

# Hydrodynamic Modelling for Development of a Port in an Estuary



A. K. Singh , L. R. Ranganath  and M. Karthikeyan 

**Abstract** Sharavathi River originates and flows entirely within the state of Karnataka in India. It is one of the few westward flowing rivers of India with huge discharge during monsoon, and the major part of the river basin lies in the Western Ghats. The total length of the Sharavathi River is around 128 km, and it joins the Arabian Sea at Honnavar in Uttara Kannada district of Karnataka. The present study deals with the development of port for providing berthing facilities for coal and iron ore-carrying vessels of 10,000 DWT capacity in the basin of the Sharavathi River estuary. The channel as well as harbour area is proposed to be dredged up to  $-10.0$  m depth. A computer-based numerical model was developed for the port in the Sharavathi Estuary to examine the hydrodynamic characteristics of the region. The model highly resolved the region of interest and predicted sea level, currents in response to the effects of tides and slow sea level changes. Such a model could be used to predict the movements of sediments throughout the vicinity of the proposed harbour. Tidal hydrodynamic simulations reveal that the flow field is conducive without significant circulation with the suggested modified layout. The annual deposition of sediment is expected, in the approach channel. The capital dredging for proposed port development is estimated to be about 4.0 M Cum, and the total maintenance dredging is estimated to be about 1.0 M Cum. Results from the model show that the currents in the estuary are predominantly due to the effects of the tide; the tidal range is around 1.58 m. These tides can generate currents, with current speeds reaching up to 1.3 m/s in the vicinity of Badagani Estuary in the North and up to 0.8 m/s in the

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vicinity of Sharavathi Estuary in the south. The simulations generated by the model and associated analyses provide a first-order picture of the flow and distribution characteristics of the port environment which may aid in management decision processes and provide an enhanced understanding of the oceanography of the region.

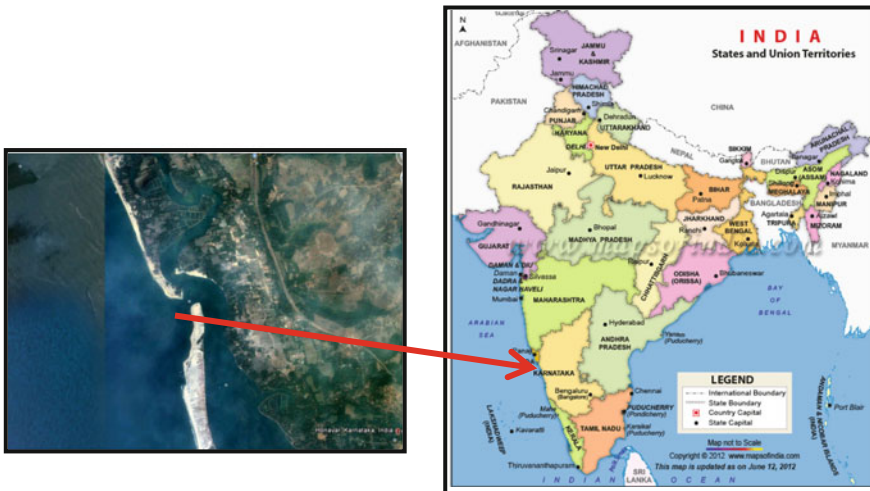
**Keywords** Tides · Current · Sediment transport · Hydrodynamics · Harbour

## 1 Introduction

Honnavar lies on the coast of the Arabian Sea and on the banks of the river Sharavathi, forming an estuary. It lies midway between Panaji and Mangalore (Fig. 1). There is a proposal for the development of a port at Honnavar, Karnataka for providing berthing facilities for coal and iron ore-carrying vessels of 10,000 DWT capacity.

The proposed layout (Fig. 2) consists of a northern breakwater of 820 m length and southern breakwater of 865 m length having a clear gap of 360 m in between them. The iron ore berth, coal berth and multipurpose berth are located inside the creek. The channel as well as harbour area is proposed to be dredged up to  $-10.0$  m depth. Mathematical model studies were carried out to assess the flow field and sedimentation pattern in the proposed harbour along with two alternative layouts.

This paper describes the mathematical model studies carried out to understand the tidal hydrodynamic behaviour of flow and probable siltation pattern in the harbour area of the proposed development of port at Honnavar.



