Numerical Assessment of Inlet Stabilisation Strategies at the Agniyar River Mouths

Sruthi Sangeetha
sangeethasruthi01@gmail.com
National Institute of Technology Calicut
Kiran A. S
National Institute of Ocean Technology
Ram kumar S
National Institute of Ocean Technology
Anand K.V
National Institute of Technology Calicut
Vijaya Ravichandran
National Institute of Ocean Technology
Balaji Ramakrishnan
National Institute of Ocean Technology

Research Article

Keywords:

Posted Date: November 18th, 2025

DOI: https://doi.org/10.21203/rs.3.rs-7870843/v1

Additional Declarations: No competing interests reported.

NUMERICAL ASSESSMENT OF INLET STABILISATION STRATEGIES AT THE AGNIYAR RIVER MOUTHS

Sruthi. Sangeetha[1], Kiran A.S[2], Ramkumar S[3], K.V. Anand[4], Vijaya Ravichandran[5], Balaji Ramakrishnan[6]

[1]M.Tech Student, Offshore Structures (Corresponding author), NIT Calicut, [4]Assistant Professor, NIT Calicut,[2,3,5,6]Scientist, NIOT Chennai

ABSTRACT

The Agniyar river basin is situated in central Tamil Nadu along the coast. Geographically, it lies between 9°55'00"-10°45'00" N latitude and 78°15'00"-79°30'00" E longitude. The present study focuses on solving the problem of inlet closure at the Agniyar river mouths, which detrimentally affects the nearby fishing community. Inlets are short and narrow waterways connecting bays, lagoons, or estuaries with the ocean. In microtidal, wave-dominated environments, inlets usually close seasonally and can cause problems with navigation and poor water quality. This study suggests a suitable solution to keep the inlet navigable and open. The efficiency of these configurations in preventing the closure and ensuring the perennial access is evaluated using Delft 3D FM Suite 2021. A 2D Hydrodynamic model coupled with wave and morphology was set up using Delft3D Flexible Mesh and validated with observed data. The third-generation SWAN model was used to compute the transformation of waves, and the Bijker transport formula was used to compute the sediment transport rates in the model. A yearly study suggests that dredging is a primary solution to overcome the sand bar formation. Results from this study will increase knowledge on sustainable coastal management practices and the livelihoods of fishermen affected by them.

1 INTRODUCTION

Coastal inlets are dynamic and complex systems that play a vital role in maintaining healthy coastal ecosystems. Coastal inlets are constantly changing, shaped by the movement of water and sediment. Understanding why and how they close seasonally is key to managing them effectively. (Ranasinghe, 1999) and colleagues created a model to investigate how sandbars can block tidal inlets at certain times of the year. The model looks at how sediment moves both along the shore and across it, helping to explain what causes these closures. They looked at different ways in which inlets behave and explained why it is important to understand these processes for practical coastal engineering. The model was checked against real-world situations, giving a clearer picture of the complex dynamics that control how inlets change over time.

Tidal basins—including lagoons and estuaries with connected inlets—intersect most of the world's shorelines. Research shows that inlet closure is strongly influenced by wave steepness, wave incidence angle, and longshore sediment transport (LST). LST emerges as the dominant factor, especially when wave steepness exceeds critical thresholds or the wave incidence angle is large.

Marcel J.F. Stive and Z.B. Wang (2003) examined the processes at mesoscale and macroscale levels, such as channel formation and bar development, and their effects on nearby coastlines. Their work highlights how tidal channels in lagoons and estuaries self-organise, forming alternating bars and channels. Their study indicates that sand movement, more than silt, drives changes in inlet morphology. Predicting how tidal basins respond to natural forces and human activities requires understanding how these processes unfold over time and across space. Factors like channel shape, tidal prism, delta volume, and sediment balance are key to understanding and managing inlet closure.

Corresponding author: sangeethasruthi01@gmail.com

In the Palk Strait, tides follow a semi-diurnal pattern, with two high and two low tides each day. The tidal range is relatively small, between 0.5 and 1 meter, because the area is shallow and semi-enclosed. These tides are important for moving and flushing sediment, particularly near estuaries and deltas such as those at Pamban and Rameswaram (Ramesh et al., 2015). The wave climate in the strait is moderate, mainly caused by local winds, with short fetches and wave periods. Wave heights usually range from 0.5 to 1.5 meters but can increase during monsoon or cyclonic events. The nearby landmasses, including Sri Lanka and the Indian coast, reduce wave energy compared to the open east coast (Dattatri et al., 2001; Nayak et al., 2012).

(Hayes, 2013)studied how tidal inlets form, evolve, and interact with barrier islands. Their work shows how inlet morphology develops naturally and how human activity can influence coastal areas. Barrier islands are shaped by migration and sediment processes, with tidal range and wave energy being important factors. The tidal prism strongly affects the inlet's size and the sand volume in the ebb-tidal delta. As the bay's tidal prism grows, the inlet widens, and more sand accumulates in the delta. Inlets can be classified as wave-dominated, tide-dominated, or transitional depending on how tides and waves influence them.

2 STUDY AREA

The Agniyar River inlet is a double-mouth dynamic system that connects the Agniyar River to the Bay of Bengal. It represents a mixing zone where freshwater from the river interacts with saline ocean water. Tidal currents play a significant role in controlling inlet morphology. Seawater intrudes into the inlet during high tide, promoting sedimentation and accretion, whereas river outflow enhances erosion and scouring during low tide. In addition to tidal exchange, longshore currents and wave action contribute to sediment transport, influencing the stability and periodic closure of the inlet. Fig 1 shows the Agniyar River inlet with its active mouths, M1 and M2.

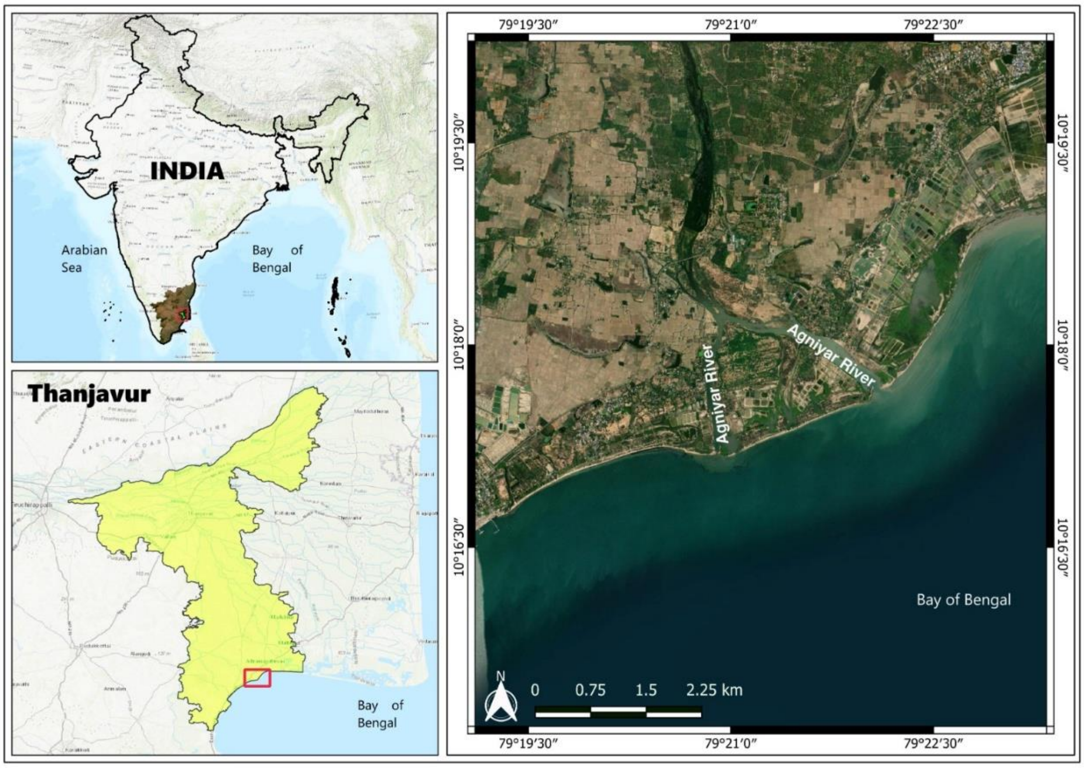


Fig. 1. Location of the Agniyar River basin, Tamil Nadu, India.

Corresponding author: sangeethasruthi01@gmail.com

Monsoon and non-monsoon periods

The Agniyar River basin falls under a tropical monsoon climate. The year is broadly split into two periods: the monsoon season from June to December, which includes the Southwest monsoon (June–September) and the Northeast monsoon (October–December), and the non-monsoon season from January to May, covering the Winter (January–February) and Summer (March–May) months. Most of the annual rainfall occurs during the monsoon, strongly influencing river flow, water storage, and sediment transport to the coastal inlet. In contrast, the non-monsoon period is relatively dry, with minimal runoff. On average, the basin receives yearly rainfall between 910 mm (in the South Vellar region) and 932 mm (in the Agniyar region).

