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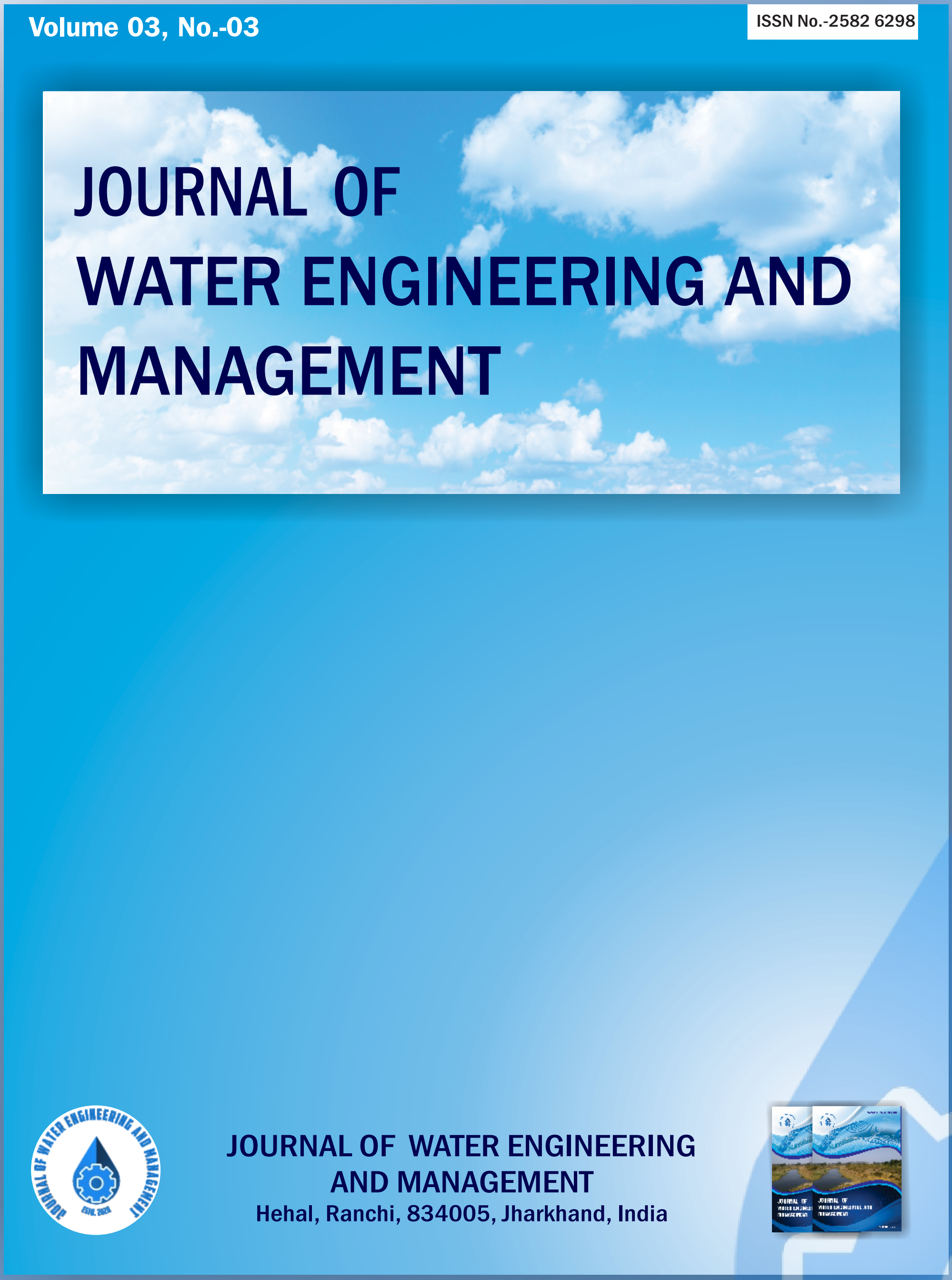

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Research Paper

# *Hydrodynamics and Sediment Modelling for a Fishery Harbour at Konkan Region of Maharashtra, India*

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## ABSTRACT

Coastal regions are among the most important places for urban development and industrial expansion. However, the system is active and it must be well examined before any infrastructure is planned, to avoid harm from natural processes like degradation, sedimentation, and sometimes sea-generated natural disasters. Numerical modelling of the coast to forecast the area's natural parameters is an important technique for assessing these systems. Coastal regions are of critical importance to most of the world's citizens with a significant bearing on economic activities. In the present study, a well-calibrated mathematical model of Vengurla, Maharashtra, has been developed using MIKE 21 flexible mesh software, with the latest prototype data and also carried out 2-D hydrodynamic studies for the proposed 500m breakwater and approach channel. The simulated model will be tangled with the sediment transport model to ascertain the likely pattern of siltation in the area. After studying the Hydrodynamic model, it was observed that in existing conditions, currents varied in the range 0-0.02 m/sec inside the Vengurla creek and 0-0.15 m/sec in the seawater and currents under the proposed condition varied in the range 0-0.029 m/sec inside the Vengurla creek and 0-0.22 m/sec in the seawater. No severe circulation or eddies were observed near the beach area in the existing condition as well as in the proposed condition, hence no siltation have occurred in that area. From the sediment model, it was observed that there is not much siltation/erosion after the construction of the proposed breakwater and deepening of the approach channel.

**Keywords:** Hydrodynamic, Coastal region, Fishing harbour, MIKE 21 HD, Siltation, Vengurla creek.

## INTRODUCTION

India is one of the fastest emerging large economies globally, with a GDP growth rate of 7.5% in 2015-16, and ports play a vital role in the country's overall economic development. Approximately 95% of India's merchandise trade (by volume) passes through seaports (Indian Ports Associations, 2021). In India, the backbone of the country's trade is mainly the Maritime sector and has grown manifold over the year. About 14.2% of the population of India is living in this coastal belt. Hence the development of this coastal belt is not essential for trade but also for the betterment of people living along this coastal belt. For the establishment and development of industries, coastal regions are found to be the most favourable spot. India being the 3rd most significant exporter of fisheries, constructing new fishing harbours, and maintaining older fishing harbours and port also plays an important role. Sedimentation diminishes the channel's breadth while simultaneously lowering its oceanic depth. However, accretion or erosion is a natural occurrence that occurs when loose sediments are transported from a source to a sink area. Natural sedimentation zones are referred to as shoals, flats, banks, sheets, bars, etc. To analyze the flow and sedimentation pattern, it is essential to recognise the active movement in the study zone. A beneficial tool is numerical modelling accessible for engineers; numerical models supplement and replace physical models in many studies regarding estuaries, coastal and offshore phenomena.

Various research on tidal hydrodynamics and sedimentation near the Indian coast has been conducted in India. It has been found that the Western coast has more tidal ranges than the eastern coast. The Arabian Sea in the west has a flatbed slope and is more profound, whereas the Bay of Bengal has a steep bed slope with comparatively low depth. This shows that the west coast has favourable conditions for natural harbours. And a result of which significant industries are setups in the coastal region**.** Shukla et al. (2015) recommended dredging as a necessary practice to keep the port depths at the desired level. Raganatha et al. (2017) constructed an averaged depth model to reflect the hydrodynamics and trends of sediment movement in the Gulf of Khambhat along India's west coast during rainy and non-rainy seasons. The results demonstrated the overall average current speed inside the gulf as 0.75 m/s during the non-rainy season and roughly 1 m/s during monsoon. Nair et al. (2011) studied the coastal stretch between Kayamkulam and Arattupuzha which is part of the Kayamkulam–Thottapally sector Kerala's coast. The MIKE 21 and Hydrodynamic Model (FM) were used to simulate coastal dynamics. In comparison, the LITPACK coastal suite (DHI) was used to investigate shoreline change. The findings revealed that the construction of breakwaters at the site has exacerbated erosion on the north bank of the Kayamkulam inlet. Sharvanthi et al. (2015) developed a better understanding of silt movement through the central coast of Kerala. Sharma and Agarwal (2017) showed the effects of various river discharge conditions on sedimentation in the navigational channel and river mouth of the Karnataka state's Yedamavinahole River. The results showed that there would be no significant change in the existing morphology of the river and mouth during non-monsoon periods, but that during low river discharges, sedimentation would be on the order of 0.6 m in the river stretch in front of the proposed reclamation, which would require dredging. Sawant et al. (2017) studied the hydrodynamic and mud transport consequences for various proposed coastal structures near Mandwa port on India's west coast. Different proposed constructions included offshore breakwaters, reclamation with a projected Ro-Ro jetty, dredging the approach canal, and a marina complex. The current at different locations matches 70-90 percent for peak flooding, peak ebbing, high water, and low water, according to many calculations of the flow field. Many more studies were conducted in different coastal areas of India (Ranganatha et al., 2014; Barve et al., 2015; Pradhan et al., 2018; Kanga et al., 2020). In the present paper, Hydrodynamic conditions along the shoreline of the Vengurla coast in Maharashtra were simulated using MIKE 21 HD and MIKE 21 MT modules for the existing and proposed conditions. Sediment transport pattern and variation for the existing and proposed condition along the shoreline was also investigated.