**Fig. 1** Study location

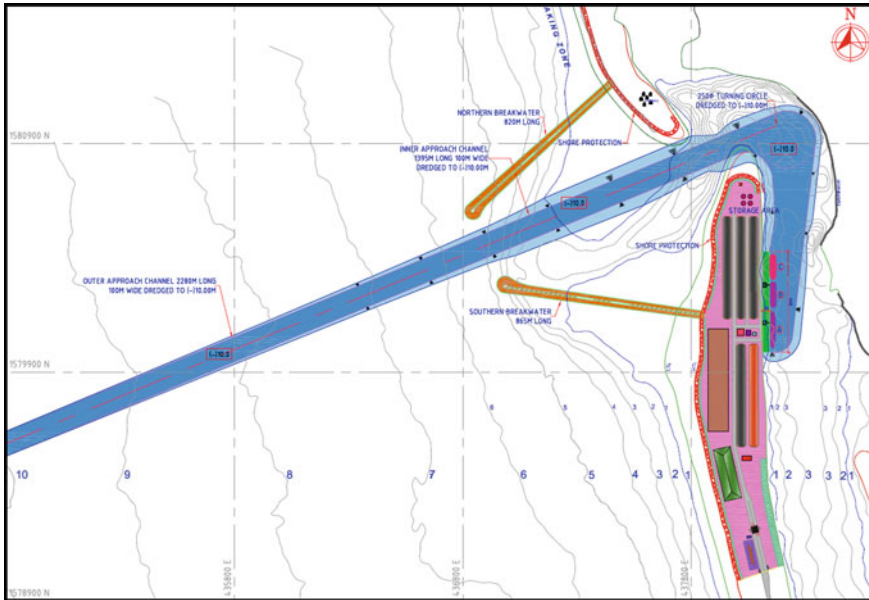


Fig. 2 Layout of the proposed port

## 2 Site Condition

### 2.1 Bathymetry

Bathymetric survey of the nearshore region at the proposed site near Honnavar was obtained (Fig. 3) and used. The nearshore bathymetry was superimposed on the C-MAP bathymetry to cover the model region for hydrodynamic studies.

### 2.2 Tidal Levels

Tidal observations were done at Honnavar Jetty during 1–17 April 2011 at an interval of one hour. The data analysis indicated that the observed tidal range was 1.8 m during High tide and about 1.0 m during Low tide and the same was considered initially and further it was extrapolated to longer duration. The tide used for model studies is shown in Fig. 4 and the corresponding values are in Table 1.