In addition to fluvial inputs, coastal sediment transport significantly influences the inlet morphology. The littoral drift along the Palk Bay coast exhibits seasonal reversals—generally northward during the Southwest monsoon (due to waves approaching from the southeast) and southward during the Northeast monsoon (with waves approaching from the northeast). Depending on wave energy and sediment availability, these opposing drift directions cause periodic siltation and closure of the Agniyar river mouth. Therefore, understanding riverine sediment discharge and longshore sediment transport is essential for evaluating inlet mouth opening schemes.

3 MATERIALS AND METHODS

The Delft3D Flexible Mesh (FM) suite (developed by Deltares, The Netherlands) was used to simulate hydrodynamics, wave propagation, and sediment transport at the Agniyar River inlet. Delft3D-FM is an integrated numerical modelling system capable of representing complex coastal and estuarine morphodynamics through coupled flow–wave–morphology simulations.

3.1 Model Setup

The model domain encompassed the Agniyar River mouth and the adjacent coastal zone along the Bay of Bengal. A curvilinear unstructured grid was generated using D-RGFGRID, providing high resolution near the inlet region to capture complex flow patterns. Bathymetric data were incorporated into the D-FLOW FM module to define bed elevations. The open boundaries were forced with tidal levels, wave spectra, and wind conditions, while river discharge was applied at the upstream boundary.

3.2 Numerical Framework

The D-FLOW FM module solves the depth-averaged unsteady shallow water equations (Saint-Venant equations) to compute water levels and current velocities. The D-WAVE module (based on the SWAN spectral wave model) simulates wave transformation and energy dissipation, governed by the spectral action balance equation. The D-MOR module calculates sediment transport and bed level changes by solving the advection–diffusion equation for suspended sediment concentration. These modules were dynamically coupled to account for wave–current interactions influencing sediment mobility.

3.3 Model Execution and Validation

The coupled hydrodynamic–wave–morphological model was run for representative monsoon and non-monsoon conditions to examine the seasonal variation in inlet behaviour. Model outputs, including tidal elevation, current

Corresponding author: sangeethasruthi01@gmail.com

velocity, and sediment transport, were validated using available field and secondary data. Shoreline evolution was evaluated using Sentinel-2 satellite imagery, providing a comparative assessment of observed and simulated morphological changes.

3.4 Output Analysis

Post-processing was done using D-QuickPlot and MATLAB to visualise current vectors, sediment flux, and morphological evolution. The model outputs—shoreline change, longshore sediment transport rate, and bed level variation—were analysed to assess inlet dynamics under different opening schemes. The results provide a quantitative understanding of how tidal, fluvial, and littoral processes interact to shape the Agniyar River inlet. To initiate the Delft3D FM modelling process, several preparatory steps are necessary. First, the model domain and boundaries are defined to establish the simulation area. Next, generate a grid with sufficient resolution using D-RGFGRID to represent coastal features accurately. Import bathymetry data into the D-FLOW module at the bed level to provide the model with essential topographic information. Boundary conditions, such as tidal, wave, and wind inputs, must also be specified. Finally, select the required Delft3D FM modules, including D-FLOW, D-WAVE, and D-MOR, to simulate hydrodynamics, wave dynamics, and sediment transport. After completing the setup, proceed to the simulation phase by running D-FLOW to simulate hydrodynamics, including water levels and currents. Next, utilise D-WAVE to simulate wave dynamics, encompassing wave heights and directions. Couple D-FLOW and D-WAVE to account for interactions between hydrodynamics and wave dynamics. Finally, D-MOR will be run to simulate sediment transport and morphological changes, providing insights into coastal evolution. After completing the simulations, analyse the results using various tools. Visualise the output with D-QUICKPLOT to facilitate comprehension. Shoreline evolution using satellite images from Sentinel, to evaluate shoreline change and morphological evolution, and to assess the impact of simulated processes. To ensure model accuracy and reliability, additional analyses are performed. To verify simulation accuracy, validate model results against measured data, such as bathymetry and sediment transport. Conduct sensitivity analysis on key parameters, including wave climate and sediment characteristics, to understand their impact on model outcomes. Refine the model as needed to improve its performance. The Delft3D FM modelling process yields valuable outputs, including shoreline evolution maps and time-series data, longshore sediment transport rate estimates, and insights into coastal morpho-dynamics and sediment transport processes. These results provide essential information for understanding and managing coastal environments.

Corresponding author: sangeethasruthi01@gmail.com

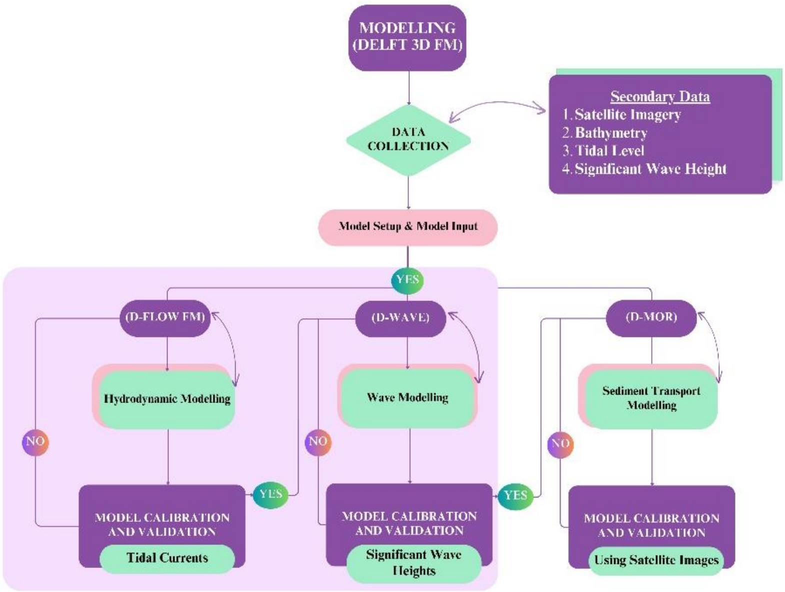


Fig. 2. Workflow for numerical modelling of the Agniyar River inlet.

4 NUMERICAL STUDY

A fully coupled Flow–Wave–Morphology model was developed using the Delft3D Flexible Mesh (FM) Suite to simulate hydrodynamics, wave action, and sediment transport at the Agniyar River inlet. The flow and wave components were dynamically linked, allowing bidirectional exchange of hydrodynamic and wave parameters at each time step.

4.1 Model Domain

The model domain encompassed the Agniyar River mouth and its adjacent coastal zone along the Bay of Bengal. It extended approximately 8 km offshore and 12 km inland from the coastline near Mallipattinam Harbour to Adirai Beach. The model was projected in the WGS 84 / UTM Zone 44N coordinate system. Bathymetric data and shoreline boundaries were digitised using Google Earth Pro and imported into Delft3D-FM for domain definition.

4.2 Grid Generation

An unstructured mesh was generated using the D-RGFGRID tool, with finer resolution (20–30 m) at the inlet and coarser spacing (up to 600 m) offshore to optimise computational efficiency. The grid structure was refined to maintain mesh orthogonality and ensure numerical stability near the double-mouth system. Separate computational meshes were created for flow and wave models, and later integrated through online coupling for simulation. The wave model was developed using a structured rectangular grid, with finer resolution (~80–100 m) near the inlet and coarser spacing (~180–200 m) offshore. This grid configuration ensured stable coupling with the unstructured hydrodynamic mesh and accurate wave transformation across the coastal zone.

4.3 Data Collection and Model Bathymetry

Topographic and bathymetric data for the Agniyar coastal domain, extending from the shoreline to the creek, were obtained from the National Institute of Ocean Technology (NIOT), Chennai. Bathymetric measurements were collected using a single-beam echo Sounder and pole soundings, with depths ranging from −6.25 m to +1.3 m relative to mean sea level. The bathymetric data were interpolated onto the computational mesh using a

Corresponding author: sangeethasruthi01@gmail.com

triangulation-based interpolation technique to ensure smooth spatial transitions. The same bathymetry was adapted to the structured grid for wave modelling to represent nearshore depth variations that influence wave propagation, refraction, and breaking. The final interpolated bathymetric surface formed the foundation of the hydrodynamic and wave models, ensuring consistent seabed topography across coupled simulations.

4.4 Tidal Forcings

Measured tidal data for the Agniyar River inlet were obtained from NIOT at offshore, nearshore, and inlet locations with sampling intervals of 10–20 minutes. The time series were processed to extract astronomical tidal constituents, including principal diurnal (K1), principal semidiurnal (M2, S2), and shallow-water components (M3, M4, M6), which were applied as boundary forcing in the hydrodynamic model. Offshore tidal levels were imposed at the water-level boundaries, while lateral boundaries were set as zero-gradient Neumann conditions. Observation points were established within the domain to monitor water levels, flow velocities, and sediment concentrations.

