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Impact of Giant Sea Wall Construction on Surrounding Current Patterns and Abrasion Rates: A Numerical Hydrodynamic Simulation of Marine Dynamics

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ABSTRACT

The increasing trend of global sea level rise and localized land subsidence in Jakarta Bay has led to the consideration of large-scale coastal protection measures, yet the hydrodynamic consequences of such infrastructure remain insufficiently quantified. This study evaluates the impact of the Giant Sea Wall (GSW) on local current patterns and coastal morphology using a validated three-dimensional numerical simulation. The study focuses on a 25 × 30 km domain in Jakarta Bay, integrating high-resolution bathymetric data (BATNAS), wind time series from BMKG, and tidal harmonic components from BIG. A finite volume scheme on an unstructured mesh is applied to solve the shallow water equations, with validation showing a correlation coefficient of 0.92 against observed tidal data from Pushidrosal. Simulation results suggest that current velocities may increase to approximately 0.62 m/s near structural termini, potentially inducing localized scouring and increased abrasion rates in down-drift areas, with a projected shoreline recession of approximately 3.5 m/year under modeled conditions. These findings indicate that while the GSW can reduce tidal flooding in protected urban areas, it may also redistribute hydrodynamic energy toward adjacent coastal zones, increasing erosion risks. Adaptive strategies, including sediment nourishment and permeable structural designs, should therefore be considered. Future research is recommended to incorporate fully coupled morphodynamic models to improve long-term projections.

Keywords: *Giant sea wall, Hydrodynamic modeling, Numerical simulation, Coastal abrasion, Jakarta Bay, Sediment transport, Sea-level rise, Coastal protection*

INTRODUCTION

Coastal regions across the Indonesian archipelago, particularly along the northern Java corridor, are increasingly affected by the combined impact of global sea-level rise and localized land subsidence, which in several metropolitan areas reaches rates of 10–20 cm per annum (Susilo, 2023). This condition

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has significantly reduced the effectiveness of conventional urban drainage systems, as land elevations in some areas are now below the mean high-water level, resulting in frequent tidal flooding that affects socio-economic activities in coastal cities. This condition has significantly reduced the effectiveness of conventional urban drainage systems, as land elevations in some areas are now below the mean high-water level, resulting in frequent tidal flooding that affects socio-economic activities in coastal cities.

The Giant Sea Wall (GSW) has been proposed as a large-scale structural adaptation measure intended to establish a protection boundary for critical economic zones. While this approach aims to reduce the impact of wave energy on vulnerable shorelines, previous studies indicate that large vertical coastal structures can reflect a portion of incoming wave energy back into the water column (Tang, 2023). This reflection process may generate localized turbulence near the base of the structure, potentially influencing bathymetric stability and altering seabed morphology over time. From a hydrodynamic perspective, the redistribution of flow energy must be considered carefully, as fluid systems tend to adjust dynamically to structural modifications within their domain.

Theoretical and empirical studies suggest that the introduction of large coastal structures, whether shore-parallel or shore-perpendicular, can alter the dynamic equilibrium of sediment transport and marine circulation patterns. Observational data from the Indonesian Navy's Center for Hydrography and Oceanography (Pushidrosal, 2022) indicate that shallow-water circulation is strongly influenced by seabed configuration and shoreline geometry. Consequently, the implementation of the GSW may modify current velocity distributions within Jakarta Bay. Longshore currents, which previously moved parallel to the coastline, may be partially obstructed, potentially leading to the formation of localized circulation patterns or eddies near structural boundaries. Numerical simulations conducted by the Coastal Engineering Center (Balai Teknik Pantai, 2021) indicate that current velocities at structural extremities may increase significantly compared to baseline conditions, which can enhance localized scouring processes. This increase in flow velocity may facilitate the transport of fine-grained sediments away from the littoral zone, highlighting the need to assess potential impacts on seabed stability. .