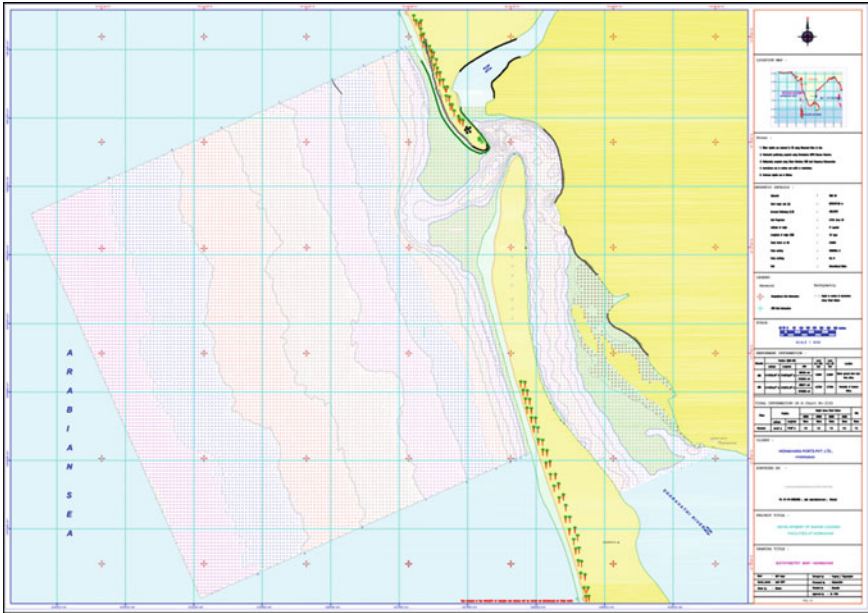


Fig. 3 Bathymetry survey

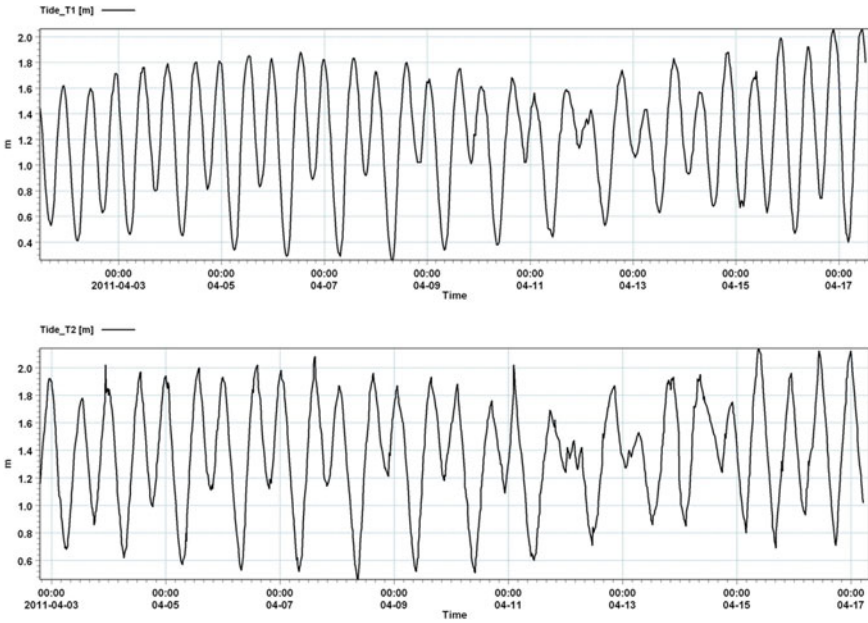


Fig. 4 Observed tide

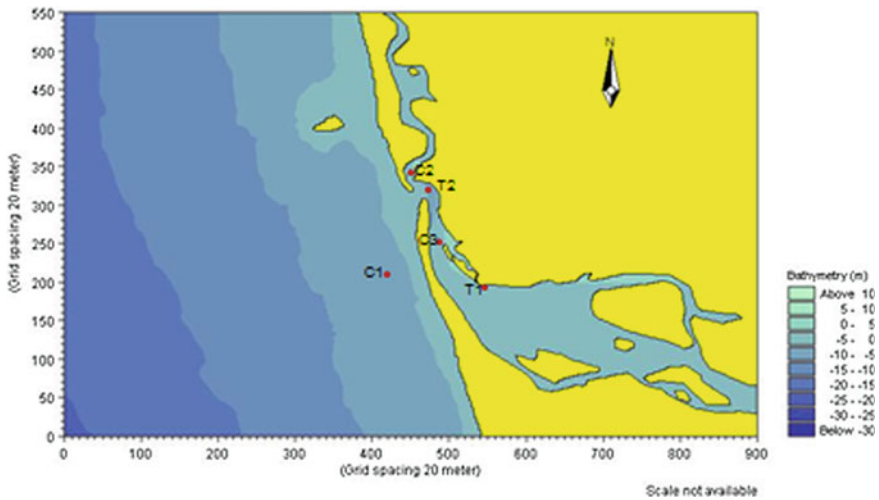
**Table 1** Tidal levels at Honnavar

Tidal levels	
Mean Higher High Water (MHHW)	+1.8 m
Mean Lower High Water (MLHW)	+1.5 m
Mean sea level	+1.2 m
Mean Higher Low Water (MHLW)	+1.0 m
Mean Lower Low Water (MLLW)	+0.4 m

### 2.3 Current Observations

Currents observed at three locations (Fig. 5) one in the open sea and the other two inside the Sharavathi River covering spring and neap tide for a duration of 2 weeks during 1–17 April 2011. The current observations were taken at every 20 min interval and at a water depth of 2.6 m below the surface.

The analysis of the data indicated that there is a reversal of flow during flood and ebb phase and the average currents at C1 location in outer sea varied from 0.05 to 0.25 m/s with an average value of 0.1 m/s. At C2 location inside the river, the average currents were of the order of 0.55 m/s with a peak value of about 1.2 m/s. Similarly at C3 location inside the river, the average currents were of the order of 0.27 m/s with a peak value of about 0.8 m/s.



**Fig. 5** Model region with field observation point

**Table 2** The sediment size distribution at Honnavar

Locations		Soil description	D50 (mm)	Sand (%)			Silt and clay (%)
				Coarse sand	Medium sand	Fine sand	
River	S1	Coarse sand	0.52	54.03	31.88	13.77	0.20
	S2	Fine sand	0.18	18.72	3.93	56.30	19.04
	S3	Fine sand	0.43	22.71	47.71	28.86	0.45
	S4	Coarse sand	0.60	68.31	25.15	6.28	0.20
	S5	Coarse sand	0.52	52.17	33.60	13.33	0.40
Open sea	S6	Silt and clay	0.17	22.55	8.48	36.14	31.30
	S7	Silt and clay	0.17	18.07	11.90	39.59	29.69
	S8	Fine sand	0.32	13.23	40.03	23.51	19.92
	S9	Fine sand	0.31	16.36	34.87	29.17	15.96
River	S10	Coarse sand	0.53	55.33	26.31	17.05	1.00
	S11	Fine sand	0.28	16.63	39.28	35.77	7.76
	S12	Coarse sand	0.52	53.28	35.82	9.92	0.70

## 2.4 Sediments

Water samples were collected at 12 different locations during spring and neap tides at the site. Total 120 samples were analysed and the suspended sediment concentration varied from 15 to 195 mg/l during different phases of tide and water depth. The average value of  $0.01 \text{ kg/m}^3$  was considered in the model studies. The average D50 value of the sediments at the site was considered as 0.40 mm for simulation. Table 2 shows the sediment size distribution observed at Honnavar.

