Study on Maintenance Dredging for Navigable Depth Assurance in the Macro-tidal Hooghly Estuary

V. Maheshvaran, K. Murali, V. Sundar and K. Chitra

Abstract Hooghly Estuary is a tide-dominated estuary in the east coast of India, experiencing heavy siltation in the navigation channel. This frequent siltation affects the movement of vessels, thus, hampering the efficiency of the port. The quantity of siltation is related to the physical and environmental conditions and the geometric configuration of the entrance as well as the navigation channels. This study aims at investigating the possibility of smooth navigable channel to the Haldia Dock Complex with a minimum quantity of maintenance dredging. The monitoring of the channel through bathymetry survey at regular intervals has been carried out. The filed survey involved identification of the zones of siltation, changes in the depth and estimation of sediment volumes at 10 different sections along the Eden bar. It was found in the study that the siltation depth varies between the spring and neap tide periods due to the variation in the tidal currents. From the field monitoring surveys, it is found that there is predominant erosion from neap-to-spring tidal cycle. These aspects are brought out in the manuscript along with the stability details of the Eden channel, throughout the year.

Keywords Dredging · Estuary · Navigation channel · Siltation
Tide-dominated estuary

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1 Introduction

Inland ports are situated within an inland water body such as rivers or lakes with a navigable channel connecting it to the sea. Duisburg Inner Harbour on the river Rhine, Germany is the world's largest inland port. An estuary is the portion of the river that experiences the tidal flux. Estuaries can be divided into three parts, a marine process dominated outer part with net bed load transport occurring towards inland, a central portion, where bed load convergence occurs, and a river hydrodynamics dominated upper part, where the net bed load transport occurs seaward [1]. Ports located in the estuaries are more prone to siltation and the navigation channel is less stable compared to ports located in upper parts of a river.

Estuaries can broadly be classified as tide dominated and wave dominated. In the case of the former type, the sediments move along the estuary due to the tidal amplitude leading to erosion or deposition of sand along the estuary which depends on the residual of the tidal amplitude during its flooding and ebbing. In the case of the wave-dominated estuary, the tidal flux being much less compared to the movement of wave-induced sand along the coast, sandbar formation takes place in the vicinity of the confluence of the estuary and the ocean, thus hampering the movement of vessels into the estuary.

2 Background

The Hooghly Estuary is located along the east coast of India, in the state of West Bengal. The river Ganges branches off into the Hooghly Estuary forming one of its first deltaic offshoots. The Hooghly Estuary is a tide-dominated semidiurnal macro-tidal estuary, used as a navigational waterway for the two major ports of Haldia and Kolkata. The Kolkata Port has one of the longest navigation channels in the world. The Haldia Port is situated at about 104 km downstream of Kolkata Port (KoPT), whereas Haldia Port is located at the intersection of the Haldi River and Hooghly River. The layout of the Hooghly is shown in Fig. 1.

The net sediment transport occurs when there is a difference in the magnitude and duration between the ebb and flood tide phases. An unstable navigation channel experiences large changes in its morphology due to large magnitude of net sediment transport. The Hooghly Estuary is found to be unstable in certain reaches, and the present study has been carried out to characterize its behaviour under different tidal and seasonal conditions.

The tidal cycle in the Hooghly Estuary is 12.4 h with the flood tide lasting 3 h. There is an asymmetry in flood and ebb magnitudes with the flood current being about 2.5 m/s and the ebb current being 1 m/s as measured at the mouth of the estuary. This leads to about double the discharge rate during the flood tide as compared to the ebb phase, of about 2.6×10^5 cumecs. This leads to a net landward transport of sediment which necessitates year-round maintenance dredging to be carried out