## MATERIALS AND METHODS

### Study Area

Vengurla is located at 15.51°N and 73.38°E in the coastal region. It has an average elevation of 11 meters above the mean sea level. Vengurla is an alluring beach Taluka city in Sindhudurg district, a part of the Kokan region of Indian state Maharashtra shown in (Fig. 1), India, just 110 km north of goa. It is surrounded by a semicircle range of hills with lush green foliage mainly of cashew, mango, coconut, and different berry trees. Vengurla is a completely natural harbour, with Dutch traders and British rulers establishing the economic centre in 1665. The maximum temperature in the summer is 42 °C, while the minimum temperature in the winter is 10 °C. The mean annual rainfall is 3,155.3 mm. The primary source of livelihood of the venture is fishing. Tides in this area are mostly semi-diurnal, ranging from 0.5-2m. From September to April, the monthly mean breaking height in Vengurla is roughly 0.7m, and from May to August, it reaches 1m. The wave height fluctuates between 1.5 and 3.0 metres, while the wave period changes between 5-8 seconds from June to September, 0.5 to 1.5 metres from October to May, and 5-6 seconds from October to May. In this area, the most common wave directions are SW, WSW, W, and WNW. The sediment is transported northwards by southwesterly waves, whereas it is transported southwards by WNW waves.

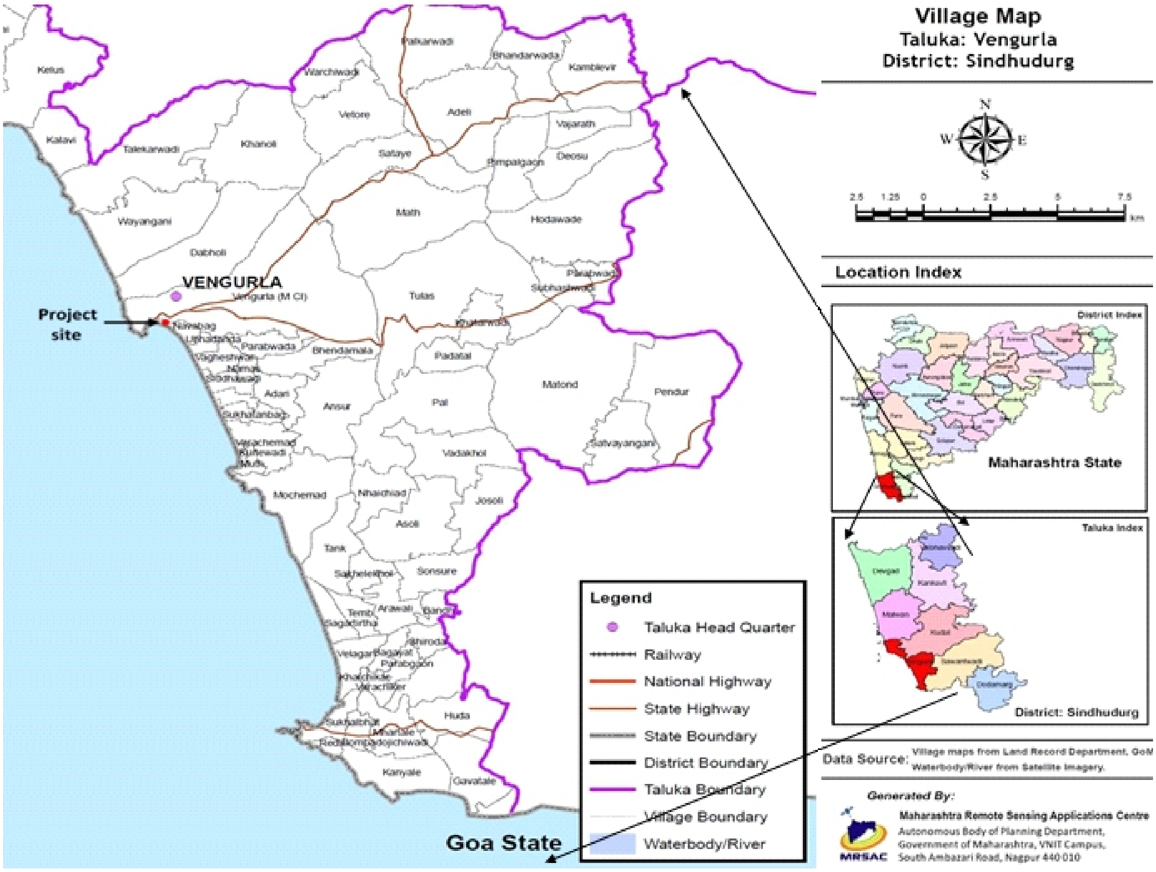


**Fig.1.** Location of Vengurla coast

## Hydrodynamics (HD) Model

The MIKE 21 Flow Model – HD employs a coarse mesh approach to model for 2D free surface movements. In lakes, estuaries, bays, coastal zones, and seas, the MIKE 21 flow model simulate the hydraulic and environmental processes. It can be utilized in situations where categorization isn't necessary. In lakes, estuaries, and coastal environments, the hydrodynamic module analyzes changes in the water table and flow as a result of different driving factors. MIKE 21 HD is the most modern and nonlinear model. It simulates flow progression in the time domain while taking into account the effects of tidal changes and wave-driven currents. It also takes into considerations how waves and tides interact. The HD module is dependent on a numerical solution of the two-dimensional shallow water, mean-depth Reynolds averaged Navier-Stokes equations. The equation of spatial discretization utilizes specific cell finite volume techniques. By dividing the continuum into non-overlapping components, the spatial domain is discretized. For time integration, an explicit technique is used. Using the MIKE 21 HD module, the hydrodynamic analysis was conducted. To explore tidal flow requirements and sediment dynamics, it is necessary to analyze in terms of velocity and variability of water level to examine the hydrodynamics of a water network. The details of the equations and the solution techniques are available in the manual (DHI, 2014). MIKE 21 Flow Module is composed of the following Modules in Fig. 2.

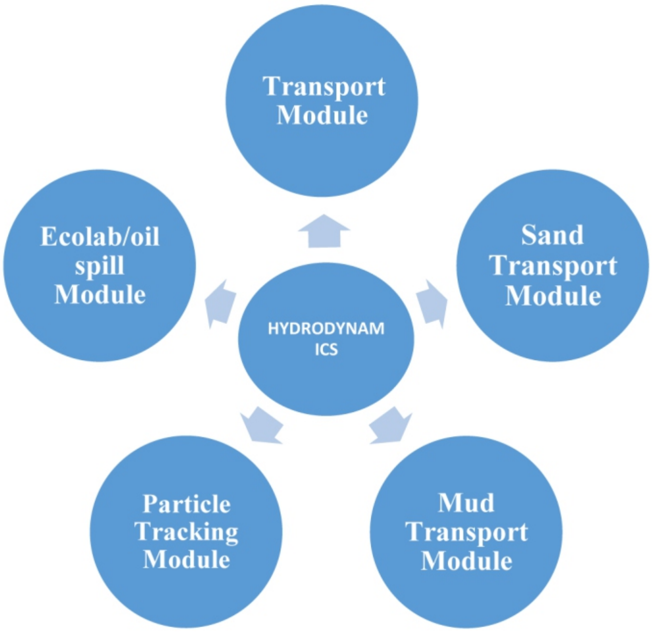


**Fig. 2.** Flow chart of module

The output of the hydrodynamic module is a current velocity pattern for various tidal conditions and seasons. In general, the forces caused by tides, wind, waves, and regional forcing are considered in this module. The site should be at a sheltered location where the wave climate is extremely mild throughout the year and does not influence the current and sand movement. The coarse grid model and the basic grid model are used in the modelling. Large grid spacing is used in the coarse grid model (in the order of 1 km based on the modelled region's size). The fine grid model's grid spacing is essential because it determines the output. The fine grid spacing should be less than 50 m in most cases. If any estuaries are to be represented, the fine grid spacing must not exceed 14 times the river mouth's width. The grid size used to model the effects of coastal buildings must not exceed 14 percent of the design length. The outside boundary of the fine grid model must be suitably far away from the project area to avoid introducing inaccuracies in the project area. The coordinates of the specified model borders, as well as the project's location, were given to UTM or Lat-Long coordinates.