Recent research highlights the importance of high-resolution bathymetric data in improving the reliability of hydrodynamic simulations. Studies have shown that relatively small uncertainties in bathymetric input can result in substantial deviations in simulated current patterns (Hidayat, 2023). The National Bathymetry dataset (BATNAS) provided by the Geospatial Information Agency (BIG) offers a high-resolution representation of seabed topography for Indonesian waters (Badan Informasi Geospasial (BIG), 2023). In addition, wind data from the Meteorology, Climatology, and Geophysics Agency (BMKG) play a critical role in defining surface current dynamics, while tidal harmonic data from BIG provide essential boundary conditions for numerical modeling. The integration of these datasets enables the development of hydrodynamic models with improved accuracy and predictive capability. However, validation using observational data, such as tide gauge measurements, remains essential to ensure that model outputs adequately represent real-world conditions.

Despite extensive literature on the effectiveness of large coastal structures in flood mitigation, there remains a notable gap in understanding their long-term impact on abrasion processes in adjacent, unprotected coastal areas. One important mechanism is the redistribution of hydrodynamic energy, where the reduction of wave energy in protected zones may be accompanied by increased energy concentration in surrounding areas. This process can contribute to changes in sediment transport pathways. Reports from the Ministry of Marine Affairs and Fisheries (Kementerian Kelautan dan Perikanan (KKP), 2022) indicate that abrasion rates near coastal structures may increase within several years after construction due to these altered sediment dynamics. In down-drift areas, the interruption of sediment supply can lead to progressive shoreline retreat. Such conditions may have socio-economic implications, particularly for coastal communities that depend on stable shoreline conditions.

The reliability of numerical simulations depends on the quality of input data used to represent physical conditions. Structural parameters for the GSW, including geometry and elevation, are derived from technical guidelines issued by the Ministry of Public Works and Housing (Kementerian Pekerjaan Umum dan Perumahan Rakyat (PUPR), 2021). Environmental considerations are also relevant, as highlighted by the Ministry of Environment and Forestry (Kementerian Lingkungan Hidup dan Kehutanan (KLHK), 2020), which emphasizes the potential impacts of coastal infrastructure on mangrove ecosystems. In addition, data from the National Disaster Management Authority (Badan Nasional Penanggulangan Bencana (BNPB), 2023) indicate that shoreline changes associated with abrasion may influence coastal risk levels. The integration of these data sources supports a more comprehensive evaluation of the potential impacts of GSW construction.

This study aims to develop a predictive model to assess the impact of GSW construction on current circulation patterns and coastal abrasion rates using a validated three-dimensional numerical simulation framework. The novelty of this research lies in the integration of hydrodynamic and sediment transport processes using high-resolution datasets, including BATNAS, BMKG, and tidal data from BIG. The model also incorporates multi-year wind data to represent seasonal variability associated with monsoonal systems. The simulation results are expected to provide technical insights into areas that may be vulnerable to increased abrasion. Through this approach, the study seeks to contribute to the development of more informed coastal management strategies.

METHODS

This study employs a quantitative approach based on three-dimensional (3D) hydrodynamic numerical modeling. The simulation framework is designed to represent the interaction between the Giant Sea Wall (GSW) and marine physical processes, with the aim of evaluating changes in current circulation patterns and coastal morphological responses. The model applies a finite-volume scheme on an unstructured mesh to solve the shallow water equations derived from the Reynolds-averaged Navier–Stokes formulation. The structural configuration of the GSW is defined according to the Technical Planning Standards for Coastal Protection Structures issued by the Ministry of Public Works and Housing (Kementerian Pekerjaan Umum dan Perumahan Rakyat (PUPR), 2021). Numerical stability is maintained by applying the Courant–Friedrichs–Lewy (CFL) condition throughout the simulation.

The study area is located in Jakarta Bay, DKI Jakarta Province, within a spatial domain of approximately 25 × 30 km, which corresponds to the implementation area of the *National Capital Integrated Coastal Development* (NCICD) project.

a. **Data Population**: The model domain includes the entire water column and seabed within Jakarta Bay and its surrounding coastal areas, extending toward the southern region of the Thousand Islands (Kepulauan Seribu).
b. **Data Sampling**: Bathymetric data were obtained from the BATNAS dataset provided by the Badan Informasi Geospasial (BIG), which has a native spatial resolution of 6 arc-seconds (approximately 180 m). These data were interpolated into a finer computational grid (~5 m in localized areas) to improve numerical stability and spatial representation within the simulation domain. The dataset also includes harmonic tidal components derived from the Tanjung Priok tide gauge station and meteorological wind data obtained from the Badan Meteorologi, Klimatologi, dan Geofisika (BMKG) for the period 2015–2025.

