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A case study on pre- and post-monsoon seabed topography using bathymetry near Kalingapatnam, Srikakulam District, Andhra Pradesh (India)

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ABSTRACT
A study of seabed topography is important to understand the landforms under sea water, which has various oceanographic applications like navigation safety, nautical charts, water volume computation, seabed sediment computation, pollution control, sediment transport, under water engineering, harbour and docks construction etc. Bathymetry is one of the tools to delineate seabed topography using echo sounding principle. In this study, bathymetric survey was carried out at near-shore areas by covering about 10 km distance along the coast and into the sea up to 20 m contour at 100 m line spacing, during pre- and post-monsoon seasons. The survey area was spitted into three zones and data was collected using dual frequency echo-sounder, which was processed and presented in Chart Datum, based on tides measured at every 10 minutes interval during survey period, using vale-port tide gauge at river Vamsadhara. The results demonstrate that the water depth is increasing gradually towards seaward and structuring gentle slope from seashore. The depth contours are running parallel to the coast during both seasons. The seabed profiles show that the seabed experienced erosion and deposition at river mouth and also in the northern side of study area. The overall seabed topography suggests that this region is suitable for coastal development activities in the southern part, where the seabed has adequate natural depth and lesser sediment migration.

Key Words: Pre- and post- monsoon bathymetry, Sediment deposition, Sediment volume computation, Near-shore sediment deposition, Monsoon, Kalingapatnam

INTRODUCTION

Kalingapatnam is a village in Srikakulam district of Andhra Pradesh situated in eastern part of India. It is located in Gara mandal of Srikakulam revenue division and falls in geographical coordinates 18.3387° N and 84.1211° E. It has one of the major beach sand deposits in the state. Kalingapatnam is the place where river Vamsadhara enters into Bay of Bengal. The nearest port and fishing harbour is Visakhapatnam, which is located 110 km south from Gopalpur (Figure 1). The seabed topography has been studied through bathymetric survey carried out in two different seasons, covering approximately 40 sq. km off Kalingapatnam coast, using single beam, dual frequency echo sounder. Bathymetry is the key tool to understand depth profiles and to measure/monitor/quantify the sediment distribution/movement in water-bodies (Richard et al., 2000). The total study area has been divided into three zones in order to study in detail (Figure 2). Acoustic depth sounding was first used in 1930s but until the 1950s or 1960s, it did not replace reliance on lead line method. Depending on applications and depths, a variety of acoustic depth systems are used throughout the hydrographic survey industries, these include single beam acoustic system, multiple transducer channel sweep systems, and multi-beam sweep systems. (Lavery et al., 2010; Sathishkumar et al., 2013; Manik et al., 2014; Mohamed et al., 2016). The Echo-sounding systems measure the elapsed time that an acoustic pulse takes to travel from a transducer to seabed and back (Figure 3). The travel time (t) of the acoustic pulse depends on the velocity (v) of propagation in the water column. The corrected depth (d)/seabed can be computed by the measured travel time of the pulse for known sound velocity:

$$d = \tfrac{1}{2} * (v \cdot t)$$

Where, d is corrected depth, v is average velocity of sound in the water column, t is measured elapsed time from transducer to seabed and back to transducer.

Bathymetric study is commonly used in pre-dredge, post-dredge monitoring, navigation, pipeline laying projects, jetty/wharf/breakwater/seawall constructions, shoreline changes/monitoring, to calculate de-silting quantity, channel design etc., (Fröhle and Kohlhase, 2004; Thompson et al., 2015; Yaacob et al., 2017). In view of this, bathymetric investigation has been carried out to study the feasibility of developing coastal infrastructure through analysis of seabed topographic contours, vertical depth profiles and volume of sediment accumulation, between pre- and post- monsoons for the above mentioned three zones (Smith and Marks, 2014).

