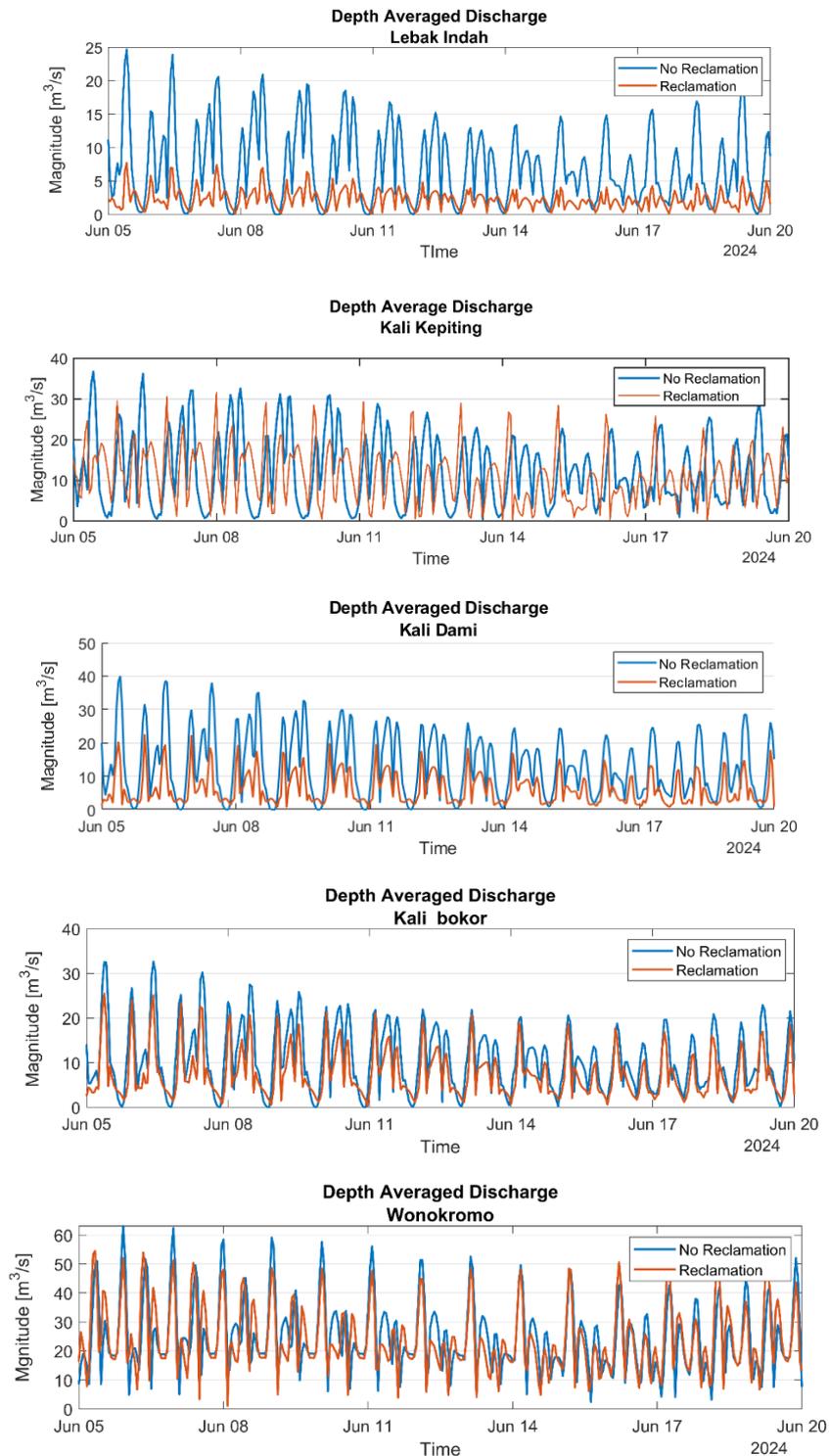
3.5. Channel discharge

Flow discharge is a key parameter, representing the volume of water entering and leaving through the channels. The modeling results at the observation points indicate variations in discharge based on the depth-averaged discharge magnitude. This value represents the average discharge passing through a cross-section (inflow and outflow).