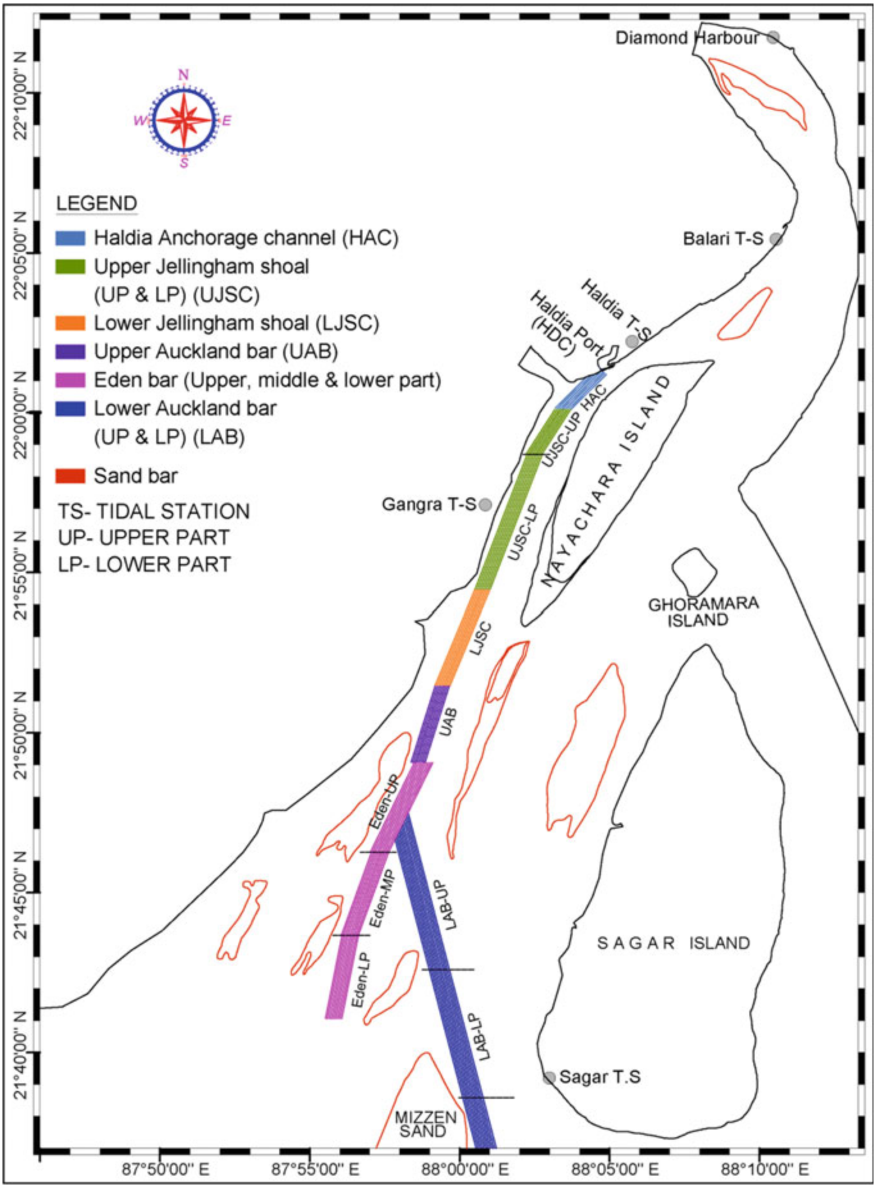


Fig. 1 Layout of Hooghly Estuary

in order to maintain the navigable depth in the channels [2] of about 25 Mm^3 per annum [3]. A few researchers have reported their investigations on Hooghly Estuary [4–6].

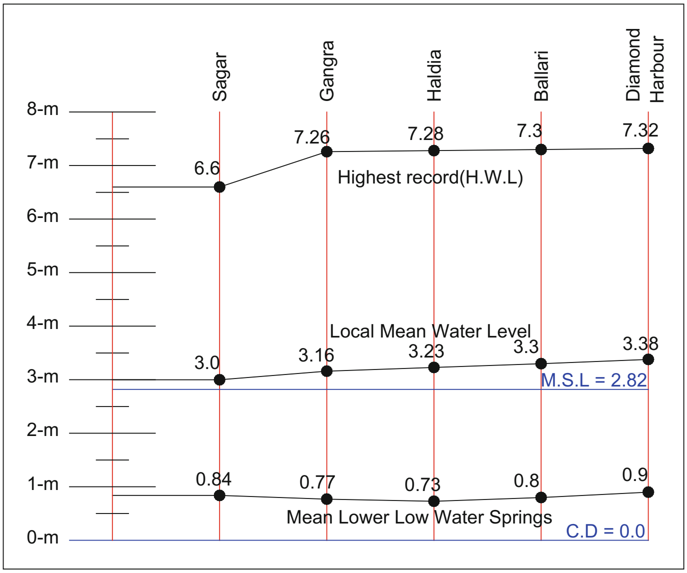


Fig. 2 Tidal level at five stations in Hooghly Estuary

Frequent siltation of navigational channel affects the movement of vessels to the harbour which in turn, reduces the efficiency of the port. The quantity of siltation is related to the physical and environmental conditions and the geometric configuration of the entrance as well as the navigation channels. The tide-induced flow plays a dominant role in the silting up of the navigational channel. The different tidal levels at different stations (Sagar, Gangra, Haldia, Ballari and Diamond Harbour) are shown in Fig. 2.

3 Present Study

The present study focuses on the investigation of the proposal for the permanent operation of Eden channel as the navigational route to Haldia Dock Complex in place of Auckland channel. The main aim is to reduce the maintenance dredging quantity. In order to investigate this proposal, a detailed understanding of the morphodynamics of the estuary is required. This can be done by surveying the initial depths of all the navigational channels and thereby monitoring the change in depth in all seasons. Based on the observations, the behaviour of the navigational channels and the sediment transport mechanics can be inferred. This can be used to identify the area vulnerable to siltation in the navigational channels. Finally, the quantity of total sediment load deposited in the navigational channels can be calculated.

4 Methodology

The vulnerable locations are identified by monitoring the bathymetry at regular intervals. This study focuses on a particular portion of the navigation channel.