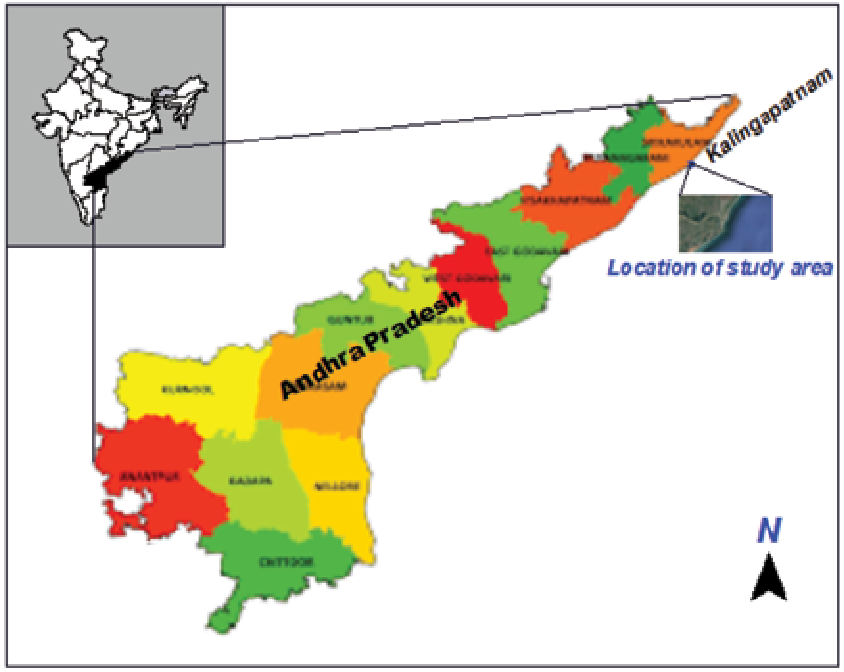

Figure 1. Location map of the studied region.

Figure 2. Satellite imagery showing zone 1, zone 2 and zone 3 of the studied region.

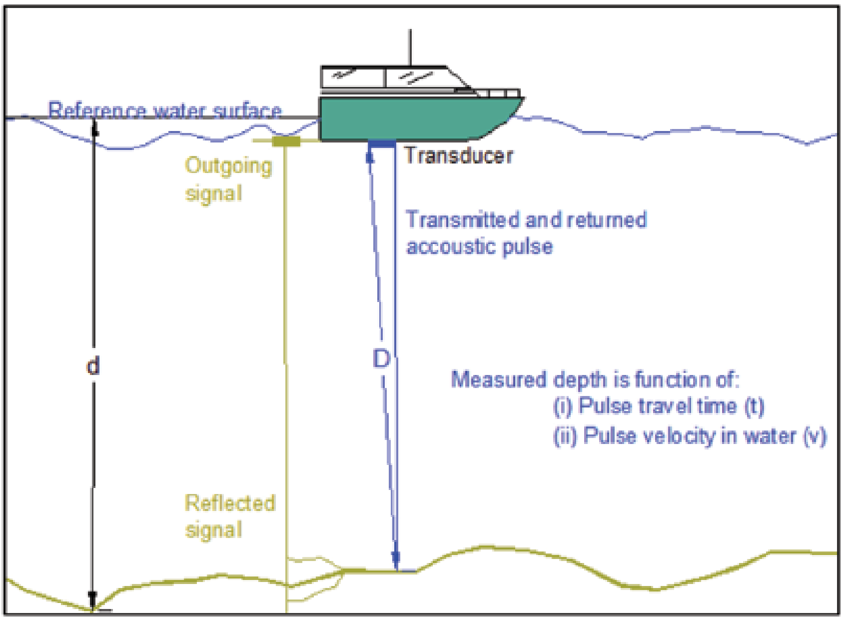

Figure 3. Schematic diagram showing principles of echo sounder.

METHODOLOGY

Data Acquisition

The bathymetry data acquisition was carried out using Teledyne Odom Echo-trac CV 100 and Trimble SPS 351 DGPS systems. The Echo-sounder and DGPS system were installed onboard and operated in accordance with the manufacturer's instructions. The transducer was installed rigidly to a strut at star-board side on fishing boat. The transducer shoe was immersed 1 m below water surface not to experience turbulence and aeration, when the vessel steams at survey speed. Prior to commencing survey works, the echo-sounder was calibrated against a bar check. The technical specification of echo-sounder used are: resolution- 0.01m / 0.1 ft; accuracy- ± 0.1% of measured depth for 200kHz, Depth range- 0.2 – 200 m for 200 kHz, 0.5 – 1500 m for 33 kHz; sound velocity- 1370–1700 m/s.