The wave model was forced with offshore wave parameters, including significant wave height, mean wave period, mean wave direction, and directional spreading, obtained from the ERA5 reanalysis database of the Copernicus Climate Data Store (ECMWF). Wave forcing was coupled with the flow model, so water levels and flow velocities were exchanged dynamically at each time step. These tidal and wave forcings provided the necessary hydrodynamic input for the fully coupled Flow–Wave–Morphology simulations of the Agniyar River inlet.

4.5 Wave forcings

Wave forcing was obtained from the ERA5 global reanalysis dataset (Copernicus Climate Change Service, ECMWF), which provides hourly estimates of ocean waves at 31 km horizontal resolution. Initial validation using Wave Atlas data showed discrepancies, likely due to the study area being in a coastal shadow region with limited local measurements. A larger offshore domain extending ~45 km from the river mouth was created to improve wave representation to capture wave transformation before reaching the inlet. The wave model was validated against available measurements to ensure that significant wave heights, periods, and directions were accurately reproduced within the computational domain.

ERA5 reanalysis data (Copernicus Climate Change Service, ECMWF) with 0.5° × 0.5° spatial resolution and hourly temporal resolution were used to provide wave forcing for the study. To accurately capture wave transformation toward the Agniyar River inlet, a larger offshore domain was first simulated, and the transformed wave conditions were applied as boundary forcing to the main computational domain. Wave boundaries were defined along all three open boundaries (north, east, and south)—the main wave parameters used for forcing included significant wave height, mean wave period, and direction. Model outputs at representative observation points were analysed to ensure that the simulated waves reasonably reproduced observed offshore conditions, providing reliable input for the coupled Flow–Wave–Morphology simulations.

4.6 Sediment Transport Patterns using the Integrated Model

Sediment transport at the Agniyar River inlet was simulated using the Delft3D Flexible Mesh suite, coupling hydrodynamics, waves, and morphology over one year (01/01/2023–31/12/2023). The morphology module (D-Morphology) accounted for both bedload and suspended load transport of non-cohesive sediments under combined tidal and wave forcing. Sediment characteristics were derived from NIOT measurements, representing sand with median diameters ranging from 0.26 to 0.66 mm and a specific 2650 kg/m³ density. Settling velocities

Corresponding author: sangeethasruthi01@gmail.com

for non-cohesive sediments were calculated following Van Rijn (1993).

The integrated model was used to analyse sediment concentrations and transport patterns within the computational domain. Different inlet mouth opening schemes were evaluated to assess their influence on sediment dynamics and morphological evolution. Model outputs provided insights into longshore and cross-shore sediment transport processes, sediment accumulation zones, and potential inlet stability under varying forcing conditions.

5. RESULTS & DISCUSSIONS

5.1 VALIDATION

5.1.1 Tide validation

The hydrodynamic module (D-Flow FM) was validated against measured tidal data at offshore (5 m), nearshore (2.5 m), and north creek locations. Simulated water levels closely matched the observed time series, with minor discrepancies attributed to the difference in temporal resolution between model forcing (1 hour) and observations (10–20 min) (Figs. 3,4 and 5). The results confirm that the model accurately reproduces tidal dynamics within the study area.

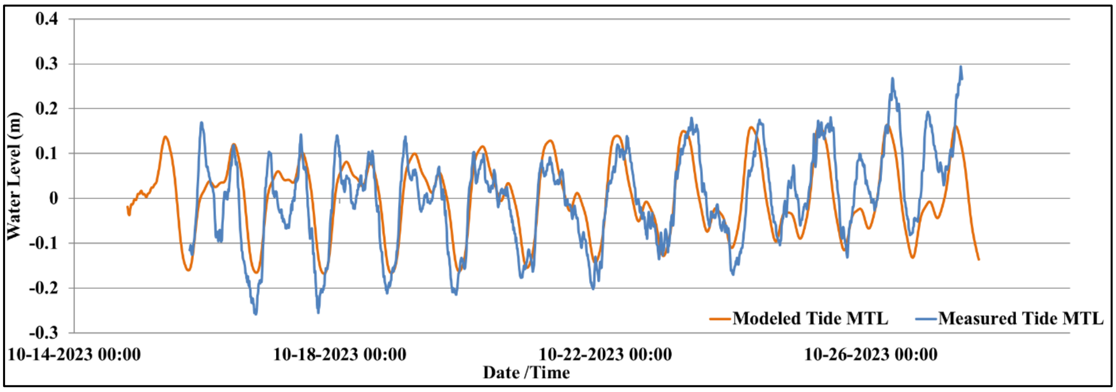


Fig. 3 Delft 3D FM Modelled vs Measured tide MTL at 5m water depth

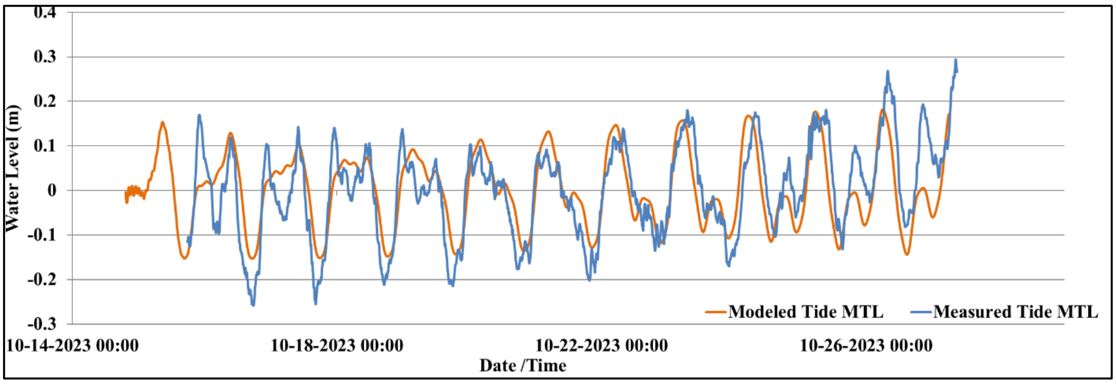


Fig. 4 Delft 3D FM Modelled vs Measured tide MTL at 2.5m water depth

Corresponding author: sangeethasruthi01@gmail.com

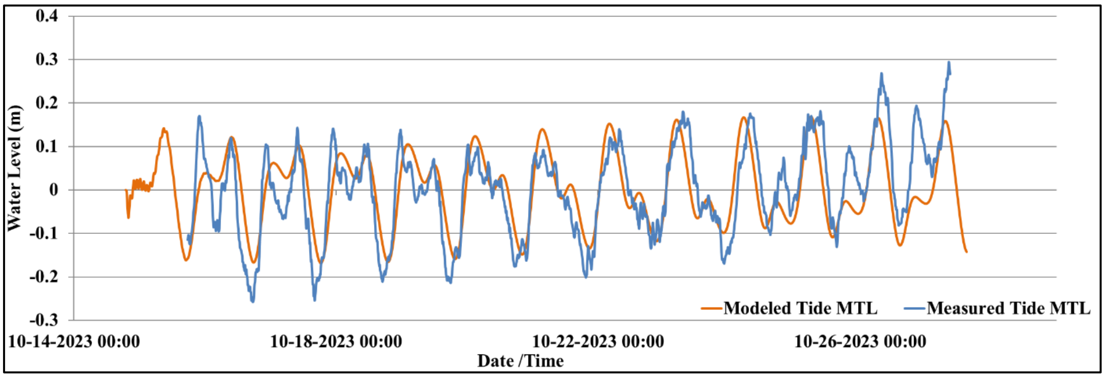


Fig. 5 Delft 3D FM Modelled vs Measured tide MTL at North Creek

5.1.2 Wave Validation

Wave simulations using the coupled D-Wave module were validated with ERA5 reanalysis data and in situ measurements. The model captured the seasonal variability of significant wave heights and mean wave periods at 2.5 m and 5 m water depths. Deviations in wave height were noted in sheltered areas due to local bathymetric shadowing. Overall, wave transformation patterns were adequately represented (Fig. 6).