## Bathymetry and Tidal Data

Bathymetry is the study and mapping of the topography of the seabed. It entails the estimation of the depth of water in the ocean and resembles topographic maps. Bathymetry data were collected from Jeppesen charts using C-MAP. CMAP uses Jeppesen Norway's Global Electronic Chart Database CM-93 Edition 3.0. Bathymetry data, i.e., both the surveyed data and the data obtained from C-MAP, were integrated using latitude-longitude and respective depth contours. MIKE was used to smooth down the final bathymetry. Bathymetry represented the Vengurla coast and at the seaward end, an open boundary connects 73°33'25.41"E to 73°35'20.13"E longitude and 15°51'43.09"N to 15°46'45.02"N latitude. C-MAP was used to obtain land demarcation coordinates and coordinate wise bathymetry data were rectified using Google earth pro. The bathymetry was created using MIKE Zero bathymetry, a tool for creating and manipulating coarse grids. The bathymetry contains three types of mesh finer, fine, and coarse mesh up to the depth of -5m, -9.05m, and -16.5m. The combined final bathymetry of this model contains a region of approximately 10 × 7 km and ranges up to -16 m seawater depth.  The tide levels at any location are managed mainly by latitude, the comparative locations of the moon and sun to the earth, the geography of the area and river discharge. The tidal level can be measured visually using staff gauges or can be recorded by instruments. In this study, the field data was collected during March 2021 at an interval of 15 min. This tidal data shows a 2m tidal range for spring tide and a 0.5 m tidal range throughout the neap tide. The field measured level of water is utilized as the boundary condition for simulation analysis in Fig. 3.

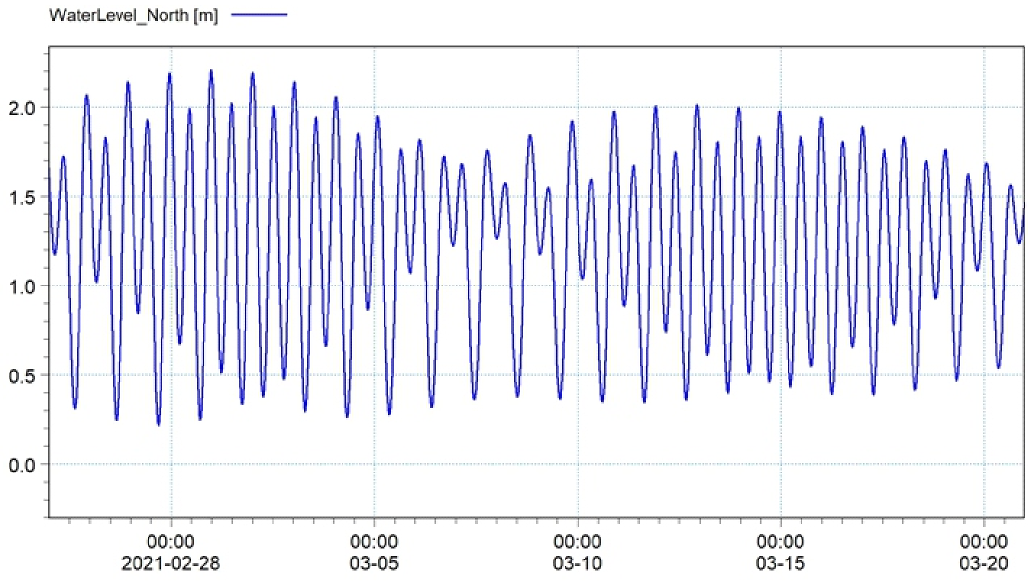


**Fig. 3.** Tidal level in boundary (March 2021)

In the model's sea section, there were three open limits. Tidal variations were employed as boundary conditions at the northern and southern available boundaries, but no flow conditions were imposed at the western open border. The flexible mesh enables the maximum degree of flexibility. The spatial discretization of the wave action conservation equation was accomplished using an unstructured finite volume approach. In total, the mesh contains 1435 nodes and 2457 elements. as shown in Fig. 4 (existing condition) and Fig. 5 (proposed condition).

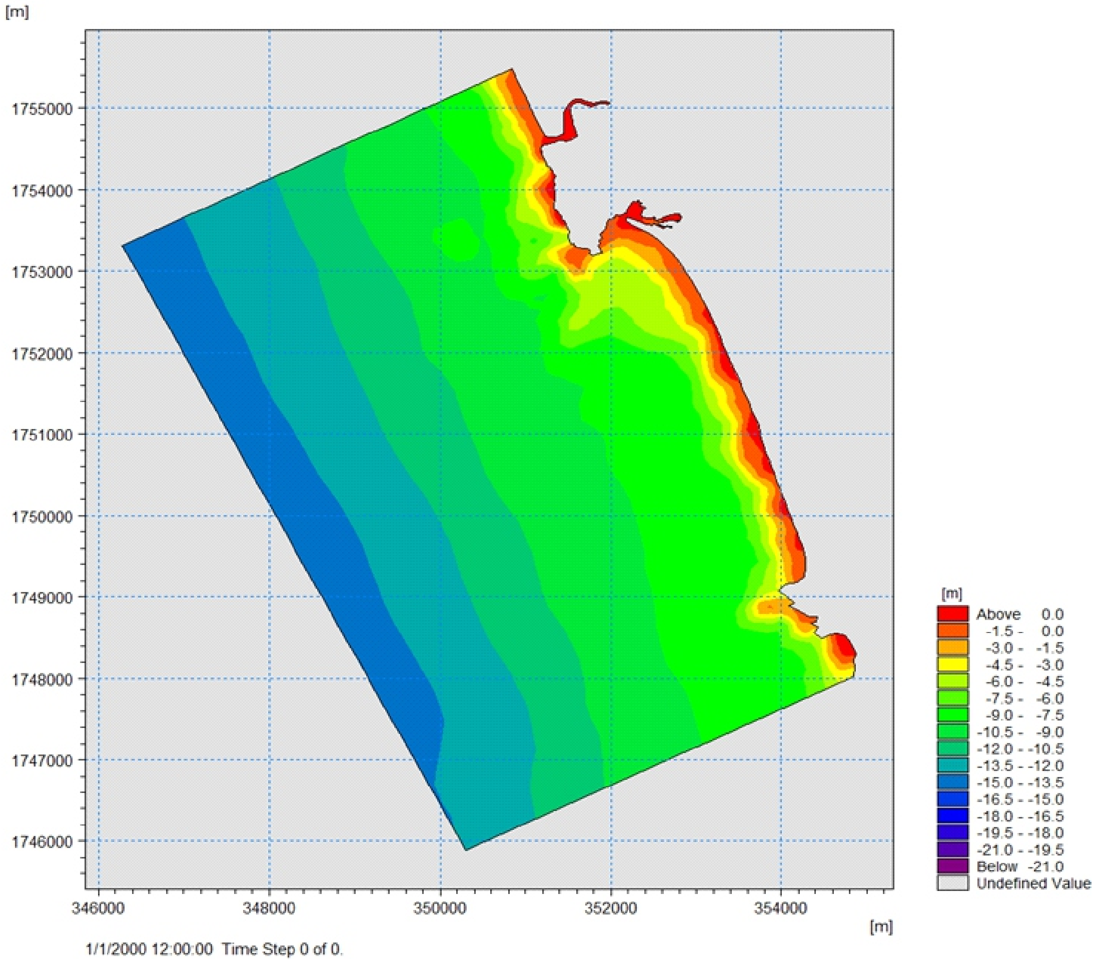


**Fig. 4.** Bathymetry of the existing condition

## Current and Sediment Data

The currents vary spatially and temporally in both magnitude and direction. Knowledge of currents is essential in assessing siltation in channels and harbours water to understand the geomorphic changes. The analysis of current data gives current strength and direction at a particular location during flood and ebb. In our study, current data were collected at locations (73°37'18.595"E and 15°21'25.538"N) at a depth of 2.1m during March 2021. The water surrounding the project site, at the entrance of the creek, is extremely murky and turbid. Suspended solids concentrations are incredibly high and fluctuate widely. Table 1 summarizes the analysis of the suspended solids in the project area. The average value of $D_{50}$ (mm) of beach samples (1-5) is 0.224 mm and is used for model studies. For this model, the simulation period was one month, and the time step interval was considered 30 seconds. The specific hydrodynamic parameters, considered in the study, are solution technique, depth, flood and dry, density, eddy viscosity, bed resistance, initial condition (constant with surface elevation 2m) and Boundary Condition (Water level boundary). The studies were initially carried out in the present conditions of the Vengurla fishing harbour. For the first 23 days, the model was run for the existing condition with the tide from C Map data. The tidal input was delivered with equitable phase lag along with the northern and southern open limits. Different model options with tides were used in the simulations.