Six parts of navigation channel from Haldia Dock Complex (HDC) to Mizzen sand (up to Latitude 21° 38′ 30″ N) as shown in Fig. 1 are considered. These parts are Haldia anchorage, upper Jellingham shoal (upper and lower part), lower Jellingham shoal, upper Auckland bar, Eden bar [upper (from 21° 49′ 00″ to 21° 46′ 12″), middle (from 21° 46′ 12″ to 21° 44′ 00″) and lower part (from 21° 44′ 00″ to 21° 41′ 00″)] and lower Auckland bar (upper and lower part). It is to be noted that between upper Jellingham and Eden bar, the navigational channel has deeper depths (>6.6 m), and hence had not been considered for investigation. An initial survey from Diamond Harbour to Sagar Island was carried out to establish the baseline data and to identify the regions which require regular and high-resolution monitoring. Figure 3 shows bathymetry map of Diamond Harbour to Sagar Island surveyed in December 2015. Hence, the bathymetry surveys at regular time intervals, once a week during spring and neap tide has been carried out from HDC to Eden-LP (up to Lat 21° 41′ 00″ N) along the navigation channel from 5 February ‘16 to 31 May ‘16 representing the–pre-monsoon period from 3 June to 30 September ‘16 being the monsoon period and from 1 October to 25 February 2017 being the post-monsoon period. The pre-monsoon, monsoon and post-monsoon bathymetry survey in the Eden bar constitutes 22 surveys for pre-monsoon, 19 for monsoon season and 17 monitoring surveys for the post-monsoon season, respectively. The surveys were carried out over each of the neap and spring tide. Figure 4 shows bathymetry map of Eden and Auckland bar.

The total length and width of the channel are 15.75 km × 0.92 km, respectively. The channel has nine navigation tracks, each of which is 115 m wide. (The bathymetry survey was done along each of the navigation channels.) Single-beam, single-frequency echo sounder was used, the range of which is from 0.3 to 99.9 m with a frequency of 200 kHz. The calibration of the echo sounder was done using bar check plate and sound velocity probe. Finally, the sound velocity was fixed 1512 m/s. The depth under the vessel is then calculated from the two-way travel time of pulses and the mean speed of sound over the water column.

$$\text{Depth}\,(D) = V \times \frac{T}{2}$$

where D = Depth from reference water surface, V = Velocity of sound in the water column and T = Measured elapsed time from transducer to bottom and back to transducer.

The HYPACK survey software was used for the data collection and post-processing. This software allows importing of background maps and creating the planned line for navigating the survey vessel. It contains the post-processing module to analyse and prepare the bathymetry chart. This software is used to calculate the volume of siltation at different locations mentioned above.