## 3 Mathematical Model Studies for Tidal Hydrodynamics

The mathematical model studies were carried out using MIKE 21 software developed by Danish Hydraulic Institute, Denmark. The hydrodynamic and siltation studies were carried out with the help of MIKE 21 HD and MIKE 21 MT modules, respectively.

### 3.1 Model Description

In order to examine the tidal flow conditions and dynamics of sediments, it is necessary to compute hydrodynamics of water body in terms of velocity and water level fluctuation. The appropriate governing equations for studying water movement in

coastal areas are the 2-D shallow water equations. These are obtained by vertically integrating the 3-D Navier–Stokes equations of motion making the following simplified assumptions:

- The flow is incompressible.
- The flow is well mixed (no variation in density).
- Vertical accelerations are negligible.
- Bed stress can be modelled.

Simulation of hydrodynamics is based on the shallow water equations given below (continuity equation):

$$\frac{\partial z}{\partial t} + \frac{\partial uh}{\partial x} + \frac{\partial vh}{\partial y} = 0.$$

Equation of motion in x-direction:

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + g \frac{\partial z}{\partial x} - C_f v + \tau_{bx} - E_c \nabla^2 u = 0.$$

Equation of motion in y-direction:

$$\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + g \frac{\partial z}{\partial y} + C_f u + \tau_{by} - E_c \nabla^2 v = 0,$$

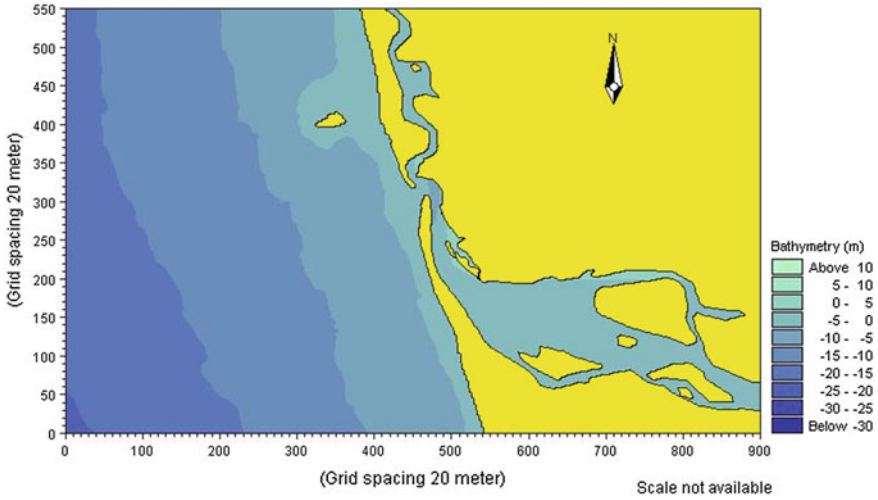
where

- z water surface elevation above the datum,
- u X-component of velocity,
- v Y-component of velocity,
- d depth of flow below datum,
- h total depth of flow (d+z),
- $C_f$  Coriolis force,
- $\tau_b$  bed shear stress and
- EC eddy viscosity coefficient.

The governing equations are solved by finite difference technique using Alternating Direction Implicit (ADI).

### 3.2 Computational Model

A 2-D mathematical model was developed using bathymetry from the recent hydrographic survey carried out during April 2011. The mathematical model domain consists of open sea portion up to  $-21$  m contour and a portion of Sharavathi River influenced with tidal fluctuation. A uniform square grid of  $20 \text{ m} \times 20 \text{ m}$  was considered for the entire model area of  $19 \text{ km} \times 11 \text{ km}$  to cover the entire proposed harbour



**Fig. 6** Computational model area

and surrounding area. The model consists of 900 grid points along x-direction and 550 grid points along y-direction. The bathymetry data extracted from the C-MAP was reproduced in mathematical model for the existing conditions along with superimposition of Hydrographic survey data of the nearshore region at Honnavar and is shown in Fig. 6.