The bathymetry survey lines were planned perpendicular to the coast and data was acquired on dual frequency mode at low band-33 kHz and high band-210 kHz (Figure 4). The water depths of 5 m and above were surveyed using 40 feet fishing trawler, arranged from Visakhapatnam fishing harbour. The near shore area and inside river Vamsadhara, wherever the depths are less than 5m, were surveyed using small FRP boat set from Kalingapatnam village (Lyzenga, 1985). The water depth in the wave breaking zone up to 0.7m from low water line was measured by Sokkia Total-station during early morning hours, whenever the sea was calm without heavy waves (Figure 5). The vessel used for survey was equipped with TRIMBLE SPS 351 Beacon Receiver for precise dynamic positioning to give the real time position. The DGPS Beacon Transmitter operated from Dolphin's nose by Department of Lighthouse and Navigation was taken as reference station for horizontal positioning corrections. The transmitting frequency of this reference Beacon transmitter is 295 kHz. The DGPS system was setup to operate on UTM North Grid, Zone 45, WGS-1984 ellipsoid coordinate. The GTS bench mark located in the light-house, Kalingapatnam, has been used as vertical reference for this study and to measure the tides in order to reduce the soundings into Chart Datum. The tide measurement was carried out during survey period at every 10 minutes at river Vamsadhara, using Valeport Automatic Tide gauge. The measured water levels were connected to Bench Mark through fly leveling method by digital Auto-level and reduced to Chart Datum.

Data Analysis:

The survey points were closely observed and invalid points were removed if any abnormal position or depths in the raw data are seen. At each line intersection, depths were checked carefully to ensure that they are within the allowable limits. The corrections and offsets were checked carefully and applied on processed data. The data taken from total station was brought into same horizontal and vertical datum applied on bathymetry and both the data sets were combined together. The corrected soundings and near-shore spot levels were sorted and exported as XYZ file format. Though there are many algorithms for gridding, the Kriging algorithm is used in this process which is one of the more flexible and accurate gridding methods; typically this algorithm is recommended when gridding the data (Kader et al., 2013). Kriging is one of the most used techniques in geo-statistics field for interpolation in which

Figure 4. Survey transects for bathymetric study.

Figure 5. Photograph showing river mouth and field activities.

the interpolated values are modeled by a Gaussian process, run by prior covariance. It is a reasonably accurate method, generally employed on cartography of seafloor. Kriging helps to obtain the shape of the seafloor as relief map in order to delineate the seabed contours in various scales (Christopheret al., 2016). Kriging is also a recommended method for terrain variation analysis, when compared with other interpolation methods such as inverse distance weighted, ANUDEM, nearest neighbor, spline approaches etc., (Hare et al., 2011; Arun, 2013). It also can compensate for clustered data by giving less weight to the cluster in the overall prediction.

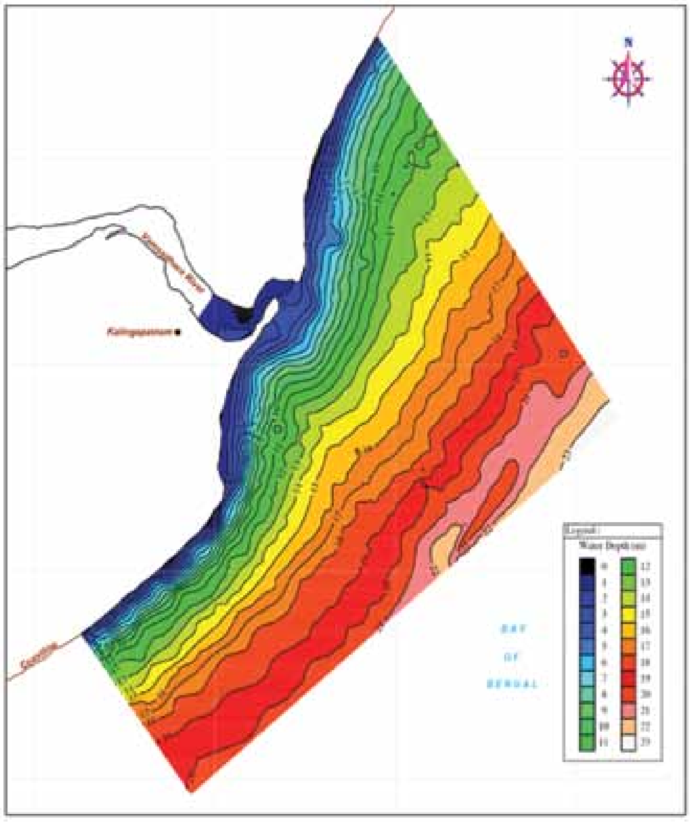

Figure 6a. Pre-Monsoon bathymetry contour map of Kalingapatnam offshore area.