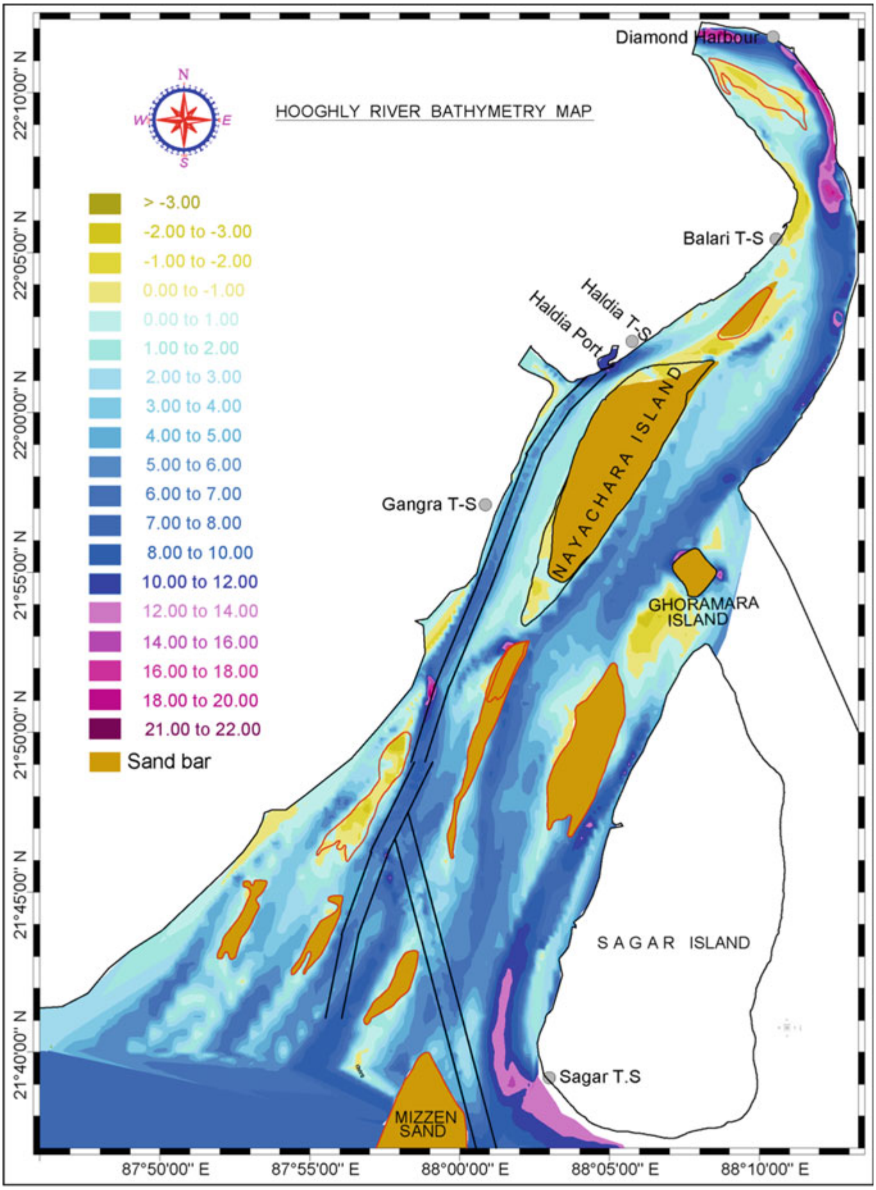


Fig. 3 Bathymetry chart from diamond Harbour to Sagar Island

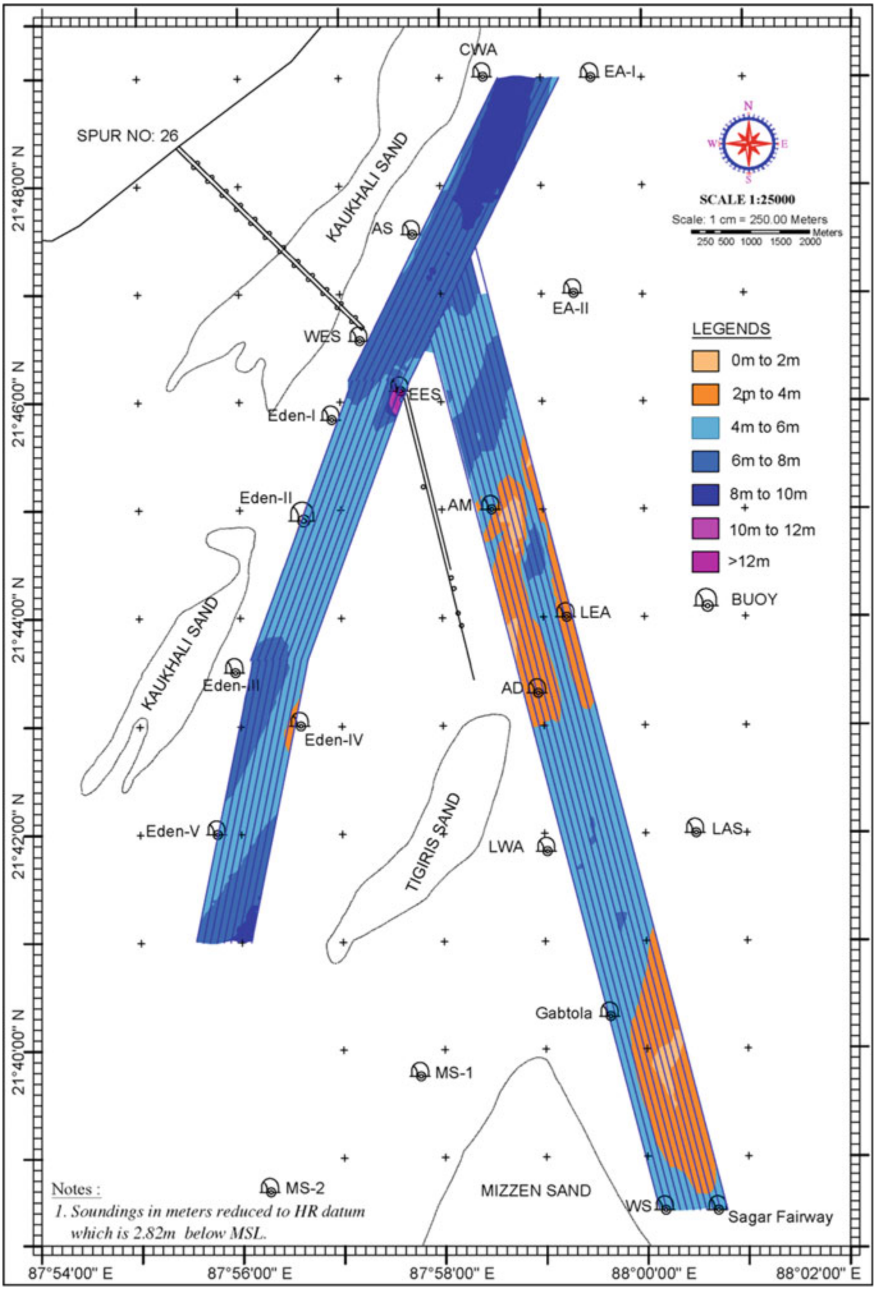


Fig. 4 Bathymetry chart Eden bar and Auckland bar

5 Details of the Monitoring Survey

Based on the survey during the above-mentioned periods, with CD as the base reference, the area of siltation, change in depth and volume of sediments in the vulnerable areas to be dredged in order to maintain the navigable depths is calculated. The siltation depth varies between the spring and neap tide periods due to the variation in the tidal flow velocities. The observations of the survey data are discussed below. All the depths dealt in the following sections are the ones measured from the reference line, i.e. below the CD at 2.82 m from MSL.

Using the surveyed data, the volume of silt accreting and eroding can be calculated. As per the results shown in Fig. 5 and in Table 1, a clear general scenario can be observed, i.e. the Eden channel seems to be accreting during the spring-to-neap (S–N) period and eroding during the neap-to-spring (N–S) period. Though, the second neap-to-spring time for pre-monsoon season shows an increased silting rate, it is observed that the erosion rate also increases considerably to counter the siltation. For the month of August, Table 1 shows the silting and scouring rate during the monsoon season which reflects a change in the natural setup, i.e. the silting volume increases linearly with time, irrespective of tidal time, but with slight reduction in silting rate during neap to spring. This aspect can be attributed to the excess silt load carried by the river during the monsoon time. Overall, it can be concluded that the Eden bar mostly erodes during neap to spring and accretes during spring to neap and this typical scenario is reflected in post-monsoon period. The influence of this setup on the stability of Eden channel is analysed and interpreted in the following section.