**Table 1** Average silt charge values in harbour area (mm)

| Sample No. | $D_{50}$ (mm) |
|---|---|
| 1 | 0.254 |
| 2 | 0.225 |
| 3 | 0.216 |
| 4 | 0.217 |
| 5 | 0.207 |

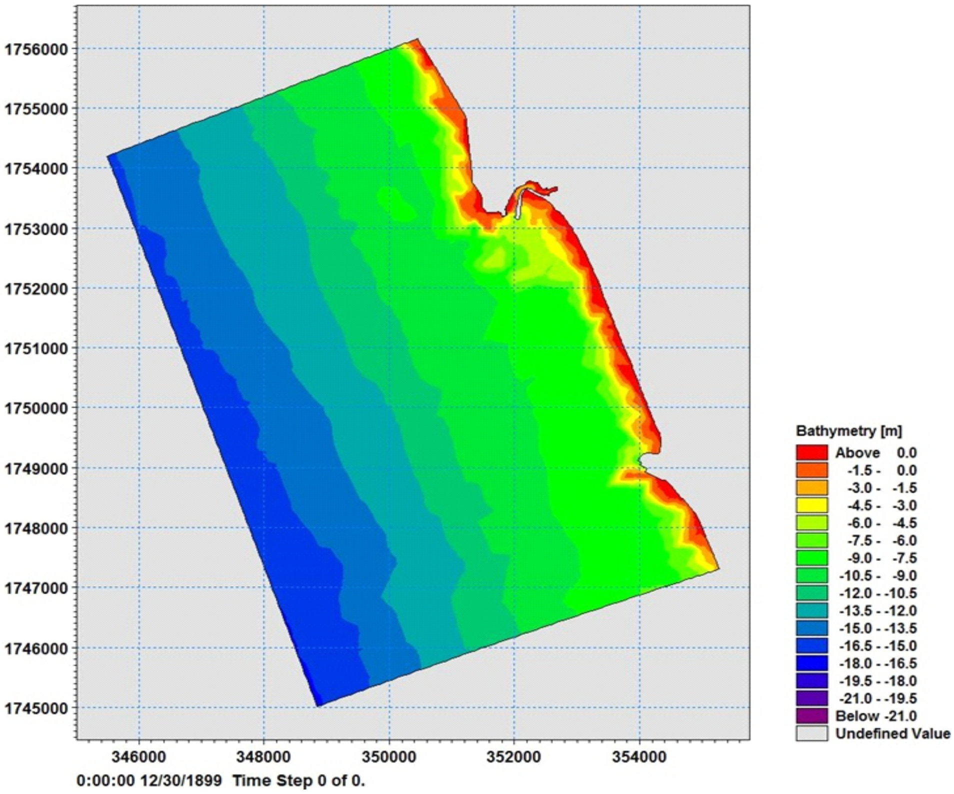


**Fig.5.** Bathymetry of proposed condition.

## Mud Transport Modelling

Cohesive fine-grained sediments with grain sizes lower than 63 microns are referred to as mud (DHI, 2014). Current and wave action brings fine particles into dispersion and transfers them. Fine-grained debris is concentrated and deposited in the furthest reaches of the area due to transport mechanisms (settling and scour lag) in estuaries (Postma, 1967). The fine-grained particle transport and deposition aspects in the model use the convective-diffusion equation caused by the moment of water. Thus, it shows that the modelling of fine-grained material movement must be mean over depth, and proper sediment process parameterizations must be used. The Mud Transport module (MT) of the MIKE 21 model is connected to the Hydrodynamic module (HD). The Mud Transport Module (MT) of the MIKE 21 flow model shows how mud or sand/mud mixtures are eroded, transported, and deposited by currents and waves.

The erosion, movement, and sedimentation of fine-grained material with a grain size of 63 m (silt and clay) due to currents and waves were simulated by MIKE 21's mud transport module. The sediment deposited on the bed solidified is also considered in the proper response of erosion processes. Because of the broken faces of minerals, clay particles are shaped like plates and the net charge of the ion is negative. A dynamic flow and sediment interaction model is used in the MT model. According to Krone (1962), the rate of deposition is calculated as follows:

$$S_D = W_B C_B P_d \tag{1}$$

where,

$W_B$ = velocity of settling (m/s)

$C_B$ = concentration near the bed (kg/m$^3$)

$P_d$ = deposition probability = $1 - \frac{\tau_b}{\tau_{cd}}$, $\tau_b \leq \tau_{cd}\tau_b$, $\tau_b$ = shear tension in the bed (N/m$^2$)

$\tau_{cd}$ = shear stress in the bed that is critical for deposition (N/m$^2$).

The sediment concentration profile may be expressed using two different phrases. Teeter's statement is based on an approximation of the vertical depositional fluxes during sedimentation, whereas Rouse's equation ensures equilibrium among upward and downward sediment fluxes. The vertical transport is associated with the close-bed concentration $C_B$, which is equivalent to the depth-averaged mass concentration, i.e., the Peclet number reflects a proportion of vertical convective and dispersive transport:

$$\mathrm{P_e} = \frac{\mathrm{C_{rc}}}{\mathrm{C_{rd}}} \tag{2}$$

where

$c_{rc}$ = courant number (convective) which is equal to $w_s \frac{\Delta t}{h}$

$c_{rd}$ = diffusive courant number = $\overline{D_z}\ \frac{\Delta t}{h^2}$

$\overline{D_z}$ = mean eddy diffusivity in depth

$C_B$ = concentration c is connected to the near-bed concentration where

$c_{rc}$ = courant number (convective) which is equal to $w_s \frac{\Delta t}{h}$

$c_{rd}$ = diffusive courant number = $\overline{D_z} \frac{\Delta t}{h^2}$

$\overline{D_z}$ = mean eddy diffusivity in depth

$C_B$ = concentration c is connected to the near-bed concentration

depth-averaged Concentration,

$$\beta = \frac{C_B}{\bar{c}} \tag{3}$$

where, $\beta = 1 + \frac{P_e}{1.25+4.75P_d^{2.5}}$

$P_e$ is Peclet number and is equal to $\frac{w_s h}{\overline{D_z}} = \frac{6w_s}{kU_f}$

$p_d$ = deposition possibility

The erosion is classified into two categories by (Mehta, 2014).