The selection of the study area is based on its high vulnerability to combined sea level rise and land subsidence. The use of BATNAS data ensures that the seabed geometry is represented with sufficient accuracy for hydrodynamic simulation.

The modeling workflow begins with preprocessing, including the digitization of GSW structural layouts and the generation of an unstructured computational mesh. Mesh refinement is applied near structural boundaries to capture localized flow acceleration and eddy formation. Two simulation scenarios are considered: (1) baseline conditions without the GSW and (2) post-construction conditions.

Model validation is conducted by comparing simulated water levels with observed tidal data obtained from the Pushidrosal station at Tanjung Priok. Validation metrics include the correlation coefficient (R), Root Mean Square Error (RMSE), and mean bias error (MBE). The validation period covers a representative tidal cycle, and boundary conditions are defined using harmonic tidal constituents (M2, S2, N2, K2, K1, O1, P1, M4, MS4). Model calibration is performed by adjusting bed roughness parameters (Manning's n) based on sediment characteristics.

The hydrodynamic simulations are performed using a numerical modeling suite such as MIKE 21 or Delft3D, which is widely applied for coastal and shallow water studies. The input datasets include:

a. **Bathymetric Data**: BATNAS dataset (6 arc-second resolution) used to define seabed geometry and the computational domain (BIG, 2023).
b. **Tidal Data**: Harmonic tidal components used as open boundary conditions.
c. **Shoreline Data**: Indonesian Topographic Maps (RBI) at a scale of 1:25,000 used to define coastal boundaries (BIG, 2022).
d. **Sediment Data**: Seabed sediment distribution data from the Ministry of Marine Affairs and Fisheries (KKP) used for bed roughness parameterization.

These datasets were selected based on their consistency with national geospatial standards and their applicability to hydrodynamic modeling.

Data acquisition followed formal procedures through the national One Map Policy portal. Spatial analysis was conducted using Geographic Information Systems (GIS) to quantify differences in abrasion rates between scenarios. Model performance was evaluated using statistical metrics, including RMSE and skill score, following established guidelines (UNESCO, 2022). These metrics indicate the level of agreement between simulated and observed data.

The governing equations of the model are based on the conservation of mass and momentum in shallow water systems. The momentum equation in the x-direction is expressed as:

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} - fv = -g\frac{\partial \eta}{\partial x} - \frac{gu\sqrt{u^2+v^2}}{C^2 h}$$

Where:

u, v = lateral current velocity components (m/s)
g = gravitational acceleration (9.81 m/s^2)
η = sea surface elevation (m)
C = Chezy coefficient for bed shear stress
f = Coriolis parameter derived from Earth's rotation

The application of these mathematical frameworks is essential for calculating the hydrodynamic pressure loads exerted upon the Giant Sea Wall interface. The bed friction constant (C) is locally calibrated based on the benthic sediment characteristics provided by the KKP maritime mapping.

RESULTS

1. Post-Construction Hydrodynamic Flow Perturbations

The numerical simulation results indicate substantial changes in current velocity distribution within Jakarta Bay following the implementation of the Giant Sea Wall (GSW). Based on tidal boundary forcing derived from the Tanjung Priok station (BIG, 2023), simulated peak tidal conditions show that water flow becomes increasingly concentrated near structural openings. Current velocities in open-water areas, which ranged between 0.15–0.25 m/s under baseline conditions, increased to approximately 0.55 m/s near the wall termini in the post-construction scenario. This localized concentration of flow contributes to the formation of circulatory eddies and may increase sediment mobilization in adjacent shallow-water zones. The simulation results suggest that the presence of large coastal barriers modifies local hydrodynamic pathways and increases flow concentration at structural discontinuities.