## 4 Literature Survey

Nayak et al. [1] inferred that during flooding, sediments move into the estuary, and during ebbing, they flow seaward resulting in erosion and formation of shoals. Sediment-dispersal patterns largely follow wind and wave patterns, a characteristic feature of the mesotidal coast. Dora et al. [2] carried out Grain character analysis of beach sediments along three selected beaches (Pavinkurve, Kundapura and Padukare) of Karnataka coast, west coast of India. Grain characteristics varied spatially and temporally along with beach orientation, foreshore slope and wave action. The study shows that the sedimentary environment at Kundapura was influenced by relatively high wave action compared to Padukare and Pavinkurve beach, and the beaches were under erosion or non-deposition with strong blow upon the process.



## 5 Discussions

Mathematical model studies were carried out using MIKE21-HD and MIKE21-MT models to assess the changes in coastal hydrodynamics and siltation pattern due to the proposed harbour at Honnavar. From the model studies using the data available, it was found that with the existing conditions the magnitude of currents varied in the range of 0.2–0.3 m/s indicating that the currents are weak in offshore and near the proposed harbour region during entire tidal cycle except at the Sharavathi River inlet where the magnitude of currents are of the order of 1.0 m/s (Fig. 7). The typical flow during different phases of tide is shown in Fig. 8

Similarly, simulations were carried out for monsoon season by increasing the river discharge to 300 m<sup>3</sup>/s and keeping all other conditions same. The typical flow during different phases of tide is shown in Fig. 9. The magnitude of currents did not change much in the offshore region and varied in the range of 0.2–0.3 m/s. At the inlet near river mouth and estuary, the magnitude of currents increased considerably due to the river discharge and reached up to 1.0 m/s. It is observed that the average depth of sediment deposition varies from 10 to 40 cm during monsoon season.

From the sedimentation studies, it could be seen that the zone of deposition is mainly in front of the river inlet and a tendency of sandbar formation is prevailing. It is observed that the average depth of sediment deposition varies from 10 to 25 cm during non-monsoon season (Fig. 10). It is observed that the average depth of sediment deposition varies from 10 to 40 cm during monsoon season.

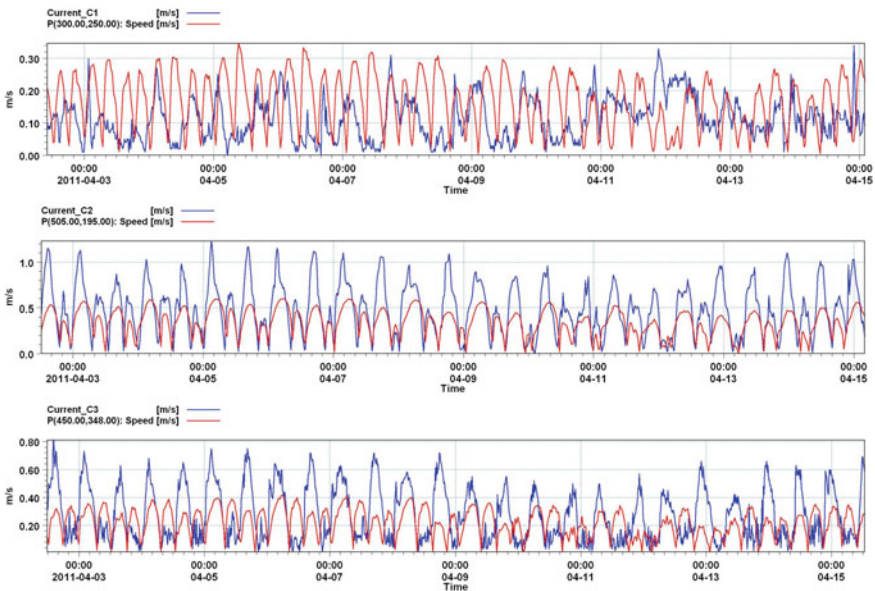


Fig. 7 Comparison of currents (observed vs. computed)

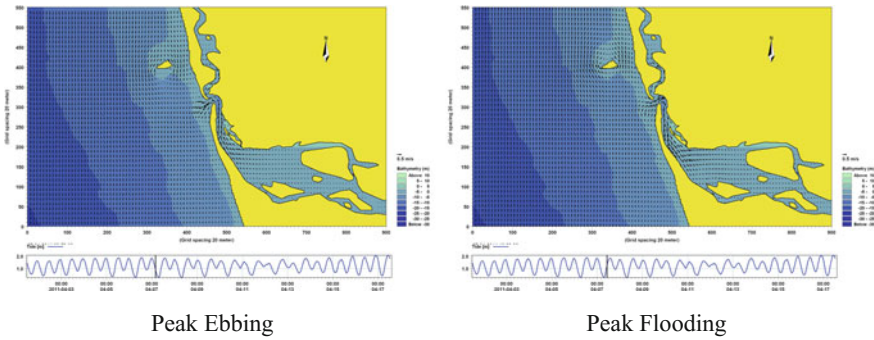


Fig. 8 Flow field in existing condition (non-monsoon)