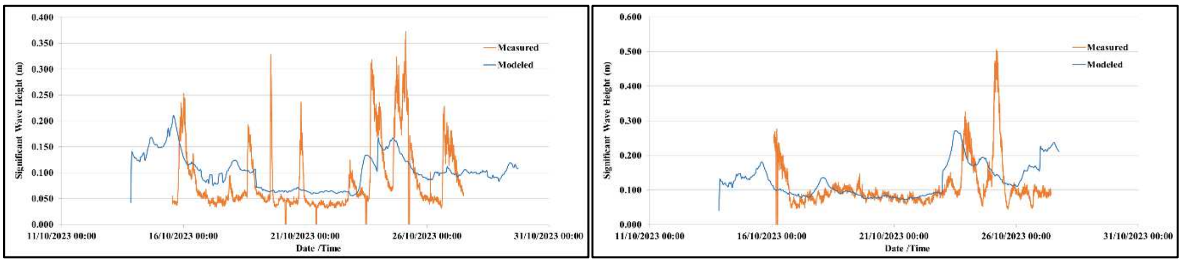


Fig. 6 Wave validation for 2.5m band 5m water depth

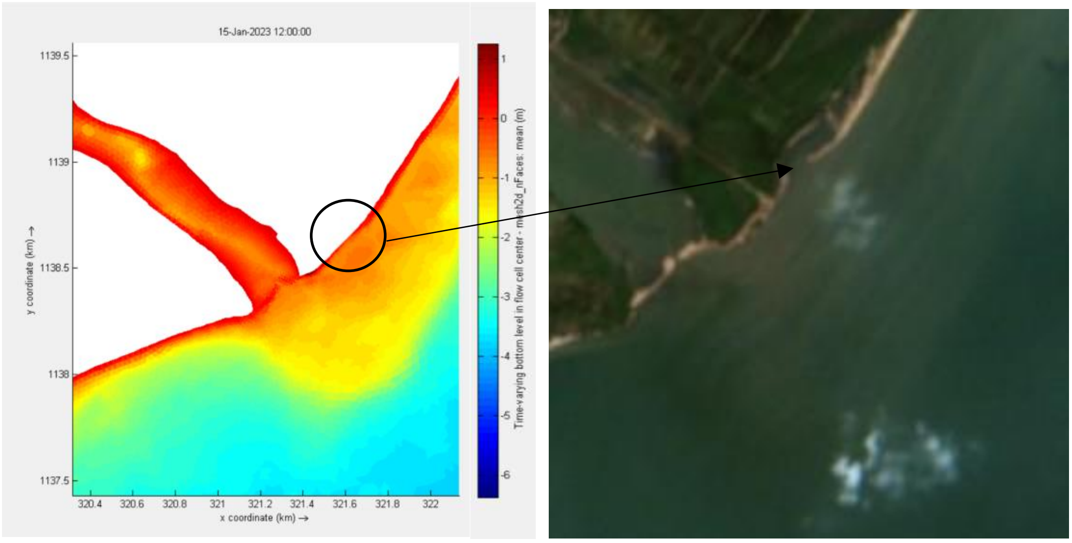
5.1.3 Morphology Validation

The morphological model was initialised with the bathymetric profile of 1st January 2023 and run for one year (January–December 2023) with a timestep of 1 hour. Model results were compared with satellite imagery and in situ bed-level measurements to assess performance.

Simulations captured the key sediment dynamics along both inlet mouths. Accretion was observed in the northern inlet zone, consistent with satellite observations in January and October 2023 (Figs. 7–8). Across the transects, seabed levels gradually deepened in central regions (approximately 75–150 m along Mouth 2 and 80–120 m along Mouth 1), indicating active scouring during February–April. From mid-year onwards, the seabed stabilised, suggesting the inlet was approaching dynamic equilibrium (Figs. 9–10).

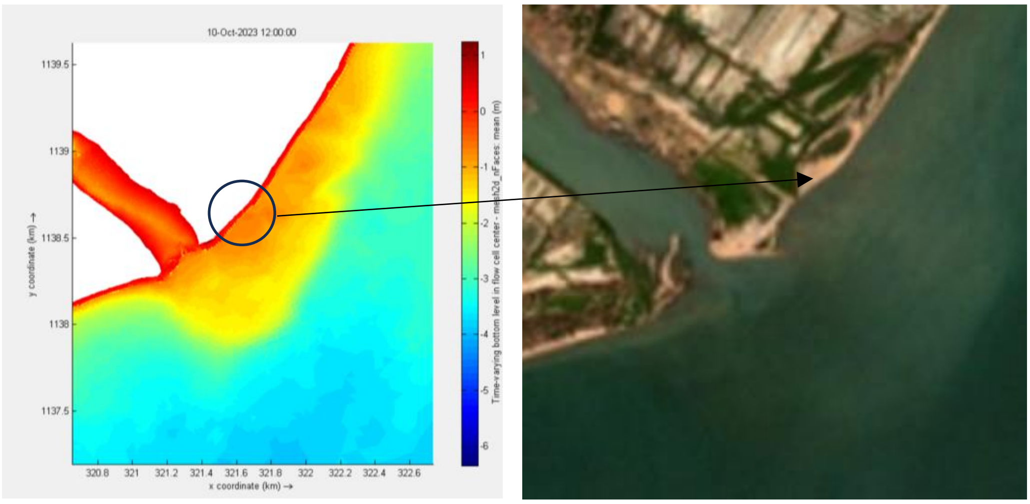
Overall, the model effectively reproduces spatial and temporal sediment transport patterns, including erosion in central channels and minor deposition along lateral zones, validating its capability to simulate morphological changes in the study area.

Corresponding author: sangeethasruthi01@gmail.com



(a) (b)

Fig. 7 (a)Simulation accretion pattern along the north side of the inlet mouth in January 2023, and (b) Sentinel satellite image of 10 January 2023



(a) (b)

Fig 8 (a)Simulation accretion pattern along the north side of the inlet mouth in October 2023, and (b) Sentinel satellite image of 07 October 2023

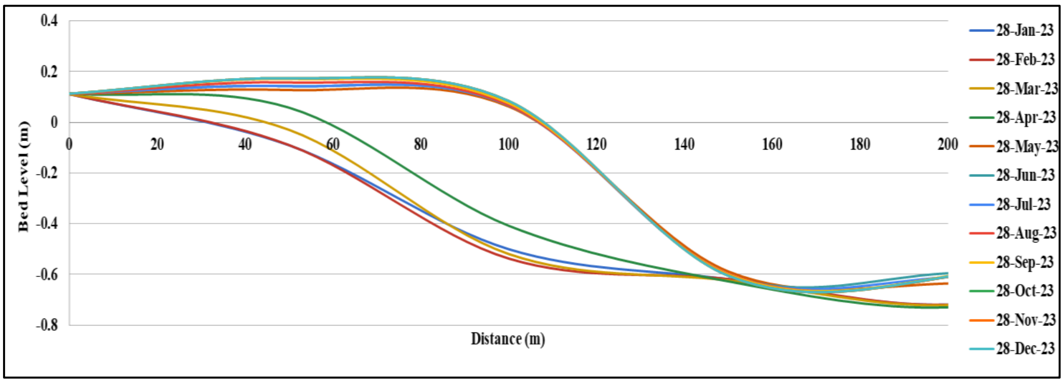


Fig. 9 Across Inlet Bed Profile: existing site condition of a year for Mouth 2

Corresponding author: sangeethasruthi01@gmail.com

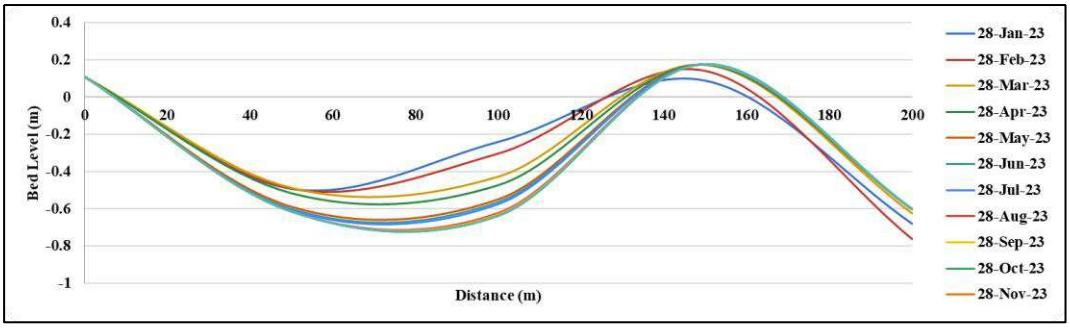


Fig. 10 Across Inlet Bed Profile: existing site condition of a year for Mouth 1

Corresponding author: sangeethasruthi01@gmail.com

6.2 DISCUSSION ON VARIOUS INLET MOUTH STABILIZATION SCHEMES INLET OPENING SCHEMES

Sediment accumulation within the inlet can be mitigated through either regular dredging or the construction of protective structures. This study evaluates two structural interventions—straight and curved training walls—alongside dredging. Hydrodynamic and sediment transport simulations were conducted for one year (1st January to 31st December 2023) with a 6-hour timestep, to examine sedimentation patterns under each approach and identify the most effective strategy.

6.2.1. Different Schemes for Stabilisation

Three dredging scenarios and three structural configurations were simulated to evaluate their impact on inlet morphology.