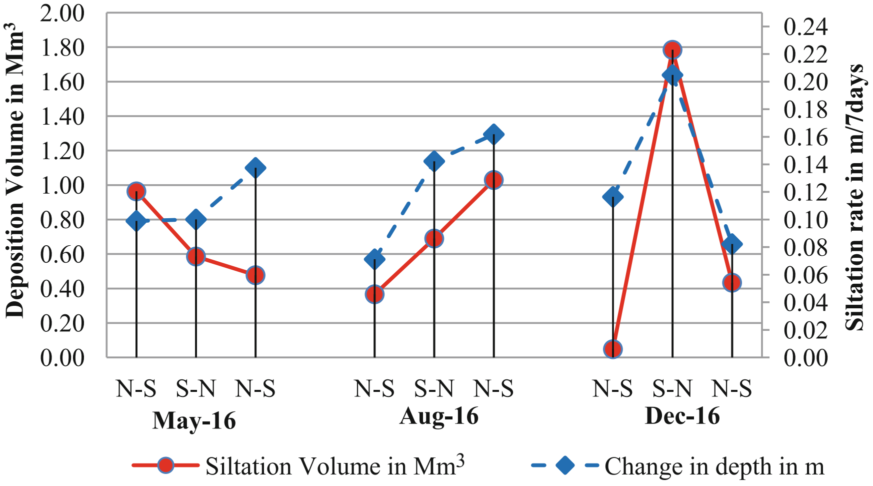


Fig. 5 Siltation depth at Eden bar for three seasons

Table 1 Silting and eroding volume calculation in Eden bar for three seasons

Sl. no	Month	Tidal time	Total surveyed area (Mm^2)	Depositing region		Siltation rate	Eroding region		Erosion rate
				Area (Mm^2)	Volume (Mm^3)	(m/7 days)	Area (Mm^2)	Volume (Mm^3)	(m/7 days)
1	May 2016	N-S	12.67	9.74	0.96	0.10	2.93	0.25	0.08
2		S-N	12.67	5.85	0.59	0.10	6.81	0.65	0.10
3		N-S	12.66	3.47	0.48	0.14	9.19	1.24	0.13
4	August 2016	N-S	11.90	5.15	0.37	0.07	6.75	0.78	0.12
5		S-N	11.90	4.85	0.69	0.14	7.05	0.75	0.11
6		N-S	10.22	6.36	1.03	0.16	3.85	0.72	0.19
7	December 2016	N-S	9.31	0.41	0.05	0.12	8.90	3.06	0.34
8		S-N	9.32	8.71	1.78	0.20	0.61	0.06	0.10
9		N-S	11.17	5.28	0.43	0.08	5.89	0.70	0.12

6 Analysis of Bed Level Changes in Relation to Eden Stability

In this activity, the Eden bar is divided into 10 sections as shown in Fig. 6. The minimum depth required for navigation in this channel is considered to be 4.6 m below the chart datum. From the results shown in Figs. 7, 8 and 9, it is seen that the depth changes in the tracks 3–7 during the different tidal times. Most of the tracks are experiencing erosion from neap to spring and depth is found to reduce in the spring-to-neap time due to siltation. In most cases, a minimum depth of 4.6 m is being maintained throughout the channel. So, whatever is accreting during the spring-to-neap time is eroded during the neap-to-spring cycle. So, it can be predicted that this cycle will be repeated, and therefore the Eden is expected to be stable throughout the year. Reversal of scenarios only in few sections in the deeper part of the channel is observed. This can be due to other exceptions during monsoon and also due to some local sediment dynamics, caused by the presence of Kaukhali and Tigris sandbars on either side of the Eden channel as observed from Fig. 6. These exceptions can be catered with occasional dredging and realignment of channel. But, considering all the natural setup and few exceptions as observed in the results afore discussed, the dominant dynamics is more towards keeping the channel stable all throughout the year.

7 Interpretation on the Usage of Eden Channel as the Main Navigational Route to HDC

It is observed that in Eden channel, the minimum depth required for the navigation is self-maintained in most of the tracks, during the entire survey period. It is also observed that significant silting occur only in the deeper parts of the Eden channel which can be maintained by dredging. The presence of shoal on either side of Eden bar is found to be interfering on the depths of some parts of the outer tracks. This can be addressed by the realignment of the channel once in a while if need arises. All the positive aspects on the stability of the Eden channel shall be attributed to the natural alignment of the channel in the direction of tidal flow. Since the channel is trying to self-maintain itself, it will be easy to maintain the minimum required depth in Eden channel through less quantity of dredging.

8 Conclusions

The variation of bed level changes has been analysed for the Eden channel for three seasons, viz., pre-monsoon, monsoon and post-monsoon. Monitoring survey has been carried out using echo sounder to study the bed level change in the channel.