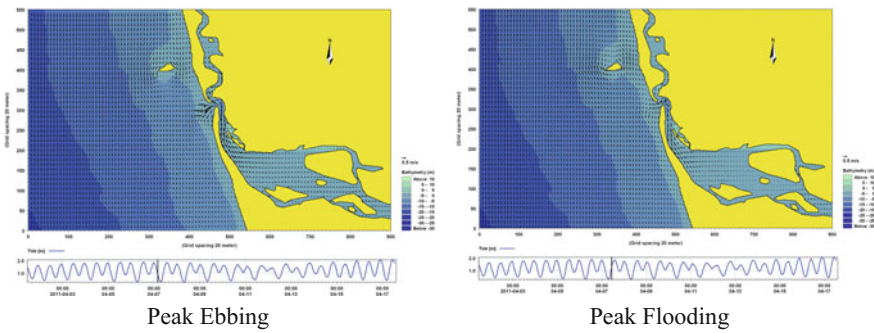


Fig. 9 Flow field in existing condition (monsoon)

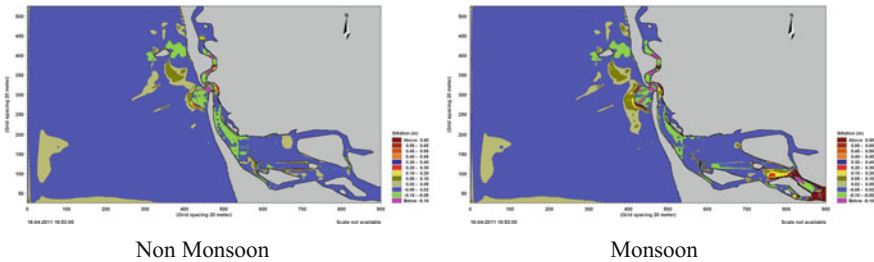
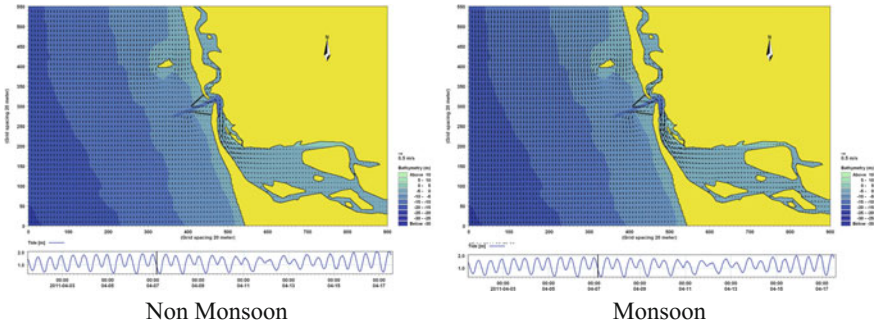
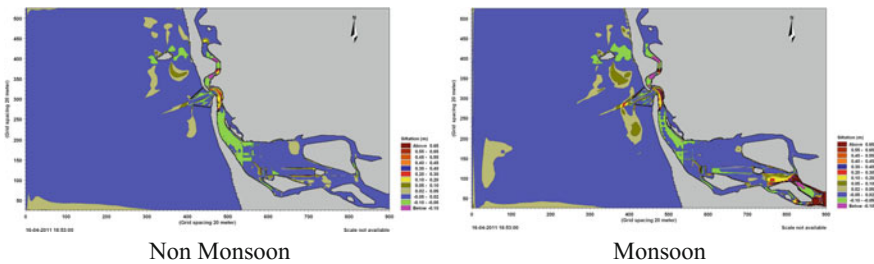


Fig. 10 Siltation pattern over a period of 1 month

With the proposed layout, the magnitude of currents varied in the range of 0.2–0.33 m/s indicating that the currents are weak in offshore which is similar to the existing condition. For monsoon conditions, the magnitude of currents did not change much in the offshore region which varied in the range of 0.2–0.3 m/s. At the river inlet and inside the estuary the magnitude of currents increased considerably due to the river discharge and reached up to 1.15 m/s (Fig. 11).