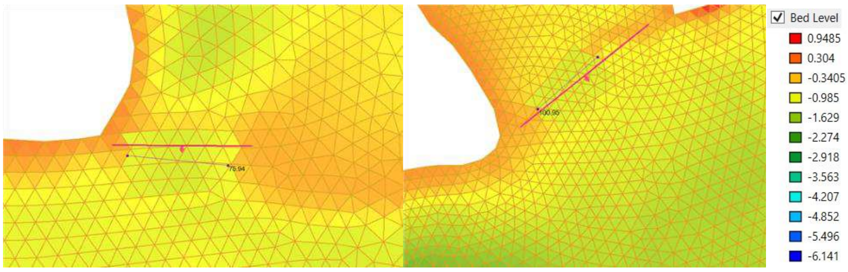
Scheme 1: Dredging Trials

For all dredging trials, the inlet bathymetry was adjusted to a uniform depth of 1 m using the 'SetValue' tool in Delft 3D FM Suite. Variations in the widths of Mouth 1 and Mouth 2 were applied to assess sediment transport and flow patterns:

Table 1: Features of Different schemes adopted for the study

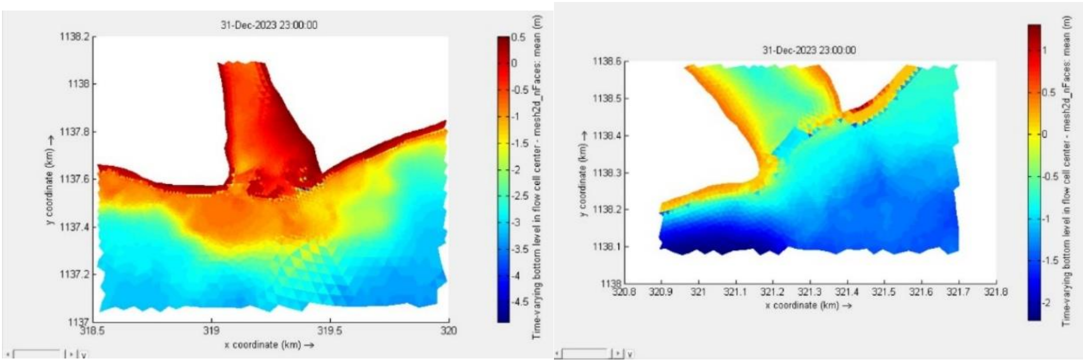
Trial No.		**Mouth 1 Width (m)**	**Mouth 2 Width (m)**	**Mouth 1 & Mouth 2 Dredging Depth (m)**
Trial 1	**Dredging -1**	75	100	1
Trial 2	**Dredging -2**	100	150	1
Trial 3	**Dredging -3**	125	200	1

- **Trial 1:** Mouth 1 dredged to 75 m and Mouth 2 to 100 m (Fig. 11).
- **Trial 2:** Mouth 1 dredged to 100 m and Mouth 2 to 150 m (Fig. 12).
- **Trial 3:** Mouth 1 dredged to 125 m and Mouth 2 to 200 m (Fig. 13).



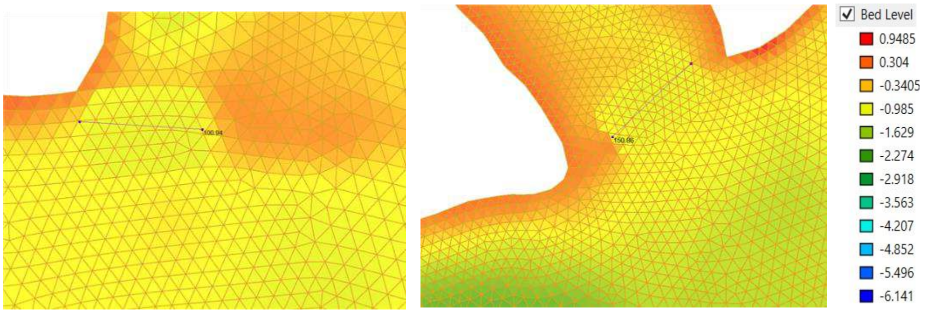
(a) (b)

Corresponding author: sangeethasruthi01@gmail.com

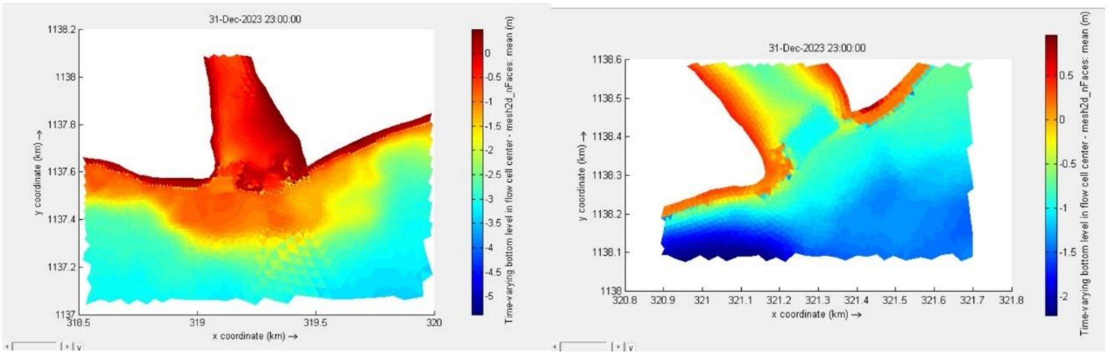


(c) (d)

Fig. 11 (a)Mouth 1 with a dredging width of 75m, (b)Mouth 2 with a dredging width of 100m, (c) Mouth 1, (d) Mouth 2, result of December 31 2023

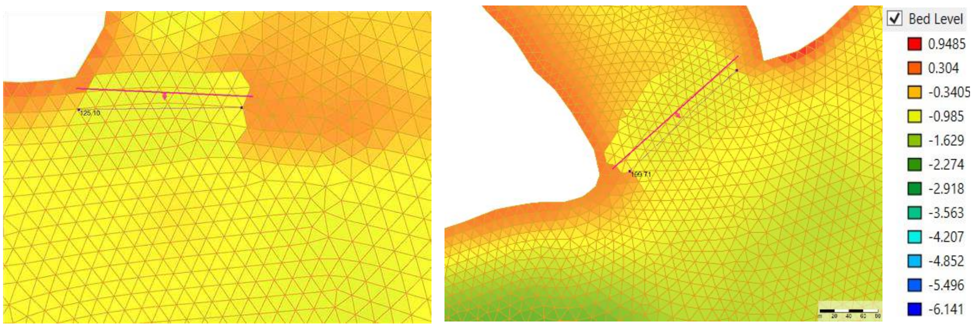


(a) (b)



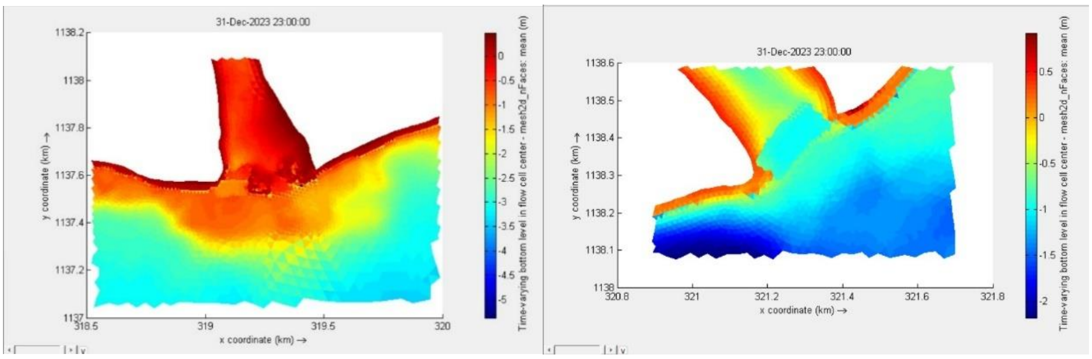
(c) (d)

Fig. 12 (a)Mouth 1 with a dredging width of 100m, (b)Mouth 2 with a dredging width of 150m, (c) Mouth 1, (d) Mouth 2, result of December 31 2023



(a) (b)

Corresponding author: sangeethasruthi01@gmail.com



(c) (d)

Fig. 13 (a)Mouth 1 with a dredging width of 125m, (b)Mouth 2 with a dredging width of 200 m, (c) Mouth 1 and (d) Mouth 2 result of December 31 2023

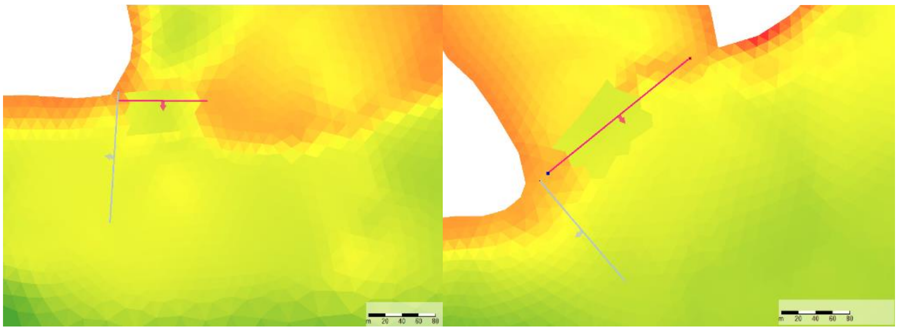
Scheme 2: Training Wall Trials

Training walls were introduced in the dredged domains to guide flow and reduce sediment accumulation. Three configurations were tested:

- **Trial 4 – Single Straight Wall:** A single straight wall (150 m × 10 m × 5 m) was placed along each inlet mouth (Fig. 14).
- **Trial 5– Double Straight Wall:** Two parallel straight walls of the exact dimensions were installed on either side of the inlet mouths (Fig. 15).
- **Trial 6 – Curved Wall:** Curved walls were designed for both inlets, with perimeters of 180 m (Mouth 1) and 260 m (Mouth 2), widths of 10 m, and heights of 5 m. Control points were used to define the curvature, and the mouths were maintained at 120 m width for Mouth 1 and 150 m for Mouth 2 (Fig. 16).