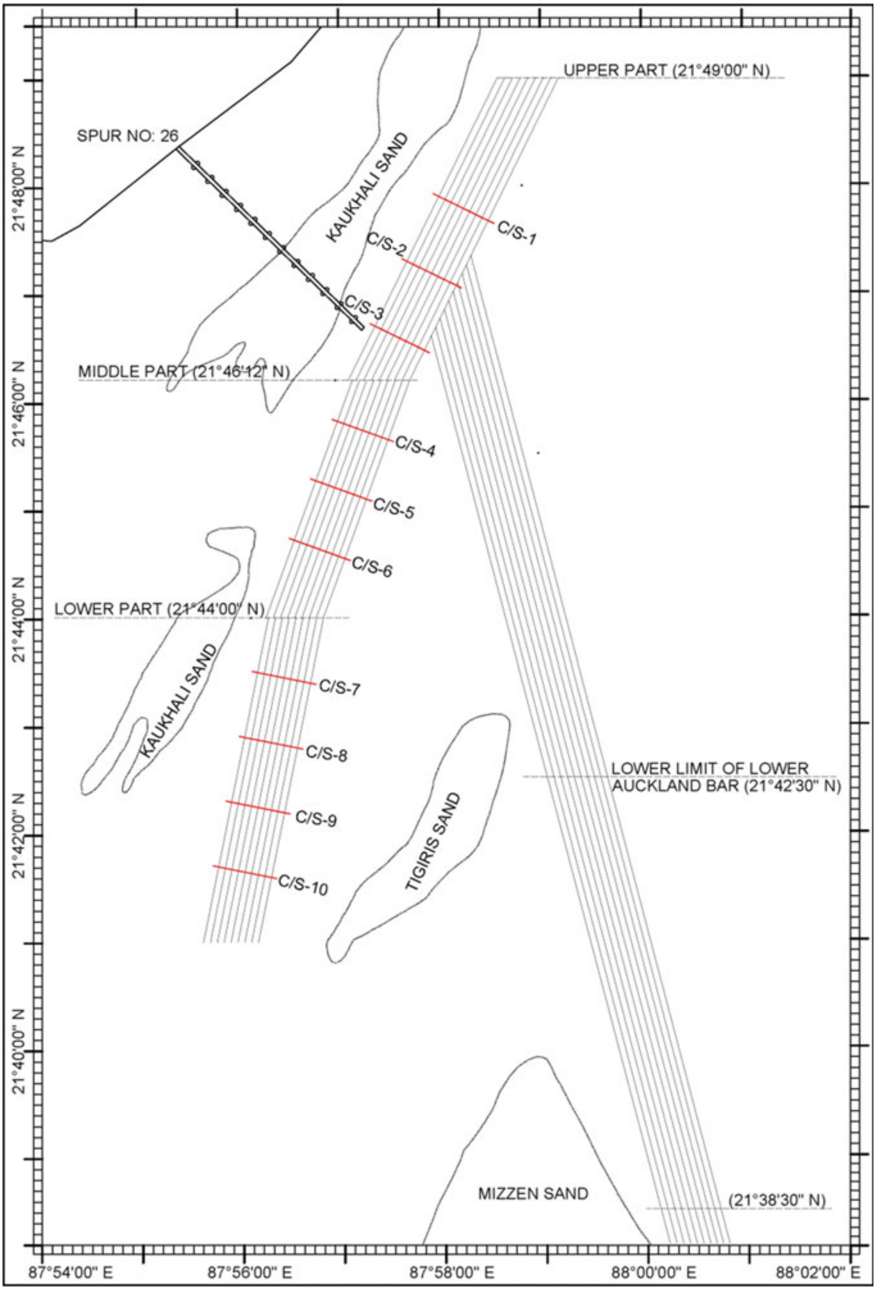


Fig. 6 Cross section at Eden bar (upper, middle and lower part)