Bed that is dense and solid:

$$\text{Erosion: } S_E = E\left(\frac{\tau_b}{\tau_{ce}} - 1\right)^n, \tau_b > \tau_{ce} \tag{4}$$

where,

E = bed's erosibility (kg/m$^2$/s)

$\tau_{ce}$ = critical bed shear stress. (N/m$^2$)

$n$ = erosion's strength

Bed is soft and moderately solidified:

$$\text{Erosion: } S_E = Eexp\,[\alpha(\tau_b - \tau_{ce})^{1/2}],\ \tau_b > \tau_{ce} \tag{5}$$

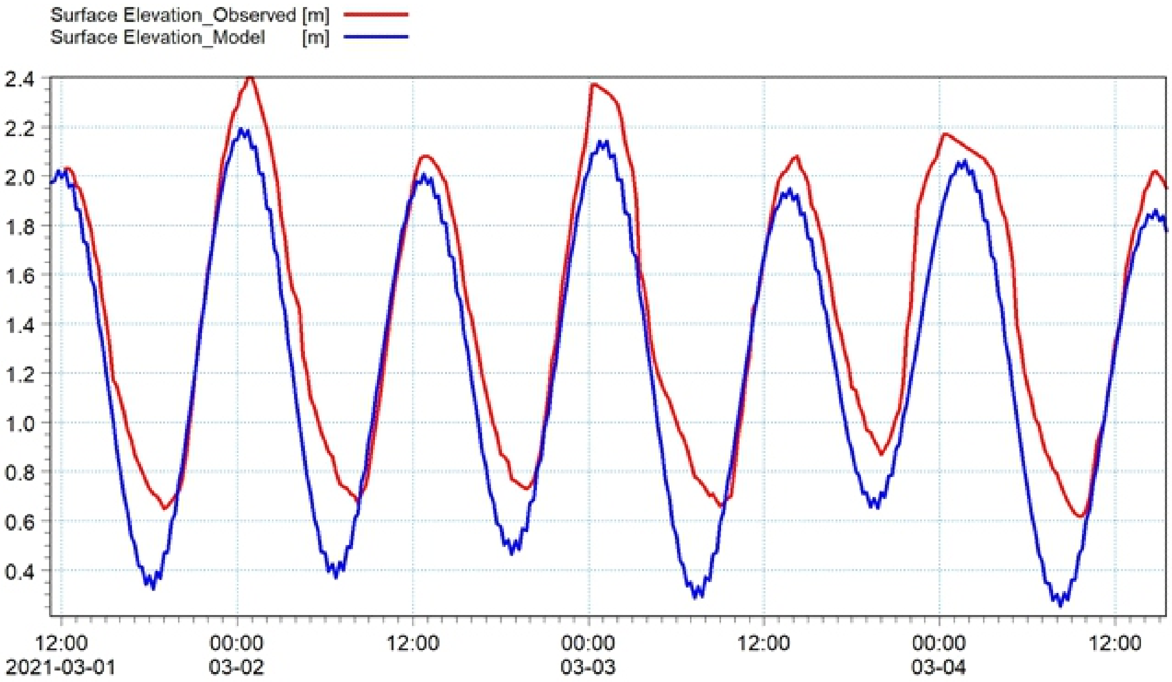
where, α is coefficient (m/N$^{½}$).

## RESULTS AND DISCUSSIONS

### Simulation of Flow Field

The model was calibrated using observed data from simultaneous tide and current observations made near the site during March 2021. The measured and computed tidal levels are shown in Fig. 6, which demonstrate a similar pattern. The flow fields at each hour tidal conditions were recorded for the present situation, and the typical velocity vector plots of different stages of tides were developed. The velocity vector plots of behavior of current speed during spring tide and neap tide periods at low water conditions, peak flood conditions, high water conditions and peak ebb conditions were obtained. The flow field during the first low water in the existing condition is shown in Fig. 7. We have not shown all the figures for all the conditions. The plots of extracted data of the model of the existing condition with respect to the current speed and surface elevations at points (1, 2, 3, 4 and 5) were developed and only for location point 1 is shown in Fig. 8. Flow field during high water changes from flood to ebb situation, due to this slack or calm condition occur. Similarly, the flow field during low water time changes from ebb to flood situation, due to this again slack or calm conditions occur.

The present condition was improved using the same model by creating breakwater at the south opening mouth of the creek and dredged the channel up to the depth of 2.5m deep. The model was run for the proposed conditions. The boundary conditions for the model would remain the same. To modulate continuous flow conditions with fluctuating tidal levels, simulations were run for 23 days. Every 15 minutes, the flow fields were measured. The typical velocity vector plots were made during different phases of the spring tide for the proposed construction. The flow field of current speed during low water, peak flood, high water and peak ebb, and again at low water with fluctuating action of the tide in proposed condition were plotted. The flow field during the first low water in the proposed condition is demonstrated in Fig. 9. A change in the proposed condition was noticed when compared to the existing condition model results. Figures 10 shows the bathymetry of the proposed condition. Again, the plots of extracted data of the model of the proposed condition with respect to the current speed and surface elevations at points (1, 2, 3, 4 and 5) were developed and only for location point 1 is shown in Fig. 11. From the plot, the current of observed and computed are of the same magnitude in both the conditions (existing and proposed conditions) at some points. There is almost no change in surface elevation but some changes in the current speed at every point. Figure 12 shows the plots of comparison of current speed and surface elevation between existing and proposed site conditions at point 1. Similar plots were obtained for all the locations.