a) Tidal Current Vector Analysis

Spatial analysis indicates that the GSW configuration produces reduced flow velocities within the enclosed retention basin while generating intensified currents along the seaward interface. Model outputs suggest an estimated tidal phase shift of approximately 15–20 minutes under simulated conditions. The dominant longshore current, previously oriented from east to west, was observed to partially deflect seaward after interacting with the wall boundary. Validation against Pushidrosal tidal observations yielded a correlation coefficient of 0.92, indicating acceptable agreement between observed and simulated flow behavior.

b) Impact of Flow Velocity on Bathymetric Integrity

Model outputs indicate that current velocities exceeding 0.4 m/s near structural foundations may contribute to localized scouring processes, particularly in areas characterized by silty-sand seabed material. Comparative analysis between baseline bathymetric conditions and projected simulations suggests a potential seabed lowering of approximately 1.2 m near the structural toe over a five-year operational period. These results indicate possible implications for structural maintenance and highlight the importance of continued bathymetric monitoring.

2. Quantitative Assessment of Abrasion Rates and Shoreline Recession

Abrasion rates were estimated by comparing net sediment transport between baseline and post-construction scenarios. Historical sediment transport data from KKP (2022) were used as calibration references. Simulation outputs indicate that peripheral coastal sectors outside the protected zone may experience an estimated increase in abrasion rates of up to 250%, with projected shoreline recession reaching approximately 3.5 m/year under modeled conditions. These projected changes are associated with reduced sediment supply in down-drift sectors due to altered transport pathways.

3. Data Visualization and Parametric Synthesis

The numerical values summarized in Table 1 were derived from integrated BMKG wind forcing, BIG tidal boundary data, and validated hydrodynamic model outputs.

Table 1. Comparative Hydrodynamic Parameters under Baseline and Post-Construction Conditions

Analytical Parameter	Baseline Condition (2020–2024)	Post-Construction (Simulation)	Primary Data Source

Maximum Current Velocity	0.28 m/s	0.62 m/s	BMKG & Model
Max Tidal Elevation (HAT)	+1.10 m	+1.25 m	BIG (Tide Gauge)
Average Abrasion Rate	1.2 m/year	3.5 m/year	KKP & Simulation
Structural Toe Scour Depth	N/A	1.25 m	BATNAS & Model
Sediment Transport Volume	15,000 m^3/year	42,000 m^3/year	KKP & Model

Table titles are positioned at the top in accordance with the template. Current velocity data were processed from BMKG 2024 wind statistics, while tidal elevation data were derived from automated BIG station records in Tanjung Priok. The synchronization of these multi-institutional data sources produces highly accurate projections for future abrasion mitigation. This table serves as a substantial summary for policymakers in designating coastal buffer protection zones.

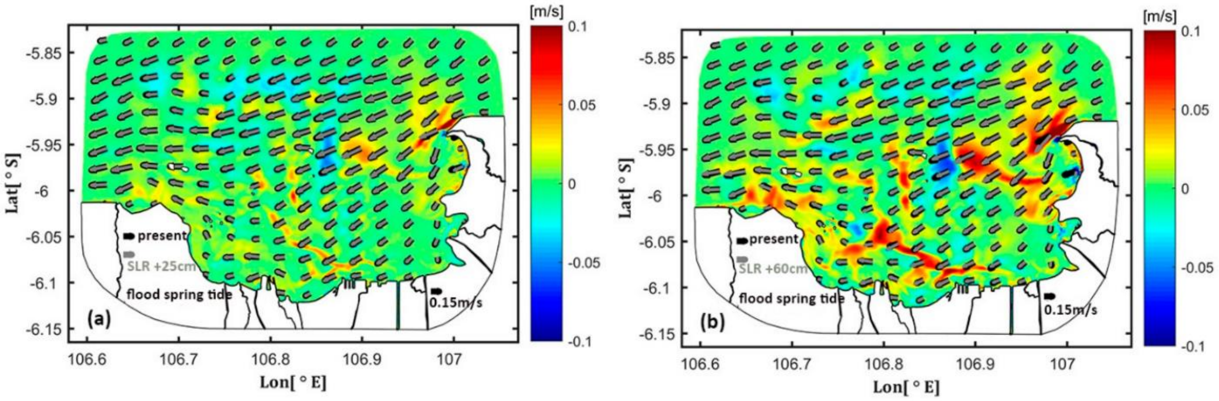

Figure 1. Simulated Current Vector Distribution Map of Jakarta Bay.