Discharge fluctuations follow the tidal cycle, with noticeable differences between the two scenarios. In most locations, maximum discharge values in the existing condition are higher than in the reclamation scenario. Variations at each location indicate that changes in discharge are strongly influenced by channel position and connectivity to the planned

reclamation area.

The simulation results show that reclamation activities significantly affect tidal discharge across the study area. Figure 9 compares the depth-averaged discharge in each channel. Post-reclamation values are consistently lower than those observed under existing conditions. Both discharge amplitude and variability decrease, especially during peak flood and ebb tides.
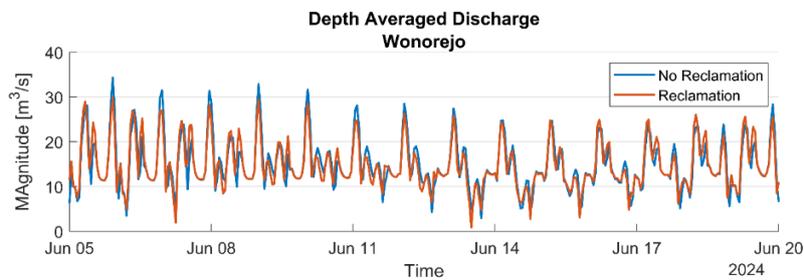
Depth Averaged Discharge
Lebak Indah

Depth Average Discharge
Kali Kepiting

Depth Averaged Discharge
Kali Dami

Depth Averaged Discharge
Kali bokor

Depth Averaged Discharge
Wonokromo

Figure 9. Depth averaged discharge at observation point

4. Discussion

The hydrodynamic modeling results indicate that the proposed reclamation in the Pamurbaya area can alter local flow behavior. The maximum current velocity under existing conditions is approximately 0.375 m/s, decreasing slightly to 0.364 m/s after reclamation. While numerically small, the spatial distribution of currents reveals changes in circulation patterns around the reclaimed zone. This reflects a redistribution of flow energy due to modifications of the seabed and shoreline. Similar effects have been reported in other coastal systems, such as Kendari Bay and the Bohai Sea, where reclamation reduced tidal circulation and tidal prism.

In terms of sediment dynamics, sediment transport occurred relatively uniformly before reclamation, following natural tidal patterns. After reclamation, sedimentation occurred throughout the study area, but with spatially varying magnitudes. Kali Kepiting showed the greatest positive depth change (0.077 m), while Kali Lebak Indah exhibited the smallest (0.17×10^{-3} m). These findings indicate that reclamation can disrupt the natural balance of sediment transport and may lead to localized accretion or erosion over time.

Depth-averaged discharge analysis shows reductions of 1–69% across all channels. The most significant decrease occurred at Kali Lebak Indah. Channels whose outlets are not directly facing the reclamation area, such as Wonokromo and Wonorejo, experienced smaller reductions. This spatial variability highlights the importance of each channel's relative position. Hydraulic connectivity to the modified coastline also plays a key role in determining the hydrodynamic response. Consistent findings have been reported elsewhere. Reclamation activities in these locations significantly reduced the volume of tidal exchange. For example, a decrease in the tidal prism was observed in Sanmen Bay. Tidal and flood discharges are closely related to the magnitude of the tidal prism, which in turn affects coastal environmental and ecological conditions.

From a practical perspective, reduced discharge can lower water-exchange efficiency in aquaculture ponds in the Pamurbaya region. Lower discharge prolongs the time required for pond filling and drainage. This may potentially reduce aquaculture productivity. Consequently, hydrodynamic changes induced by reclamation have both physical and socio-economic implications for coastal communities relying on traditional aquaculture.

This study acknowledges certain limitations. The discharge analysis only represents total inflow and outflow volumes. It does not consider dominant flow directions or vertical circulationFuture research should employ three-dimensional modeling to better understand post-reclamation flow dynamics. Alternatively, discharge vector analysis could be used to gain additional insights.