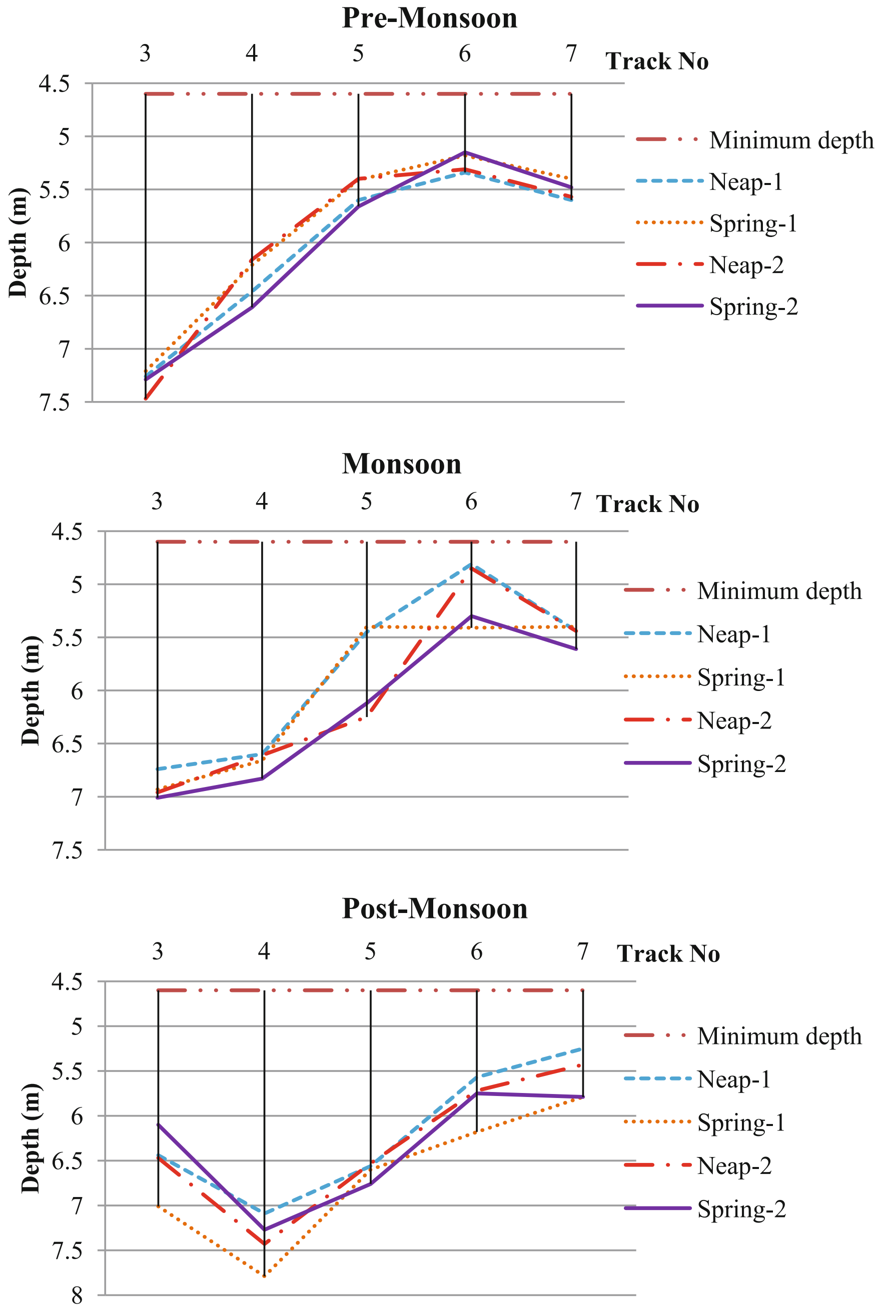
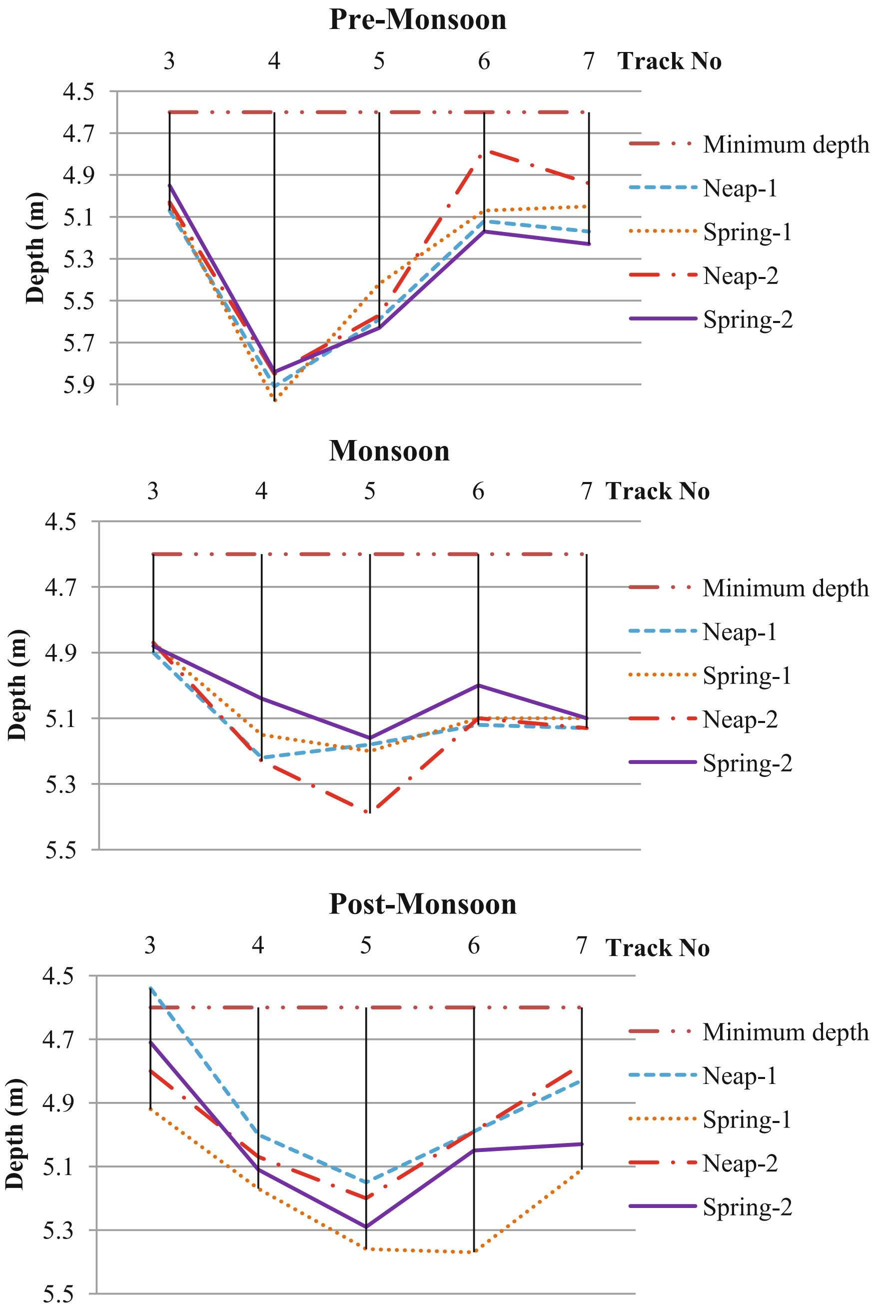