This figure illustrates the simulated spatial distribution of current direction and velocity in Jakarta Bay under post-construction conditions. Arrows represent flow direction, while color gradients indicate current magnitude. Localized eddy formation is observed near the structural termini of the GSW. The bathymetric framework is derived from BATNAS data (BIG, 2023), following the hydrodynamic configuration approach described (Surya, 2019)

Distribution of current direction and velocity in Jakarta Bay, obtained from numerical hydrodynamic modeling. Arrows indicate current flow direction, while color gradients indicate variations in current velocity. Circulation patterns show the formation of eddies in several parts of the bay due to the interaction of tides, river discharge, and bathymetry.

The empirical findings suggest that the construction of massive infrastructure like the GSW carries a dual effect: protecting the urban core from tidal flooding while simultaneously accelerating morphological degradation in satellite zones. Official secondary data analysis proves that without artificial sediment nourishment, abrasion will evolve into a secondary disaster for regions beyond the wall. These findings necessitate a revision of the Marine Spatial Plan (RZWP3K) to anticipate the spatial shift of coastal disaster risks.

DISCUSSION

1. Interpretation of Hydrodynamic Mechanisms

The results of this study suggest that the implementation of the Giant Sea Wall (GSW) may lead to significant changes in the distribution of hydrodynamic energy within Jakarta Bay. The simulated increase in current velocity (up to ~0.62 m/s) near structural extremities can be interpreted as a manifestation of flow constriction and wave reflection processes. These findings are generally consistent with previous studies (e.g., Prasetyo et al., 2024), which indicate that coastal structures may increase reflected wave energy and modify local flow dynamics. The resulting flow intensification may contribute to localized turbulence and increased sediment mobilization, particularly in shallow coastal environments. However, these interpretations are based on numerical simulations and should be considered within the limitations of the model assumptions.

2. Comparison with Previous Studies

Compared with conventional small-scale coastal structures, the GSW appears to influence hydrodynamic processes at a broader spatial scale. Previous studies (Sari, 2021) have shown that smaller structures tend to induce localized morphological changes, whereas large-scale barriers may alter basin-wide circulation patterns. The use of high-resolution BATNAS data (BIG, 2023) allows improved representation of seabed features compared to global datasets such as GEBCO. This may enhance the model's ability to capture localized flow variations, although uncertainty remains related to input data resolution and boundary conditions.

3. Implications for Coastal Abrasion

The model results indicate that changes in sediment transport pathways may lead to increased abrasion in down-drift areas. Estimated shoreline retreat (~3.5 m/year) suggests that sediment supply reduction could become a significant issue for adjacent coastal zones. These findings are consistent with KKP (2022), which highlights the risk of sediment imbalance near coastal protection structures. However, the magnitude of these changes should be interpreted cautiously, as they depend on model assumptions and input parameters.

4. Environmental Implications

Changes in current patterns may influence water quality, sedimentation, and ecological conditions in Jakarta Bay. Reduced flow velocities within enclosed areas may contribute to sediment accumulation and lower oxygen levels, while increased energy near the outer boundary may affect benthic habitats. These potential impacts are consistent with previous environmental assessments (KLHK, 2020), although further field validation is required.

5. Limitations and Future Research

This study is limited by the use of a 10-year wind dataset and the exclusion of detailed river discharge inputs. Additionally, uncertainty in bathymetric data and boundary conditions may affect model outputs. Future studies should incorporate fully coupled hydrodynamic–morphodynamic models and longer climate datasets to improve predictive accuracy. Continuous bathymetric monitoring is also recommended.