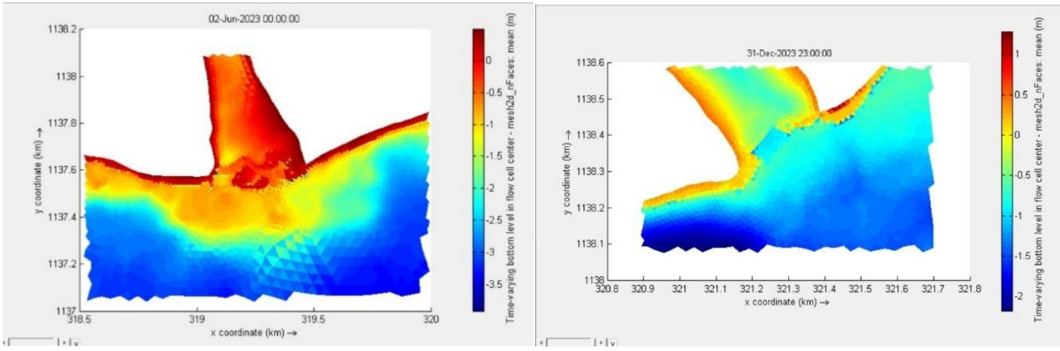
All structural simulations were run on the previously dredged bathymetry to evaluate their effectiveness in modifying sediment transport and stabilising the inlet configuration.

Trial No.	Training Wall Type	Wall Length (m)	Wall Width (m)	Wall Height (m)
Trial 4	**Single Straight**	150	10	5
Trial 5	**Double Straight**	150	10	5
Trial 6	**Curved**	(M1) 180 (M2) 260	10	5



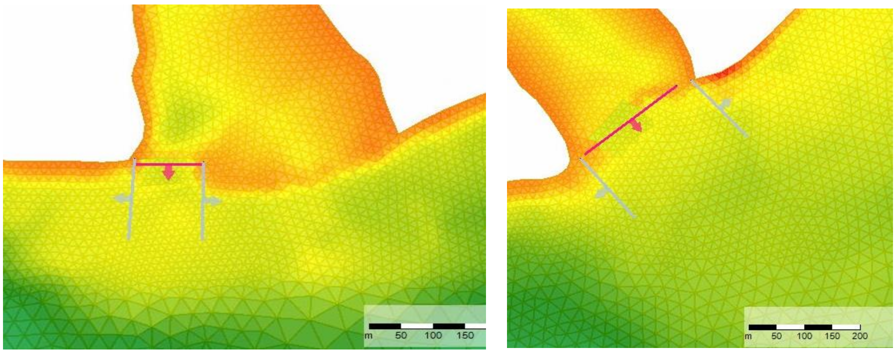
(a) (b)

Corresponding author: sangeethasruthi01@gmail.com

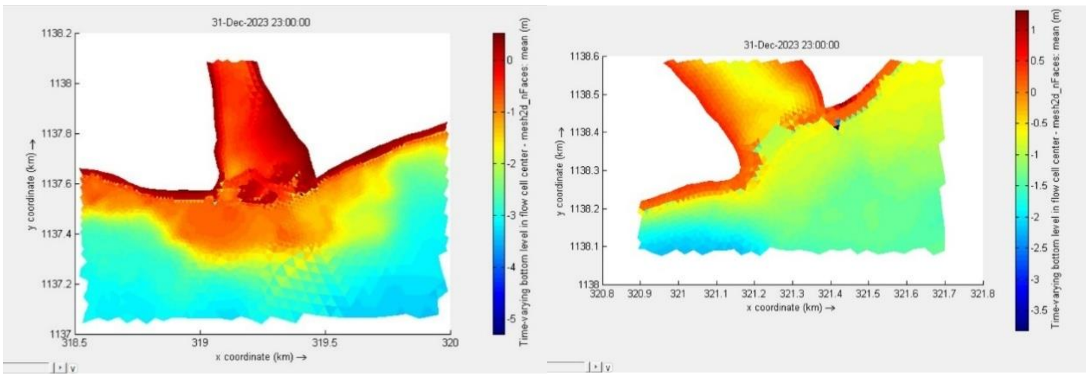


(c) (d)

Fig. 14 (a)Mouth 1& (b) Mouth 2 with training walls on dredged condition 1and (c) Mouth 1, (d) Mouth 2, result of December 31 2023



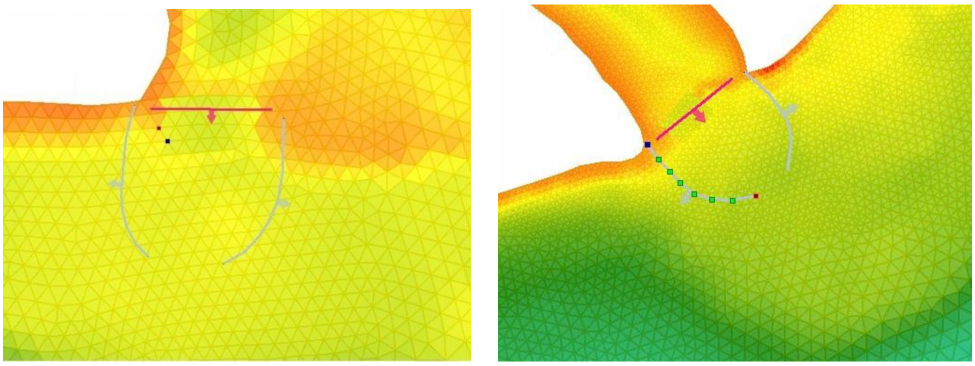
(a) (b)



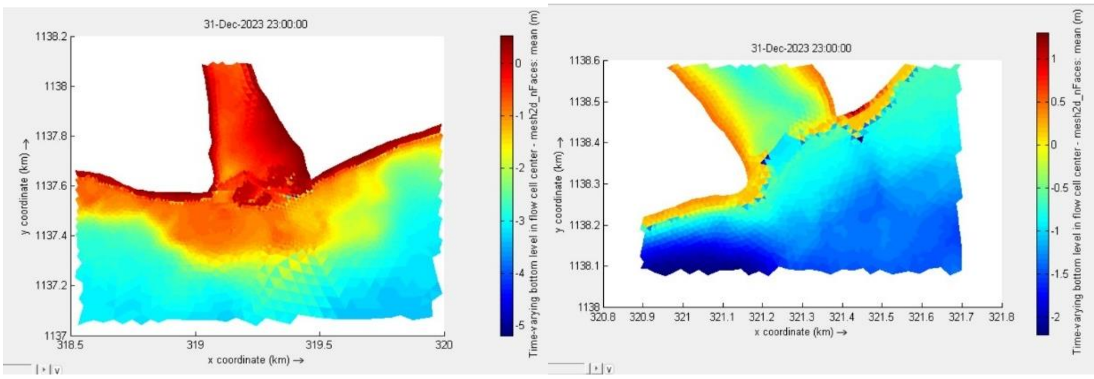
(c) (d)

Fig. 15(a)Mouth 1& (b)Mouth 2 with double training walls on dredged condition 1and (c) Mouth 1, (d) Mouth 2, result of December 31 2023

Corresponding author: sangeethasruthi01@gmail.com



(a) (b)



(c) (d)

Fig. 16 (a)Mouth 1& (b)Mouth 2 with curved training walls on dredged condition 1and (c) Mouth 1, (d) Mouth 2, result of December 31 2023

6.3. COMPARISON AND RECOMMENDATION OF INLET MOUTH STABILISATION SCHEMES

The performance of different inlet stabilisation schemes was assessed by analysing maximum bed levels along and across both Mouth 1 and Mouth 2. Longitudinal bed level profiles were evaluated at 25 m intervals, while transverse profiles were evaluated at 50 m intervals.