Fig. 7 Water depth of navigational channel at Cross Section-3 (C/S-3) for three seasons



Pre-Monsoon

Monsoon

Post-Monsoon

Fig. 8 Water depth of navigational channel at Cross Section-5 (C/S-5) for three seasons

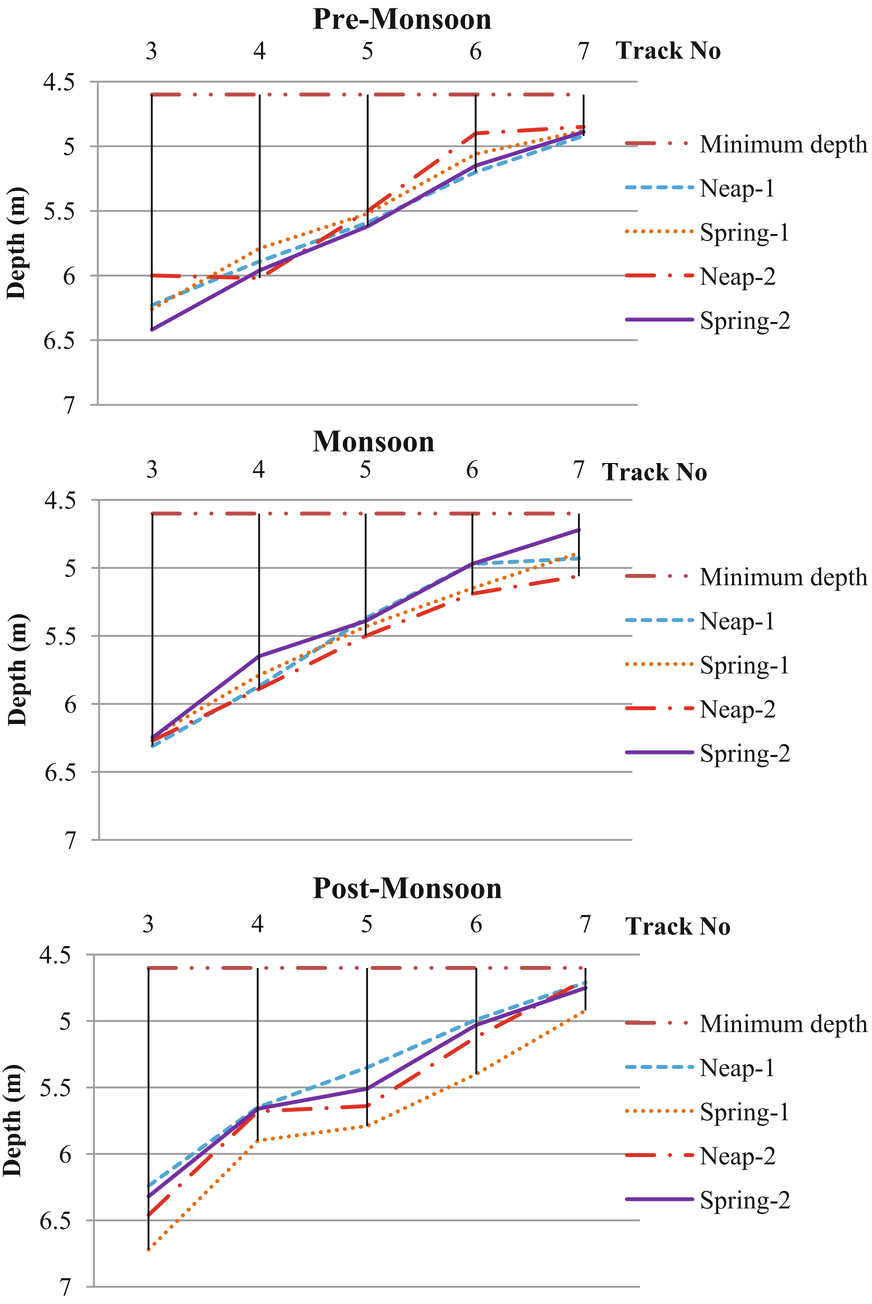


Fig. 9 Water depth of navigational channel at Cross Section-8 (C/S-8) for three seasons

Detailed analysis shows that, due to relative changes in the hydrodynamics, Eden channel mostly erodes during the neap-to-spring phase at a rate of 0.11 m/7 days and accretes in spring-to-neap phase of tidal cycle at a rate of 0.14 m/7 days on an average considering all three seasons. It is concluded that pre-monsoon and post-monsoon seasons depict a typical scenario in silting, i.e. alternate erosion and accretion corresponding to the tidal cycles. Though, the various seasons show dynamic changes in the bed levels which naturally maintains the channel depths, regular dredging in patches along the channel is to be carried out in order to maintain the minimum depth required for smooth manoeuvering of vehicles along the EDEN channel.

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