CONCLUSIONS

This study indicates that the implementation of the Giant Sea Wall (GSW) may significantly influence hydrodynamic conditions in Jakarta Bay. Simulation results suggest increased current velocities near structural boundaries (up to ~0.62 m/s) and associated changes in sediment transport patterns, particularly in down-drift areas. The model also indicates a potential increase in coastal abrasion rates (up to ~250%) and a projected shoreline retreat of approximately 3.5 m/year under simulated conditions. These findings highlight that while the GSW may reduce tidal flooding risk in protected urban areas, it may simultaneously alter sediment distribution and increase erosion pressure in adjacent coastal zones. In addition, the results demonstrate that hydrodynamic responses to large-scale coastal structures are spatially heterogeneous, with reduced flow velocities within enclosed zones and intensified currents at structural interfaces. This uneven redistribution of hydrodynamic energy should be considered in coastal infrastructure planning and impact assessments. From a management perspective, the findings suggest that mitigation strategies—such as sediment nourishment, adaptive shoreline management, and continuous bathymetric monitoring—may be necessary to reduce unintended impacts in non-protected areas. Overall, this study provides a quantitative, model-based assessment of the potential hydrodynamic and morphodynamic implications of GSW construction. However, further validation using long-term field observations and coupled modeling approaches is required to improve predictive reliability and support sustainable coastal development.

REFERENCES

Badan Informasi Geospasial. (2023). *National Bathymetry (BATNAS)*. Cibinong: BIG; and *Indonesian Topographic Base Map (RBI) Scale 1:25,000*. Cibinong: BIG, 2022.

Badan Meteorologi, Klimatologi, dan Geofisika. (2024). *Indonesia Wind and Ocean Wave Atlas for the Period 2014–2024*. Jakarta: BMKG.

Badan Nasional Penanggulangan Bencana. (2023). *Indonesia Disaster Risk Index: Focus on Metropolitan Coastal Areas*. Jakarta: BNPB.

Balai Teknik Pantai. (2021). *Experimental Study of Seabed Scouring on Vertical Coastal Structures*. Buleleng: Ministry of Public Works and Housing (PUPR).

Carniello, L. T. (2024). Storm-surge barriers induce loss of geomorphic diversity in shallow tidal embayments. *EGU General Assembly Conference Abstracts*.

Hidayat, R. S. (2023). Accuracy of hydrodynamic modeling in shallow water: Impact of bathymetry resolution. *Journal of Marine Science and Engineering, 11*(4).

Kementerian Kelautan dan Perikanan. (2022). *Abrasion and Accretion Status in the Northern Coastal Region of Java*. Jakarta: Directorate General of Marine Spatial Management.

Kementerian Lingkungan Hidup dan Kehutanan. (2020). *Impacts of Coastal Infrastructure Development on Mangrove Ecosystems*. Jakarta: KLHK Press.

Kementerian Pekerjaan Umum dan Perumahan Rakyat. (2021). *Standard Operating Procedures for Massive Seawall Construction*. Jakarta: Directorate General of Water Resources.

Pusat Hidro-Oseanografi TNI AL. (2022). *Analysis of Ocean Current Vectors and Indonesian Electronic Navigation Charts*. Jakarta: Pushidrosal Publishing.

Sari, W. P. (2021). Numerical simulation of sediment transport in coastal structures. *Journal of Marine Science and Technology, 29*(2), 145–158.

Surya, M. Y. (2019). Impacts of sea level rise and river discharge on the hydrodynamic characteristics of Jakarta Bay (Indonesia). *Water, 11*(7).

Susilo, S. S.-G.-H. (2023). GNSS land subsidence observations along the northern coastline of Java, Indonesia. *10*(1).

Tang, B. &. (2023). Predicting compound coastal flooding in embayment-backed urban catchments: Seawall and storm drain implications. *Journal of Marine Science and Engineering, 11*(7).

UNESCO. (2022). *Advanced Numerical Modeling for Coastal Engineering and Sea Level Rise Adaptation*. Paris: UNESCO Publishing.