Mouth 1:

Dredging three and Curved Training Wall configurations exhibited the most significant bed level reductions, particularly in the central reach (≈60–120 m), compared to the pre-dredged condition (Fig. 17–19). Bed level reductions relative to the original condition were substantial: 105 % at 50 m and 275 % at 100 m. These results indicate enhanced sediment transport efficiency and improved hydraulic performance under Dredging three and Curved Training Wall schemes.

Mouth 2:

Similarly, dredging three and Curved Training Wall configurations produced the deepest bed level reductions across most transects, particularly between 50 m and 250 m, compared to the pre-dredged state (Fig. 20–22). Percentage reductions across key locations for Dredging 3 were 120 % (50 m), 90 % (100 m), 70 % (150 m), and 60 % (200 m). For the Curved Training Wall, reductions were 40–42 % across the same intervals. This indicates that both configurations efficiently removed sediment, enhancing hydraulic efficiency and minimising sedimentation risk.

Corresponding author: sangeethasruthi01@gmail.com

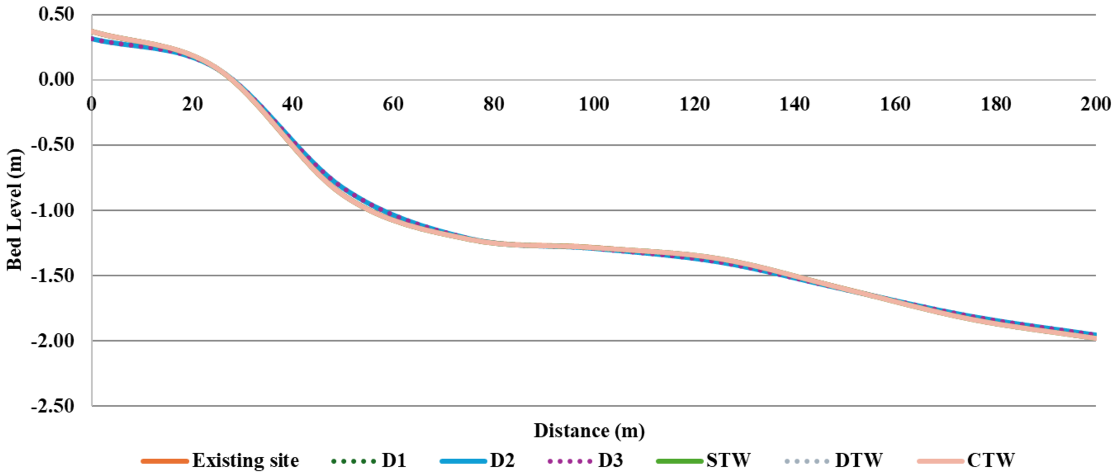


Fig. 17. Bed level variation along the north side of Inlet Mouth 2 under dredging and training wall scenarios.

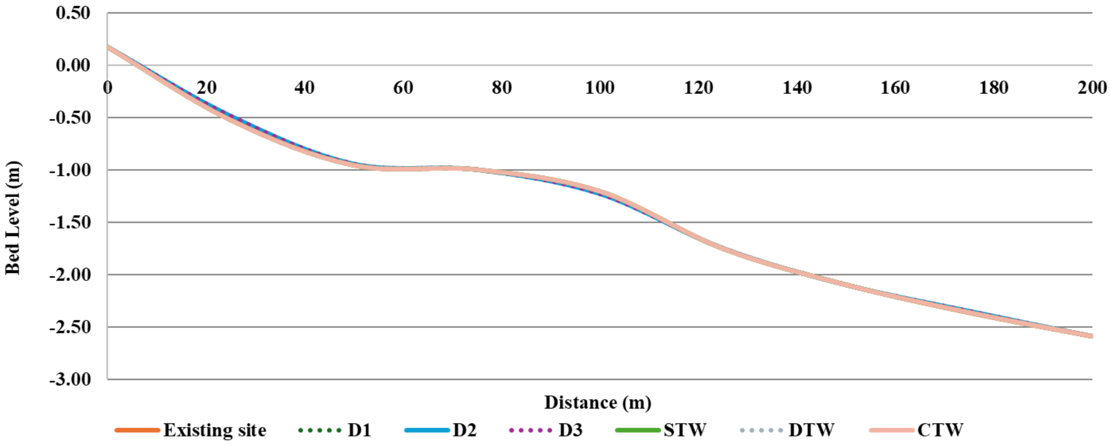


Fig. 18 Bed level variation along the south side of Inlet Mouth 2 under dredging and training wall scenarios.

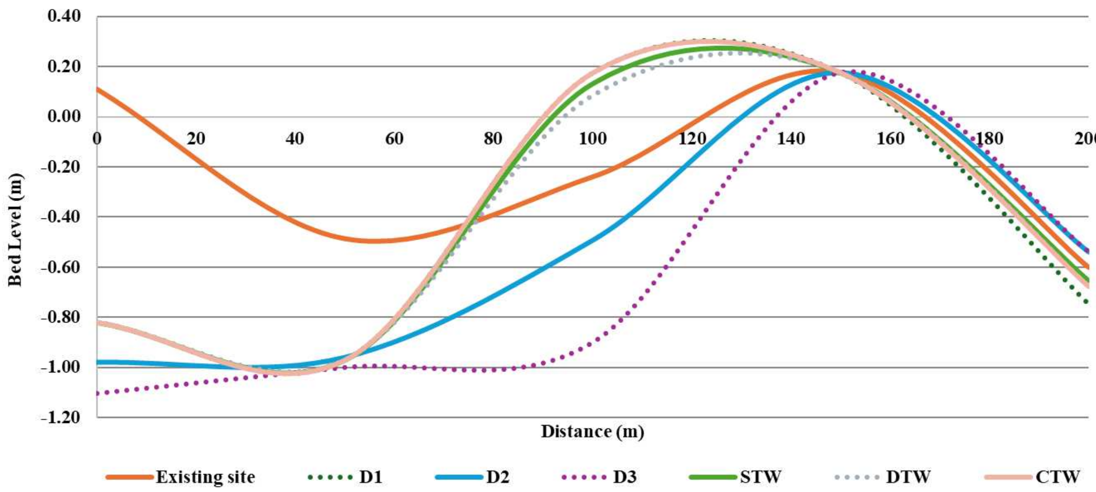


Fig. 19: Bed level variation across Inlet Mouth 1 under dredging and training wall scenarios.

Corresponding author: sangeethasruthi01@gmail.com

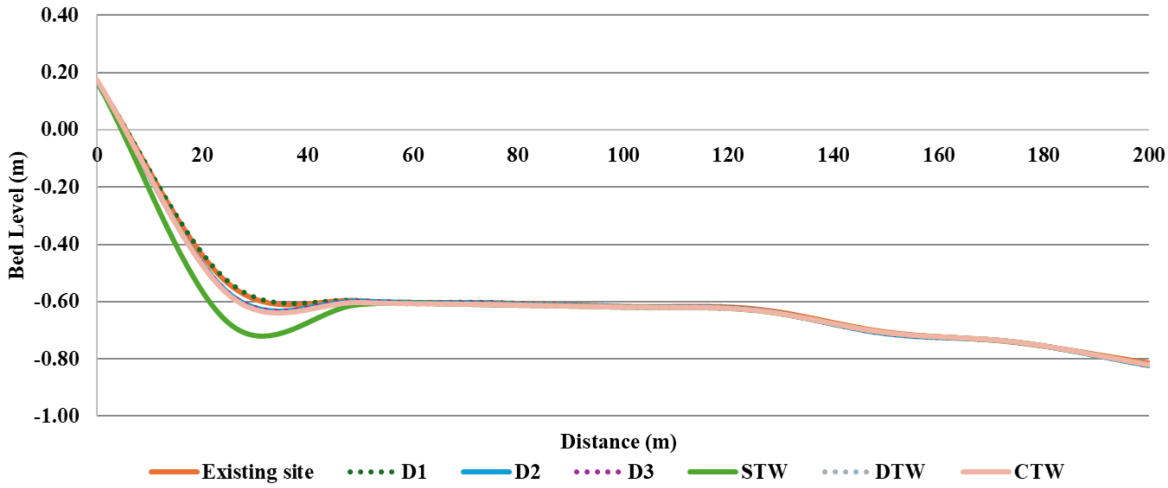


Fig 20: Bed level variation along the north side of Inlet Mouth 2 under dredging and training wall scenarios.