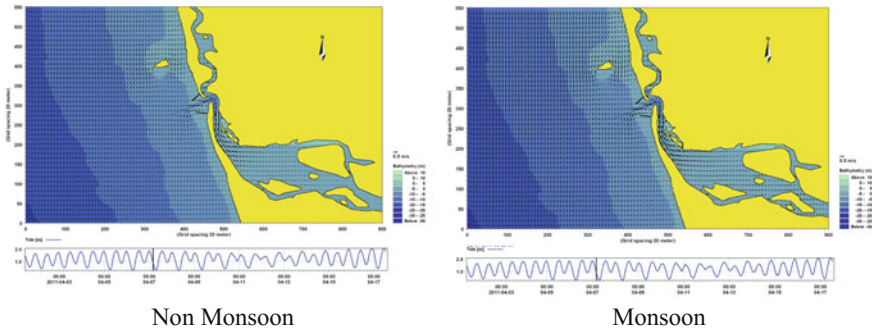
**Fig. 11** Flow field during peak ebb (proposed)



**Fig. 12** Siltation pattern over a period of 1 month (proposed)

A typical siltation pattern over a period of 1 month during non-monsoon with the proposed port layout is shown in Fig. 12. It could be seen that the zone of deposition is mainly in the approach channel extending up to  $-8.0$  m contour, specifically after the tip of the proposed breakwater and towards the offshore region which ranges from 0.5 to 10 cm, this may be attributed to the sudden change in depth of the channel when compared to the adjacent contours, also there is a tendency of erosion at the tip of the breakwater which may be attributed to the sudden variation in the flow condition, i.e. increase in flow velocity which acts as a jet facilitating removal of sediments in the channel. Inside the harbour, there is a slight tendency of sediment deposition over the shadow region of the basin which is very marginal. But inside the river, i.e. just behind the inlet, there is a trend of deposition and may be of the order of 10–25 cm.

From the sedimentation studies conducted for monsoon conditions the depth of deposition in the approach channel extended up to  $-8.0$  m contour, specifically after the tip of the proposed breakwater and towards the offshore region which ranges from 10 to 30 cm. Inside the harbour also, there is a slight tendency of sediment deposition. In the estuary, the trend of deposition has further intensified, and it is of the order of 10–40 cm.



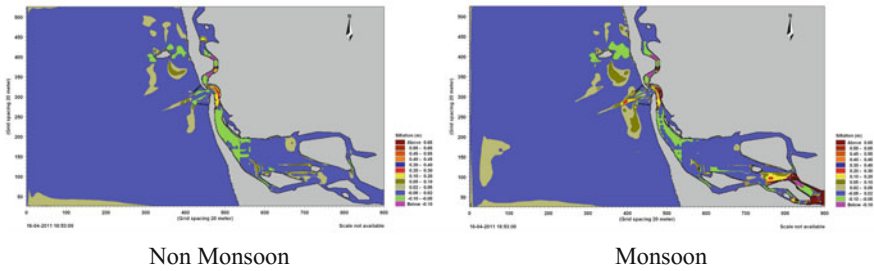
**Fig. 13** Flow field during peak ebb (alternative I)

Similarly, studies were conducted by reducing the length of the breakwater by about 30%, to optimize the breakwater length shown in Fig. 13 (alternative I). Model simulations for both non-monsoon and monsoon conditions indicated that the magnitude of currents in the offshore varied in the range of 0.2–0.30 m/s. In the proposed harbour basin, the current magnitude has reduced further due to the increased opening at the tip of the north and south breakwaters near channel entrance. It is also observed that there is no tidal circulation or eddy formation inside the harbour.

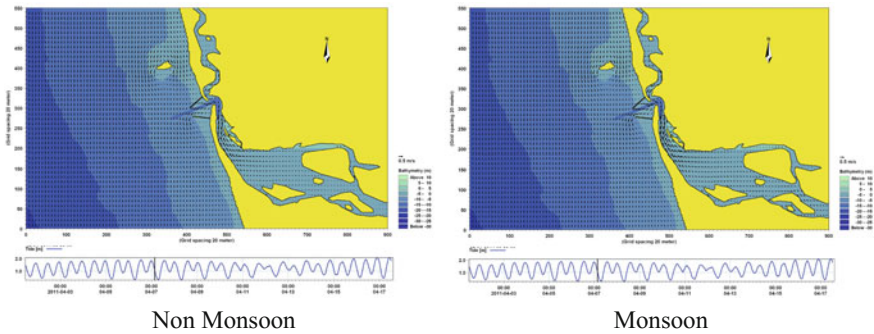
It could be seen that the zone of deposition is mainly in the approach channel, specifically after the tip of the proposed breakwaters the deposition trend is more and towards the offshore region up to a depth contour of about  $-8$  m which ranges from 0.5 to 10 cm, it reduces gradually and stabilizes, this may be attributed to the sudden change in depth of the channel when compared to the adjacent contours, also there is a tendency of erosion at the tip of the breakwater which may be due to the sudden change in the flow condition, i.e. an increase in flow velocity. Inside the harbour, there is a reduction in tendency of sediment deposition. But inside the river, i.e. just behind the inlet, there is a trend of deposition and may be of the order of 10–25 cm indicating that there is no impact of reduction in length of breakwater on sedimentation.