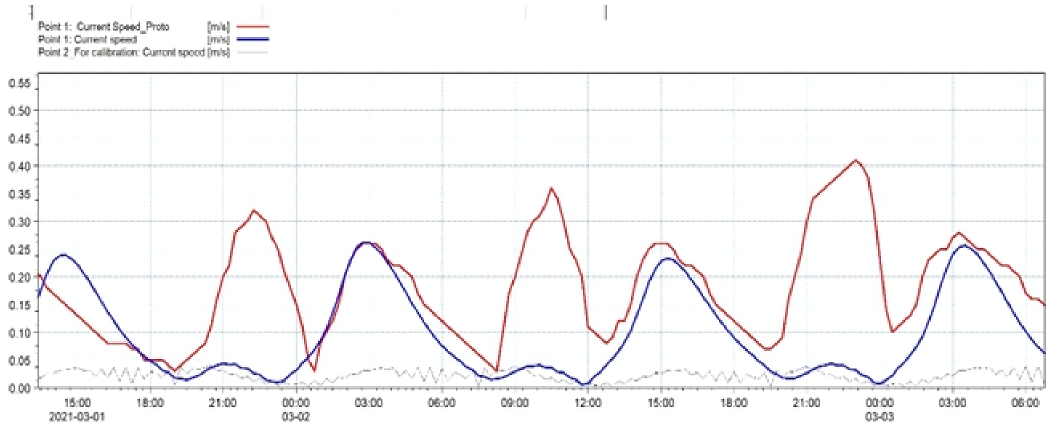


**Fig.6.** Calibration of tide and current.

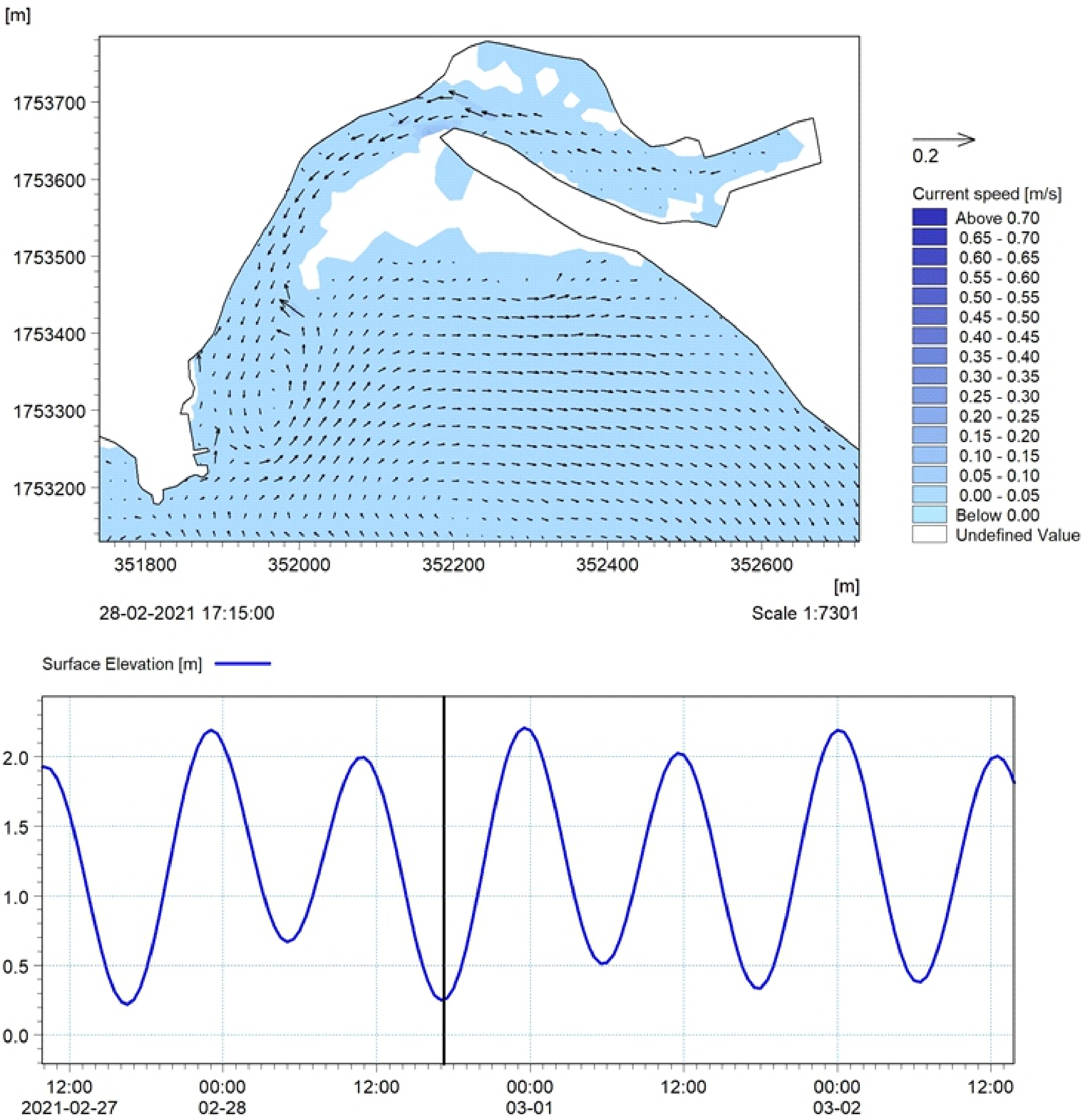


**Fig.7.** Flow field during first low water in existing condition

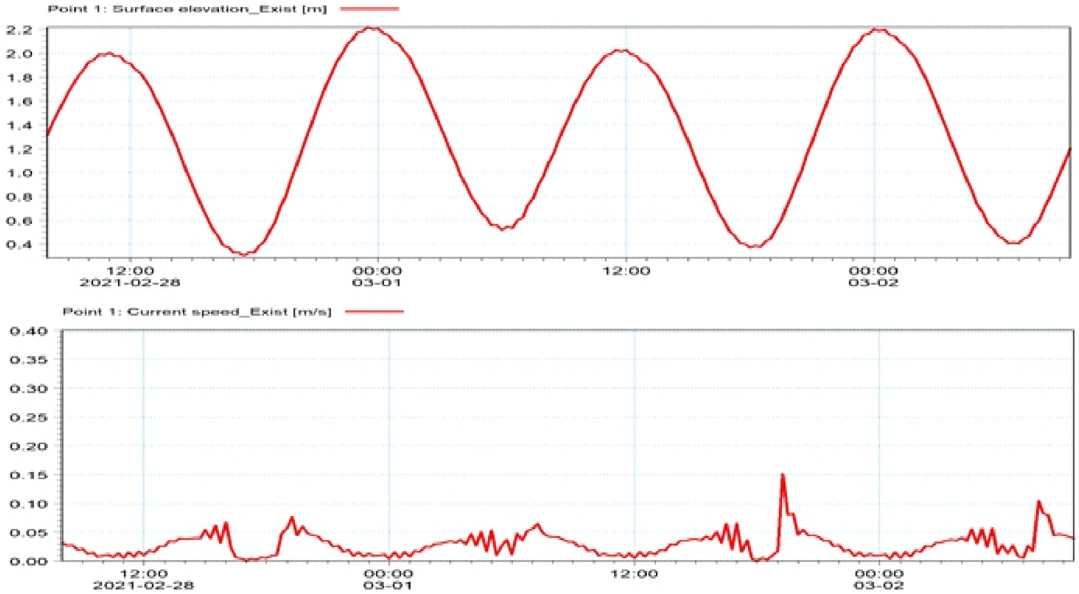
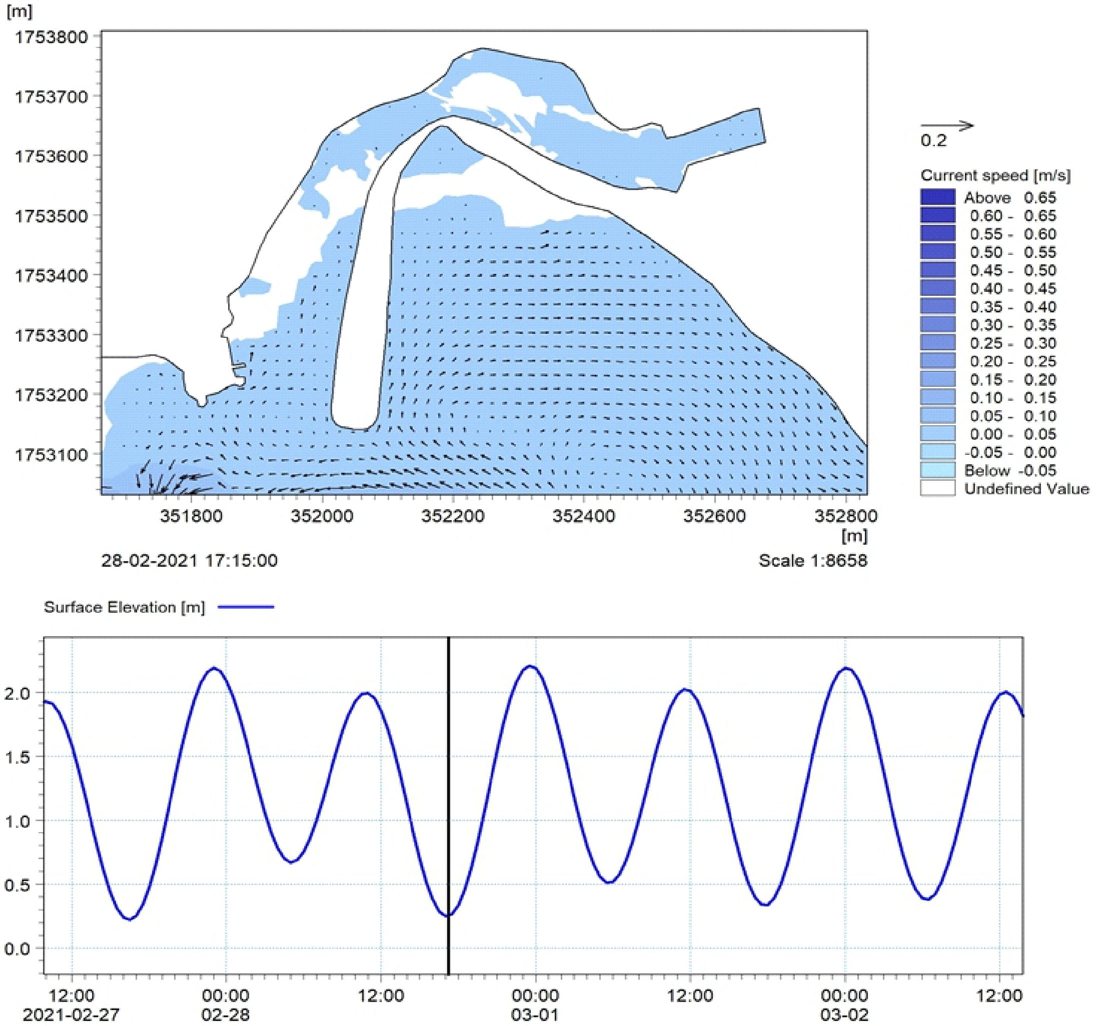