5. Conclusions

The Delft3D model successfully reproduced the hydrodynamic response of the Pamurbaya coastal system to reclamation. Model results indicate a reduction in maximum current velocity from 0.375 m/s to 0.364 m/s, accompanied by spatial redistribution of sediment transport. The greatest depth change occurred in Kali Kepiting (0.077 m), while the smallest was observed in Kali Lebak Indah (0.17×10^{-3} m). Depth-averaged discharge decreased by 1–69% across all tidal channels, with the most pronounced reductions near the reclamation boundaries.

These findings quantitatively demonstrate the coupled effects of reclamation on hydrodynamic circulation, sediment redistribution, and channel discharge, providing a new reference for coastal systems characterized by interconnected estuaries, tidal channels, and aquaculture ponds—a setting rarely addressed in previous reclamation studies.

The study establishes a scientific basis for sustainable reclamation planning and coastal management, highlighting the necessity of maintaining hydraulic connectivity to preserve tidal exchange and water quality. Periodic dredging and long-term monitoring are recommended to maintain channel flow capacity and mitigate long-term morphodynamic impacts. Further research using three-dimensional and vector-based modeling is encouraged to better elucidate post-reclamation flow–sediment interactions and vertical exchange processes in shallow estuarine environments.

References

[1] M. S. Sarda Dewi, S. Damarnegara, and U. Lasminto, "Model Numerik Disipasi Gelombang oleh Model Vegetasi Menggunakan Program XBeach," Jurnal Aplikasi Teknik Sipil, vol. 19, no. 2, p. 117, Jul. 2021, doi: 10.12962/j2579-891X.v19i2.8652.

[2] H. A. Rachman, I. G. Hendrawan, and I. D. N. N. Putra, "Studi Transpor Sedimen di Teluk Benoa Menggunakan Pemodelan Numerik," Jurnal Kelautan: Indonesian Journal of Marine Science and Technology, vol. 9, no. 2, p. 144, Nov. 2016, doi: 10.21107/jk.v9i2.1617.

[3] BPS Kota Surabaya, "Statistik Daerah Kota Surabaya 2024," Surabaya, Sep. 2024.

[4] A. Rosytha, "Studi Dampak Pengembangan Pemukiman di Wilayah Pesisir Surabaya Timur," Agregat, vol. 1, no. 1, pp. 38–43, Nov. 2016.

[5] Pemerintah Indonesia, "Peraturan Presiden Republik Indonesia No. 66 Tahun 2022 tentang RTR KSN Gerbangkertosusila," 2022.

[6] M. H. A. G. Djamil, M. R. Gumilang, and D. Hantono, "Dampak Reklamasi terhadap Lingkungan dan Perekonomian Warga Pesisir di Jakarta Utara," Jurnal Pembangunan Wilayah dan Kota, vol. 18, no. 3, pp. 296–303, Sep. 2022, doi: 10.14710/pwk.v18i3.35139.

[7] D. Sengupta, R. Chen, and M. E. Meadows, "Building beyond land: An Overview of Coastal Land Reclamation in 16 Global Megacities," Applied Geography, vol. 90, pp. 229–238, Jan. 2018, doi: 10.1016/j.apgeog.2017.12.015.

[8] P. Tian et al., "Impacts of Reclamation Derived Land Use Changes on Ecosystem Services in A Typical Gulf of Eastern China: A Case Study of Hangzhou Bay," Ecol Indic, vol. 132, p. 108259, Oct. 2021, doi: 10.1016/j.ecolind.2021.108259.

[9] S. Liu, G. Li, S. Liu, L. Xing, Y. Pan, and D. Yu, "Impacts of Reclamation on Hydrodynamic and Suspended Sediment Transport in the Bohai Sea," J Geophys Res Oceans, vol. 129, no. 1, Jan. 2024, doi: 10.1029/2023JC020570.

[10] Y. Zhong et al., "Modeling the Impacts of Land Reclamation on Sediment Dynamics in a Semi-Enclosed Bay," J Mar Sci Eng, vol. 12, no. 9, p. 1633, Sep. 2024, doi: 10.3390/jmse12091633.

[11] I. Imalpen, T. Pratono, Rastiana, A. F. Koropitan, and A. Y. YUliardi, "Hydrodynamics Modeling in Kendari Bay, Southeast Sulawesi, Indonesia," International Jaournal of Remote Sensing and Earth Sciences, vol. 21, pp. 54–65, 2024, doi: DOI:10.30536/j.ijreses.2024.v21.a3906.