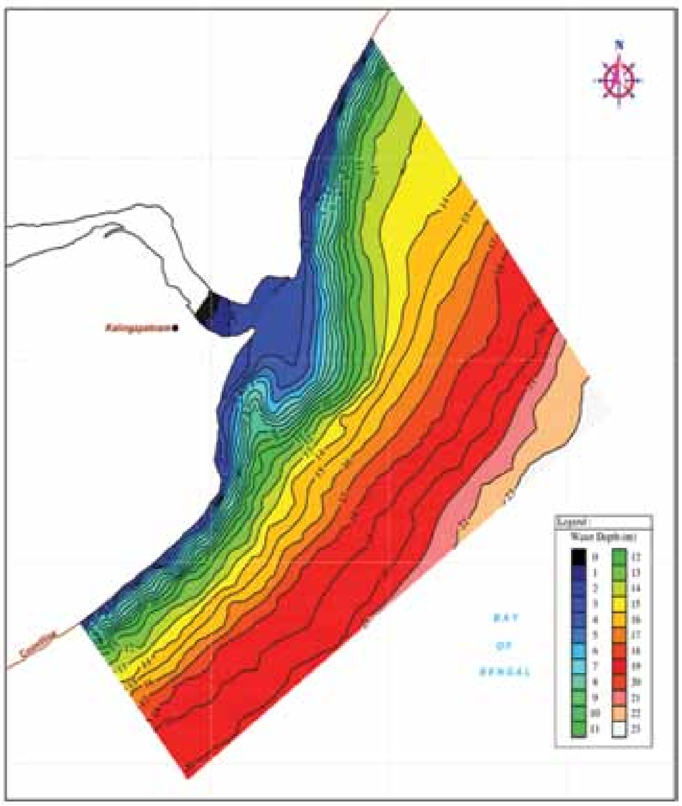

Figure 6b. Post-Monsoon bathymetry contour map of Kalingapatnam offshore area.

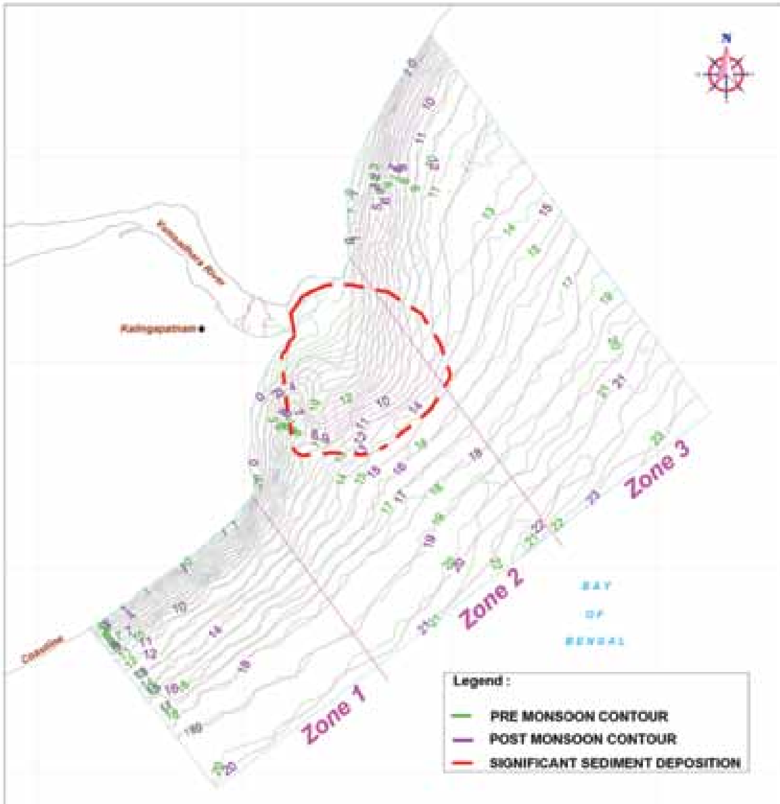

Figure 7. Contour map showing both pre- and post-monsoon bathymetric study in Kalingapatnam offshore area.