**Fig. 8.** Model extracted data of surface elevation and current speed at point 1 location in existing condition.



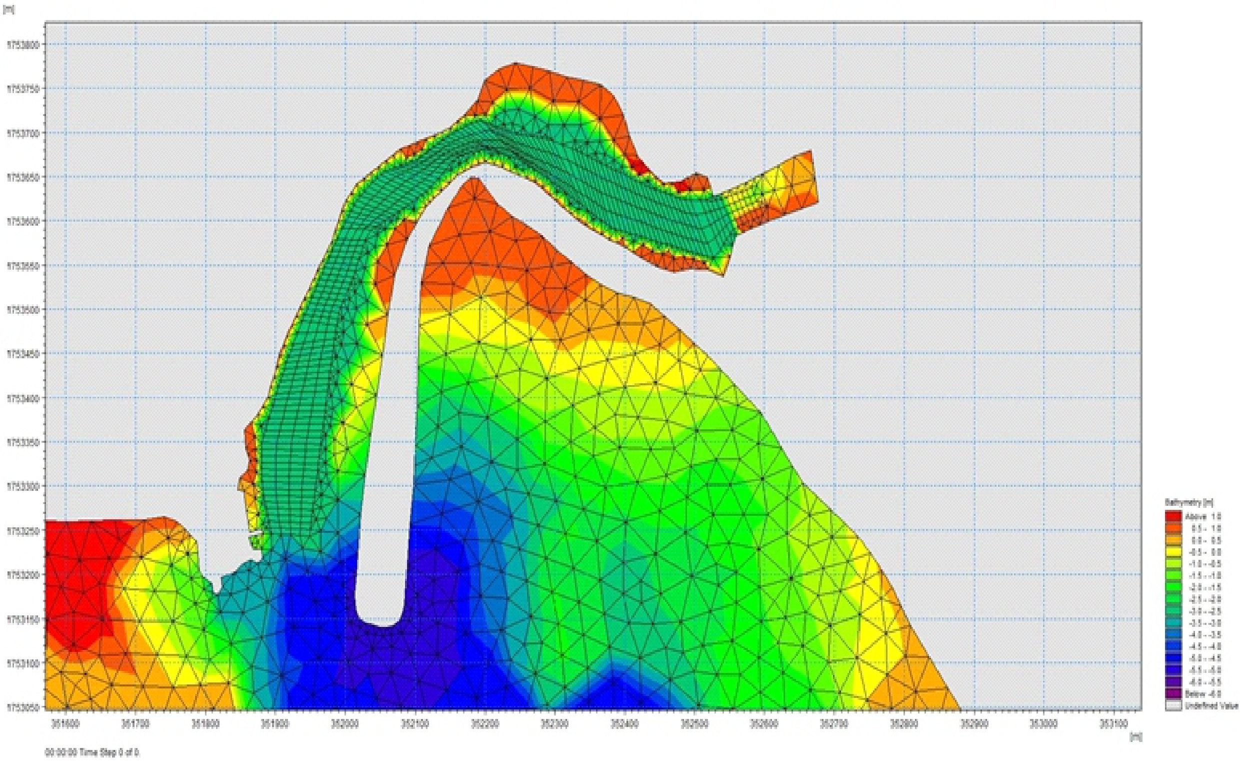


**Fig. 10.** Bathymetry of proposed condition with mesh (zoom view)

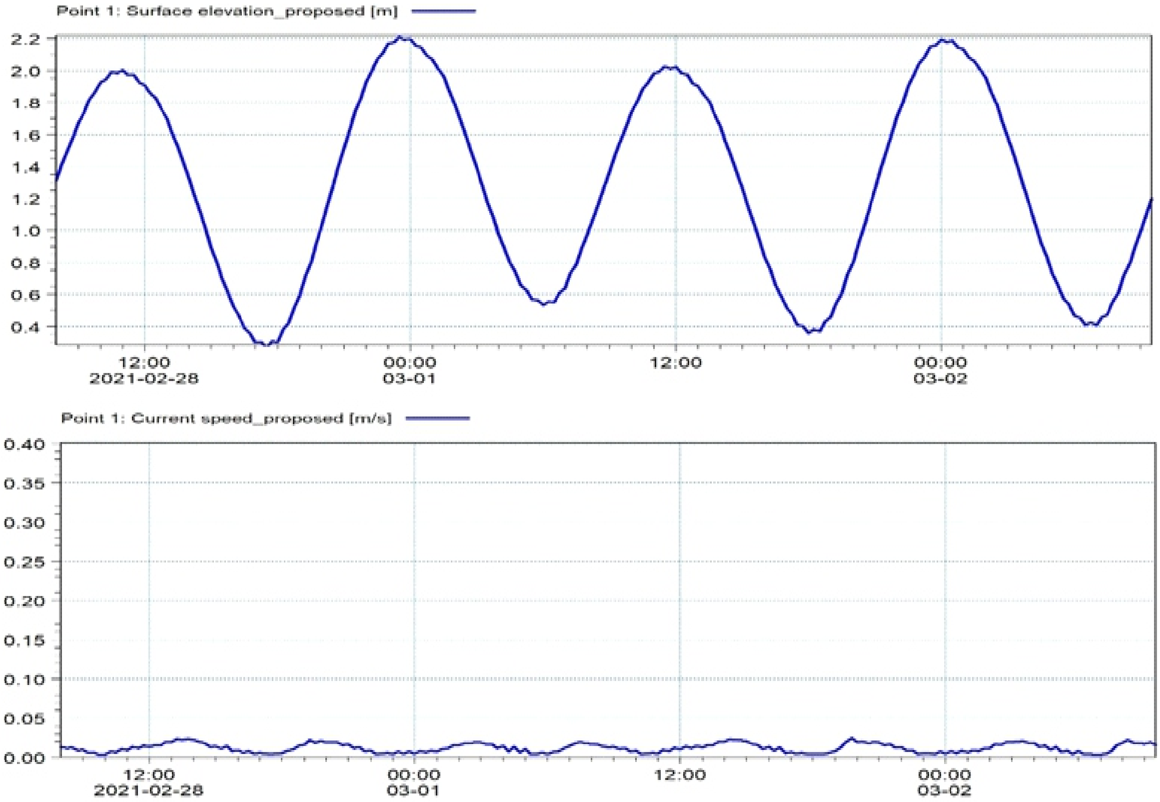


**Fig. 11.** Model extracted data of surface elevation and current speed at point 1 location in proposed condition.

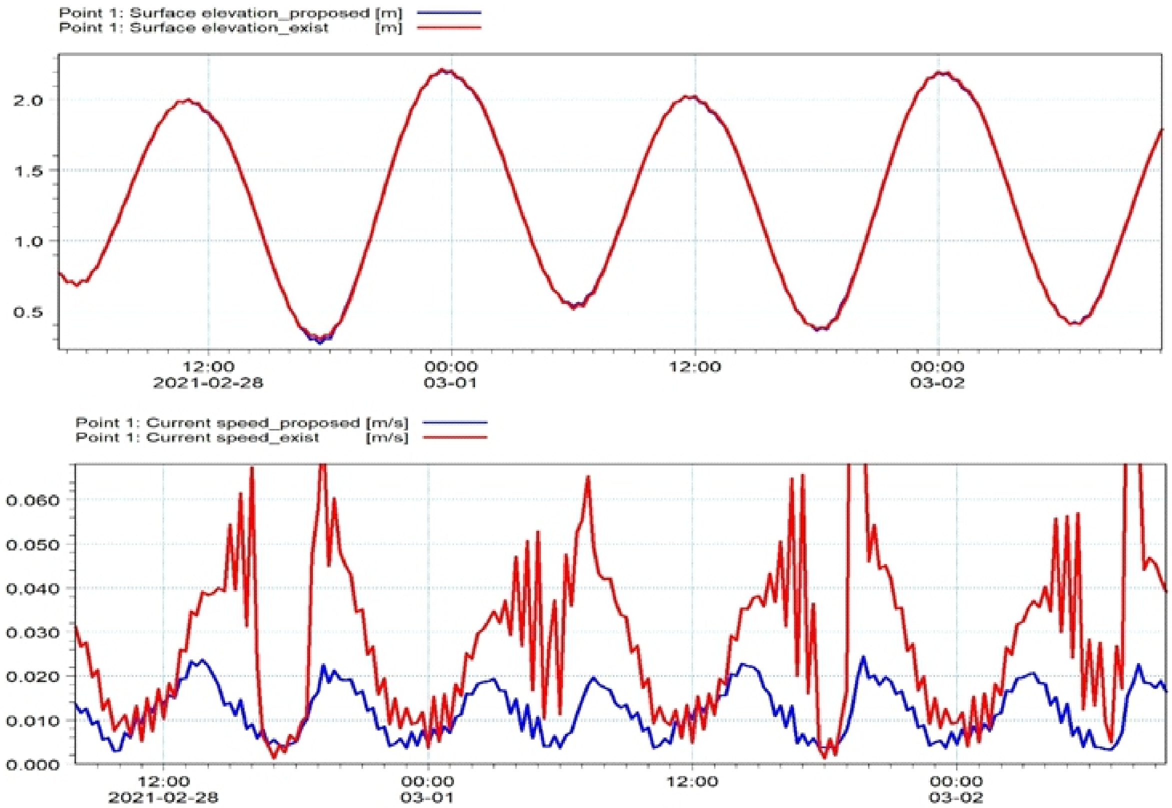


**Fig. 12.** Comparison extracted data at point 1(existing and proposed conditions).

## Simulation of Sedimentation

For a simulated period of 23 days, the mud transport investigations were conducted under existing conditions, taking into account the spring and neap tidal conditions. Sedimentation was detected at various times during the tide cycle. A typical siltation pattern over a period for the existing condition was plotted in Fig. 13. It is observed that there is a tendency of sedimentation at the mouth of the creek of Vengurla. The average depth of sediment deposition varies from 0 to 0.24m. The calibrated model with a proposed breakwater in the bathymetry has been simulated for morphological conditions coupled with hydrodynamics. The effect of the breakwater on siltation is explicitly seen in Fig. 14. Nevertheless, siltation is expected in the proposed area; however, the magnitude is tiny in terms of volume. Because of the limitations of the model and the non-availability of exact siltation data during the simulation period, it is challenging to predict exact siltation in the quantitative form. Hence morphological model studies will give predictions from the qualitative point of view only. The model was further simulated to predict the siltation pattern with the modified layout by creating breakwater on the southern side of the opening mouth of creek fishing harbours and dredging the channel as per proposal to the depth of -2.5m depth enhance natural flushing of sediments during ebb conditions. A typical siltation pattern for three weeks with the breakwater is plotted in Fig. 14. The deposition zone can be shown to be in the range of 0 to 28 cm depth on average. By comparing current speeds at five locations in the study area, it is clear that the magnitude of current speed is decreasing in the proposed