[12] P. Shi, W. Yang, X. Xu, and F. Zhang, "Response of hydrodynamic environment to land reclamation in Sanmen Bay, China

over the last half-century," Front Mar Sci, vol. 11, Aug. 2024, doi: 10.3389/fmars.2024.1448565.

[13] M. Petti, S. Pascolo, S. Bosa, and N. Busetto, "On the Tidal Prism: The Roles of Basin Extension, Bottom Friction and Inlet Cross-Section," J Mar Sci Eng, vol. 9, no. 1, p. 88, Jan. 2021, doi: 10.3390/jmse9010088.

[14] W. Herdianti, "Pemodelan Sedimentasi untuk Perencanaan Kawasan Pantai Timur Surabaya," Tesis, Institut Teknologi Sepuluh Nopember, Surabaya, 2018.

[15] E. Aprilia and D. G. Pratomo, "Pemodelan Hidrodinamika 3-Dimensi Pola Persebaran Sedimentasi Pra dan Pasca Reklamasi Teluk Jakarta," Jurnal Teknik ITS, vol. 6, no. 2, pp. 2337–3520, 2017.

[16] D. Sengupta et al., "Mapping 21st Century Global Coastal Land Reclamation," Earths Future, vol. 11, no. 2, Feb. 2023, doi: 10.1029/2022EF002927.

[17] L. Liu, D. Yuan, X. Li, and Y. Mao, "Influence of reclamation on the water exchange in Bohai Bay using trajectory clustering," Stochastic Environmental Research and Risk Assessment, vol. 37, no. 9, pp. 3571–3583, Sep. 2023, doi: 10.1007/s00477-023-02463-8.

[18] P. Saha and U. K. Navera, "A Study on Hydrodynamic and Short Term Flash Flood Analysis of Surma River Using Delft3D Model," in Proceedings of the 3 rd International Conference on Civil Engineering for Sustainable Development, Bangladesh: ICCESD, 2016, pp. 634–646.

[19] BIG, "Data Garis Pantai Indonesia 2022." [Online]. Available: https://geoservices.big.go.id/portal/home/item.html?id=2e108871cd2743d593da4c086ad57aa4

[20] M. Irmawan, M. H. Imaaduddiin, R. R. R. Alam, A. N. Refani, and A. N. Aini, "Hydrodynamic Analysis-Based Modeling of Coastal Abrasion Prevention (Case Study: Pulau Baai Port, Bengkulu)," Applied Sciences, vol. 14, no. 2, p. 940, Jan. 2024, doi: 10.3390/app14020940.

[21] D. Fitriana, M. P. Patria, and E. Kusratmoko, "Karakteristik Pasang Surut Surabaya Diamati Selama 5 Tahun (2015-2020)," JGISE: Journal of Geospatial Information Science and Engineering, vol. 5, no. 1, p. 1, Jun. 2022, doi: 10.22146/jgise.72856.

[22] ECMWF, "ERA5 Reanalysis Datasets." [Online]. Available: https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5

[23] Copernicus Marine Service, "Global Ocean Physics Analysis and Forecast." [Online]. Available: https://data.marine.copernicus.eu/products

[24] R. L. Jenkins, C. G. Smith, D. L. Passeri, and A. M. Ellis, "Model Sensitivity Analysis for Coastal Morphodynamics: Investigating Sediment Parameters and Bed Composition in Delft3D," J Mar Sci Eng, vol. 12, no. 11, p. 2108, Nov. 2024, doi: 10.3390/jmse12112108.

[25] Deltares, "Simulation of Multi Dimension Hydrodynamic Flows and Transport Phenomena, Including Sediments," 2024, The Netherlands.

[26] H. de Pablo, J. Sobrinho, M. Garcia, F. Campuzano, M. Juliano, and R. Neves, "Validation of the 3D-MOHID Hydrodynamic Model for the Tagus Coastal Area," Water (Basel), vol. 11, no. 8, p. 1713, Aug. 2019, doi: 10.3390/w11081713.