Contour maps were prepared from the gridded data at 1 m interval for both seasons (Figure 6a and 6b). The first two dimensions X and Y are the geographical coordinates in UTM. The third dimension (Z) is represented by depth with respect to Chart Datum. The relative spacing of the contour lines indicates the relative slope of the seabed. The pre- and post-monsoon contours are superimposed and analyzed for sediment movement between the two seasons (Figure 7). The development of coastal infrastructure and maintenance are mainly dependent on morphodynamic changes. In this study, the sediment deposition/erosion and its volume has been analysed and computed for each zone separately using the surfer software. The "xyz" data for two seasons were defined as an upper/post-monsoon and lower/pre-monsoon surface for each grid cell. In areas where the surface is tilted at the top or bottom of a grid cell, the software approximates the volume of the prism at the top or bottom of the grid cell column. For very coarse grids, the prisms can contain a significant volume.

RESULTS AND DISCUSSION

The results reveal that in zone 1, the seabed up to 450 m from shore is rather steeper than the seabed further seaward during both monsoons. A slope of 1:45 has been observed till 10 m depth and 1:130 between 10 m and 20 m contours. The analysis of seabed contours for both seasons do not show much variation generally as the same depth contours are running at same distance and pattern in this zone. The maximum depth of 20 m exists at a distance of about 2 km from shore. The sediments accumulation and erosion occurred on seabed between pre- and post- monsoon in this zone is calculated as 11, 78,000 m^3 deposition and 2, 99,000 m^3 erosion. Similarly, zone 2 is the area where river Vamsadhara meets sea. The near-shore area close to river mouth is identified as shallower in post monsoon bathymetry. The sediments are deposited and spread at various directions which show significant variation on post monsoon bathymetry at 1.3 km southward from river mouth (Figure 7) (Fennessy et al., 1994). The seabed near river mouth was observed as a slope of 1:80 till 10 m contour during pre-monsoon and after it has been observed as 1:130 during post-monsoon. The seabed shows a slope of 1:200 further seaward during pre- monsoon and 1:185 in post- monsoon. The depth contours do not show much variation in its pattern and location between 15 m and 20 m. In general, the depth of 20 m is observed at a distance of about 3 km from the river mouth. The total volume of sediment deposited after monsoon is calculated as 1,69,26,000 m^3 in which eroded volume is 2,47,000 m^3.