condition when compared with the existing condition when scenario. It will clearly indicate drawdown in sediment carrying capacity of water, which in turn leads to sedimentation in the area. Since, the magnitude of current speed was not much before and after the construction of breakwater, hence the sediment deposition will only be marginal and not of much concern

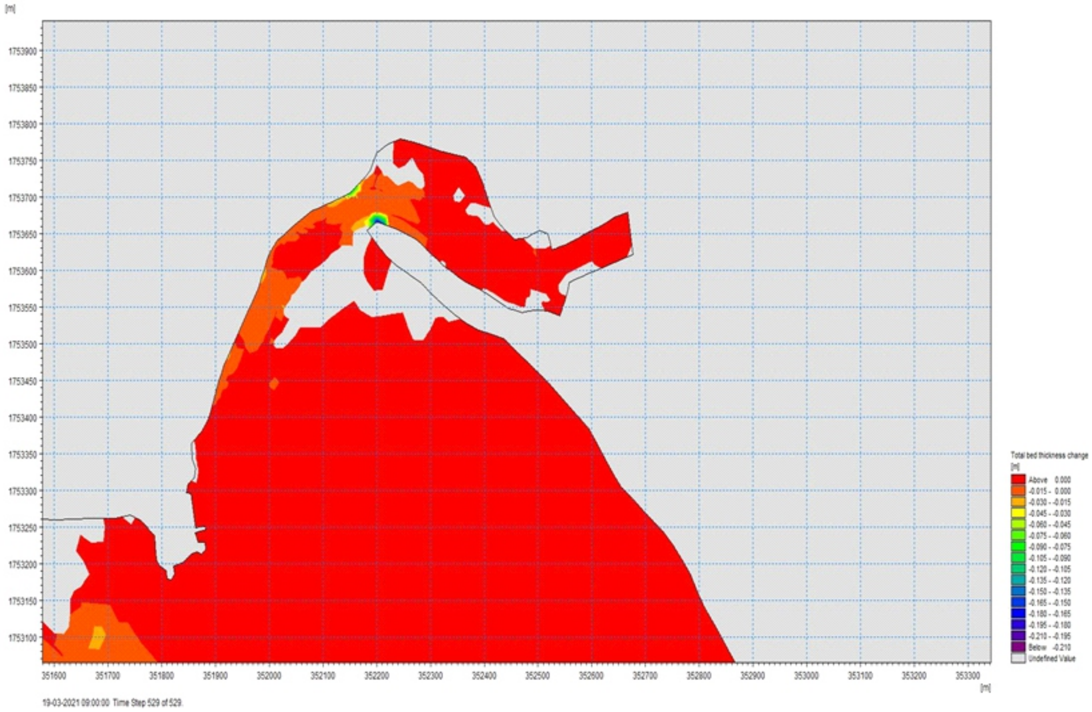


**Fig. 13.** Total bed thickness change (m) during existing condition

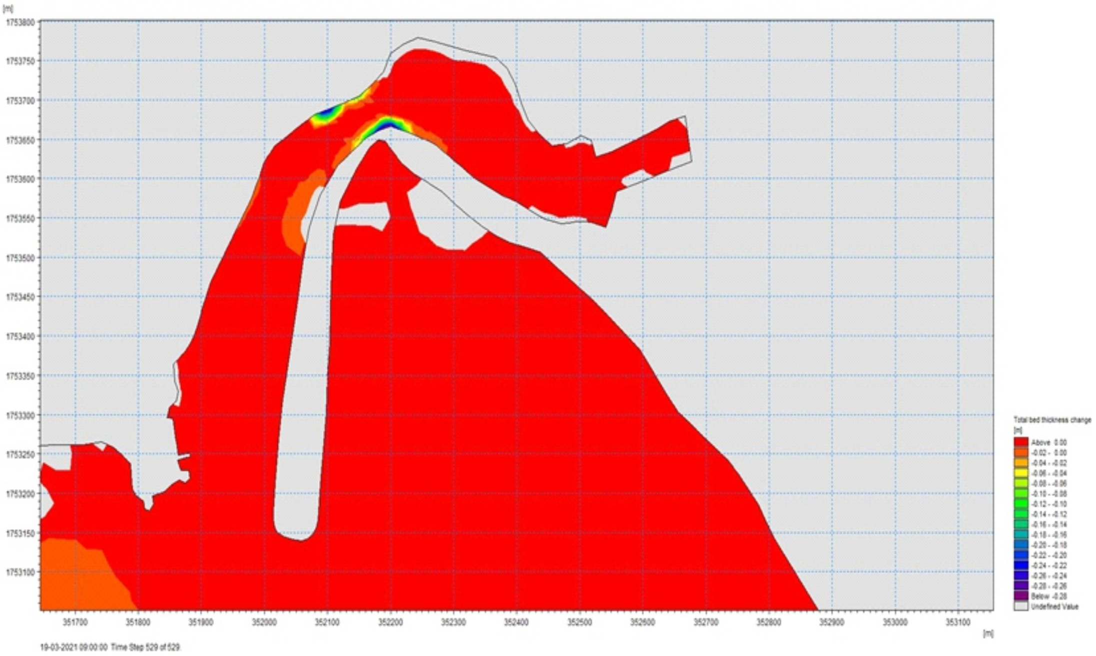


**Fig. 14.** Total bed thickness change (m) during the proposed condition.

## CONCLUSIONS

An analysis to investigate the hydrodynamic and sedimentation conditions along the Vengurla coast, Maharashtra, both in their current state and after the proposed construction. For modeling hydrodynamics and sedimentation in and around the region, the mathematical models MIKE-21 HD and MIKE-21 MT are two-dimensional finite-difference focused models. The latest recent data for each location was used to calibrate the model. The model had an effective connection with the available data of current. The follows are the principal observations of the mathematical model analyses for hydrodynamics on the mouth of the creek at Vengurla shore for present and proposed conditions:

- Hydrodynamic study with existing conditions reveals that the magnitude of currents varied in the range 0-0.02 m/sec inside the Vengurla creek and 0-0.15 m/sec in the seawater.
- Hydrodynamic study with the proposed condition reveals that the magnitude of currents varied in the range 0-0.029 m/sec inside the Vengurla creek and 0-0.22 m/sec in the seawater.
- No severe circulation or eddies has been observed near the beach area in the existing condition.
- Also, no severe circulation or eddies has been observed near the beach area for proposed conditions hence no massive siltation in that area.
- Some distortions in the streamline of southward and northward tidal currents have been witnessed near the tip of the breakwater.
- From the results of the sediment model, it could be seen that there is not much siltation/erosion after the construction of the proposed breakwater and deepening of the approach channel.

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