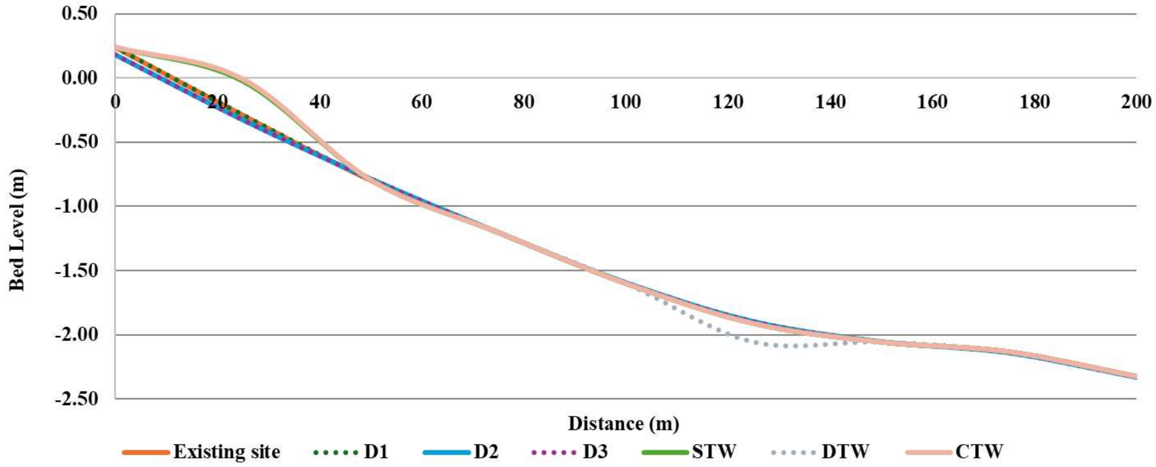


Fig 21: Bed level variation along the south side of Inlet Mouth 2 under dredging and training wall scenarios

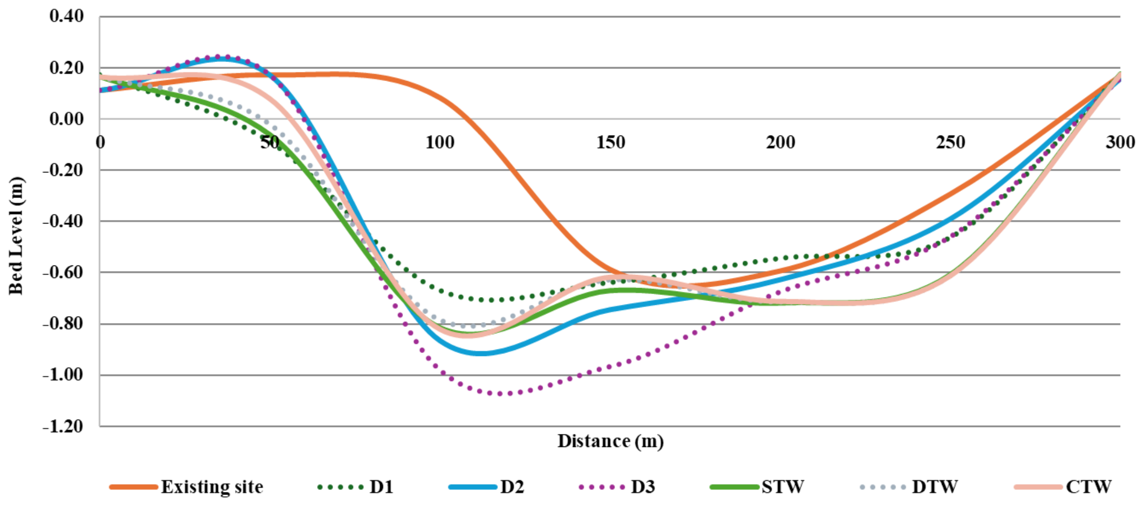


Fig 22: Bed level variation across Inlet Mouth 2 under dredging and training wall scenarios.

Corresponding author: sangeethasruthi01@gmail.com

Overall Assessment:
Among all three stabilisation strategies—dredging, straight training walls, and curved training walls—Dredging 3 consistently demonstrated the most effective sediment removal and flow improvement. While the Curved Training Wall and dredging provided a more balanced sediment distribution and gradual bed level changes, they require higher capital investment. Dredging alone offers a sustainable, cost-effective solution for maintaining inlet navigability and tidal exchange, with regular maintenance ensuring continued functionality. For long-term stability with controlled sediment redistribution, the Curved Training Wall may be considered a supplementary measure where investment is justified.
Recommendation:
Primary approach: Regular dredging (Dredging 3) to maintain inlet openness and hydraulic efficiency. **Secondary approach (optional):** Curved training wall in combination with dredging for enhanced sediment control and stability in high-investment scenarios.

7. CONCLUSION
This study assessed shoreline changes and evaluated various inlet mouth stabilisation schemes at the double-mouthed Agniyar Inlet, focusing on dredging (green measure) and training walls (hard measure, both straight and curved). Using the Delft 3D FM modelling suite, hydrodynamic and sediment transport processes were simulated over one year to examine the effectiveness of each scheme. The key findings are summarised as follows:
Dredging: The dredged inlet exhibits notable seasonal variations in bed levels, with pronounced erosion near the inlet mouth by mid-year and partial recovery by December. Despite these fluctuations, dredging maintains a stable and navigable channel, ensuring continuous tidal exchange.
Curved Training Wall: This approach provides consistent sediment management, resulting in gradual, controlled deposition and long-term stability with minimal maintenance. Mouth 1: Bed level reductions of 6% at 50 m on the north side and 3–4% at 25 m on the south side were observed. Mouth 2: Bed level reductions of 5–8% at 25 m on the north side and 90% at 25 m on the south side were observed. Across Mouth 1: Bed level reductions ranged from 100–105% at 25 m and 175–275% at 50 m. Across Mouth 2: Bed level reductions ranged from 13–20% at 200 m and 65% at 150 m.

8 RECOMMENDATIONS
After comparing the three schemes, dredging is the most sustainable and cost-effective approach for managing the inlet. It keeps the inlet open and functional year-round with minimal capital investment, adapting well to natural changes through regular maintenance. While the curved training wall offers better long-term stability, its higher cost and maintenance make dredging more practical for immediate, flexible, and affordable intervention. The curved wall could be a secondary option if long-term sustainability and reduced maintenance are prioritised over initial cost. Additionally, periodic assessments and adjustments to the dredging depth may help maintain optimal conditions as sediment dynamics evolve.

Funding declaration
No funding has been provided for this purpose. No clinical trial number applicable.

Corresponding author: sangeethasruthi01@gmail.com

REFERENCES

1. Hayes, M. O., & FitzGerald, D. M. (2013). Origin, evolution, and classification of tidal inlets. Journal of Coastal Research, (69), 14-33. https://doi.org/10.2112/SI_69_3
2. India Meteorological Department. (2021). Climatological Normals of Tamil Nadu (1981–2010). Government of India.
3. Indian National Centre for Ocean Information Services (INCOIS). (2022). Oceanographic data portal.
4. Hayes, M. O., & FitzGerald, D. M. (2013). Origin, evolution, and classification of tidal inlets. Journal of Coastal Research, (69), 14-33. https://doi.org/10.2112/SI_69_3
5. Kiran, A. S., Lokesh, T., Sankar, S., Jebakumar, P. P., Ravichandran, V., & Ramanamurthy, M. V. (2022, February). Sustainable opening of Adayar River mouth. In OCEANS 2022-Chennai (pp. 1-6). IEEE. https://doi.org/10.1109/OCEANSChennai45887.2022.9775238
6. Nayak, S., Shenoi, S. S. C., & Rao, A. D. (2012). *Wave climate of Indian seas*. Hyderabad: Indian National Centre for Ocean Information Services (INCOIS), Ministry of Earth Sciences, Government of India.
7. Ramesh, R., Purvaja, R., & Ramesh, S. (2015). Coastal processes and environment of the Palk Bay region.
8. (Ranasinghe, 1999) Roshanka Ranasinghe, Charitha Pattiaratchi, Gerhard Masselink, A morphodynamic model to simulate the seasonal closure of tidal inlets, Coastal Engineering, Volume 37, Issue 1,1999,Coastal Engineering, 37(1) 1-36. https://doi.org/10.1016/S0378-3839(99)00008-3
9. Rao, A. D., Sundar, V., & Mandal, S. (2010). Hydrodynamic and morphodynamic behavior of Palk Bay and adjacent coastal regions. Ocean Engineering,37(9),818–828.
10. Stive, M. J., & Wang, Z. B. (2003). Morphodynamic modeling of tidal basins and coastal inlets. In Elsevier oceanography series (Vol. 67, pp. 367-392). Elsevier. https://doi.org/10.1016/S0422-9894(03)80130-7
11. Velasquez-Montoya, L., Wargula, A., Nangle, J., Sciaudone, E., Smyre, E., & Tomiczek, T. (2022). Hydrodynamics of a tidal inlet under grey to green coastal protection interventions. *Frontiers in Earth Science, 10*, 991667. https://doi.org/10.3389/feart.2022.991667
12. Vikas, M. (2015). Classification of tidal inlets along the Indian coast. M. Tech thesis, Department of Applied Mechanics and Hydraulics, NITK, Karnataka, India.

Corresponding author: sangeethasruthi01@gmail.com