Further studies were conducted for monsoon conditions. The trend of sediment deposition in the channel continues with a further increase in the depth of deposition in the approach channel extending up to  $-8.0$  m contour, specifically after the tip of the proposed breakwater and towards the offshore region which ranges from 10 to 30 cm. Inside the harbour also, there is a clear increase in tendency of sediment deposition in the channel as well as in the shadow region of the basin when compared with full length of breakwater. Inside the river, i.e. just behind the inlet the trend of deposition has further intensified and may be of the order of 10–40 cm. Overall, it is clear that reduction in length of the breakwater has not reduced the quantum of siltation and is shown in Fig. 14.

The magnitude and direction of flow along with flow pattern were observed. The magnitude of currents in the offshore varied in the range of 0.2–0.30 m/s indicating



**Fig. 14** Siltation pattern over a period of 1 month (alternative I)

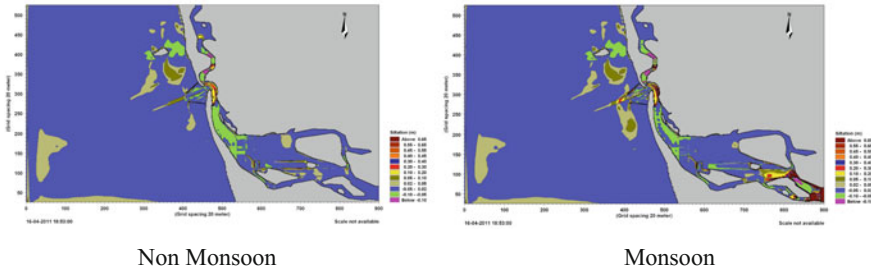


**Fig. 15** Flow field during peak ebb (alternative II)

that the currents are weak in offshore similar to that of original proposal but in the proposed harbour basin the current magnitude has reduced further due to the increased opening at the tip of the north and south breakwaters near channel entrance. It is also observed that there is no tidal circulation or eddy formation inside the harbour.

Similarly, simulations were carried out for monsoon conditions. A typical flow during different phases of tide is shown in Fig. 15. The magnitude of currents did not change much in the offshore region. At the harbour entrance, the magnitude of currents has reduced when compared with the original proposal with full-length breakwater.

A typical siltation pattern over a period of 1 month during non-monsoon and monsoon with the proposed port layout is shown in Fig. 16. It could be seen that the zone of deposition is mainly in the approach channel, specifically after the tip of the proposed breakwaters the deposition trend is more and towards the offshore region up to a depth contour of about  $-8$  m which ranges from 0.5 to 10 cm which is similar to that of full-length breakwater of the proposed layout but there is a slight increase in depth of deposition. Inside the harbour, there is not much change in the trend of sediment deposition when compared to the original proposal. Sedimentation pattern inside the river also remains similar to that of the original layout. Overall impact of shifting the southern breakwater on sedimentation pattern is not significant.



**Fig. 16** Siltation pattern over a period of 1 month (alternative II)

However, it may be noted that the sediment transport studies are more qualitative than quantitative. The exact quantification of the sedimentation in the coastal region is difficult as the process becomes complex due to continuous changes in the tide, currents and waves throughout the year.

## 6 Conclusions

From the hydrodynamic studies, it can be concluded that the flow field is conducive without significant circulation with the original proposal of port development and also with the two alternatives. Sedimentation studies reveal that the quantum of sediment deposition is minimal with the original port layout when compared with other two alternative layouts. Hence, the original port layout was found to be feasible. Only with the requirement of additional harbour area, the proposal of alternative II may be taken up. The annual deposition of sediment is expected, in the approach channel. However, provisions may be made for the periodical maintenance dredging to maintain adequate depths in the channel and basin.

The capital dredging for proposed port development is estimated to be about 4.0 M Cu m, and the total maintenance dredging is estimated to be about 1.0 M Cu m. This maintenance dredging quantity is about 0.4 M Cu m in the approach channel and 0.6 M Cu m in the basin including turning circle. This estimate is based on the model study and literature survey of ports along the west coast.

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