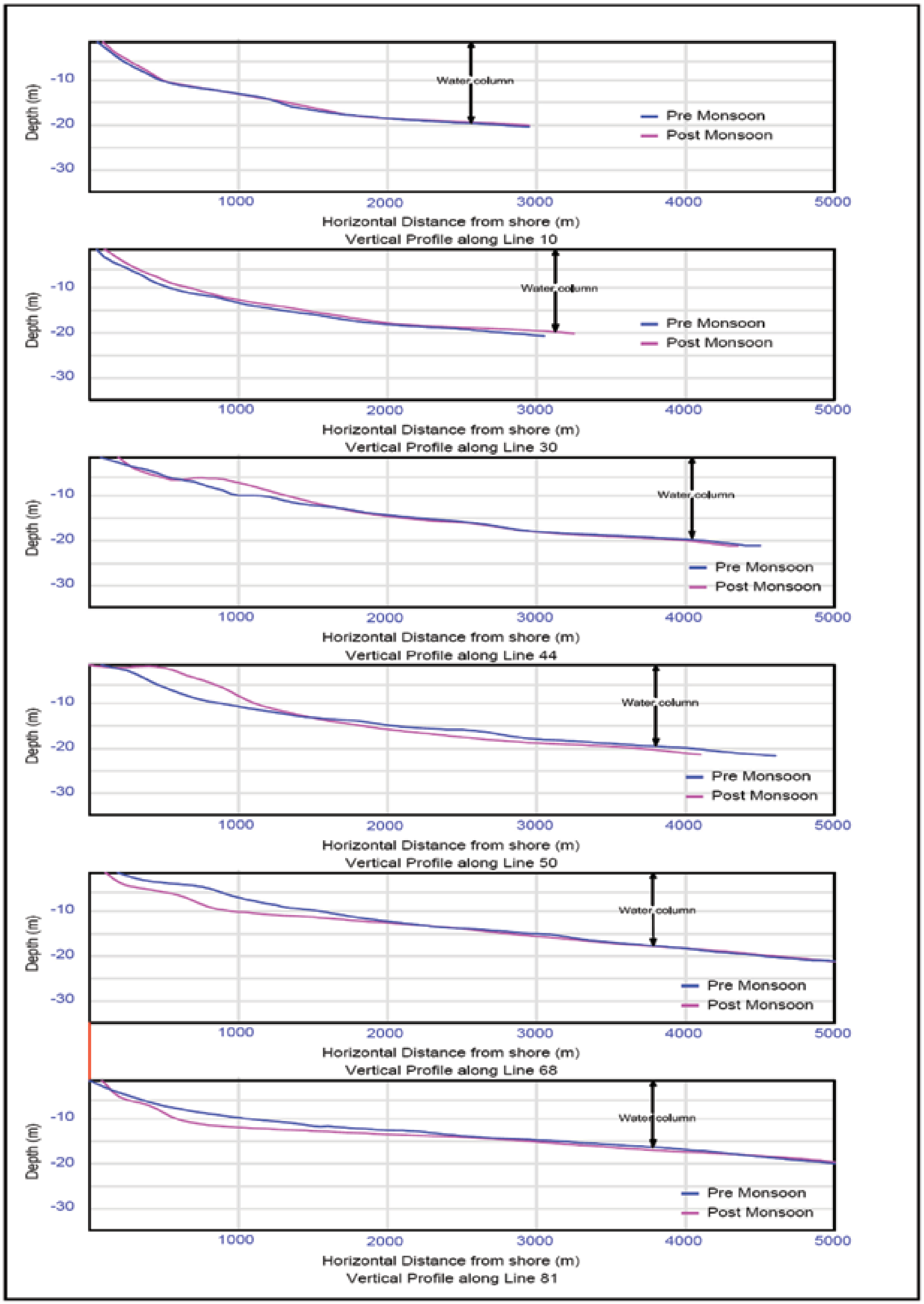

Figure 8. Typical vertical profiles during Pre- and Post –Monsoons

Table 1. Details of vertical profiles at 2 Km interval.

Lines	Start depth	End depth	Straight line distance	Vertical difference (start to finish)	Minimum depth on path	Maximum depth on path	Azimuth	Slope/ tilt
Line 10	0.13 m	20.50 m	2.94 km	20.4 m	0.13 m	20.50 m	144° 48' 48.3"	0.40°
Line 30	0.40 m	20.76 m	3.04 km	20.4 m	0.39 m	20.76 m	144° 49' 14.4"	0.38°
Line 50	1.22 m	21.77 m	4.58 km	20.6 m	1.22 m	21.77 m	144° 49' 29.8"	0.26°
Line 70	0.29 m	22.43 m	5.94 km	22.7 m	-0.29 m	22.43 m	144° 49' 42.8"	0.22°
Line 90	1.84 m	23.32 m	6.75 km	21.5 m	1.84 m	23.32 m	144° 49' 58.7"	0.18°
Post Monsoon								
Lines	Start depth	End depth	Straight line distance	Vertical difference (start to finish)	Minimum depth on path	Maximum depth on path	Azimuth	Slope/ tilt
Line 10	0.47 m	20.20m	2.944 km	19.7 m	0.47 m	20.20 m	144° 48' 43.3"	0.38°
Line 30	0.41 m	20.44m	3.044 km	20.9 m	0.41 m	20.44 m	144° 49' 44.8"	0.39°
Line 50	0.15 m	21.41 m	4.62 km	21.3 m	0.15 m	21.48 m	144° 49' 3.5"	0.26°
Line 70	1.89 m	23.11m	5.947 km	25.0 m	1.89 m	23.11 m	144° 49' 52.5"	0.24°
Line 90	1.08 m	23.08m	6.787 km	22.0 m	1.08 m	23.08 m	144° 49' 48.8"	0.19°

The seabed up to 10 m contour in zone 3 is also rather steeper than the seabed further offshore like zone 1 and zone 2. But, the near-shore part of this zone has quite higher sediment erosion than other two zones. The seabed beyond 15 m contour does not show significant erosion or deposition. The 20 m contour is running at a distance of about 3.5 km from the shoreline. The total deposited sediment volume computed between pre- and post -monsoon for this zone is 64, 51,095 m^3. The total erosion is computed as 71, 90,239.46 m^3. The vertical profiles were analyzed between 1-30 transects in zone 1, 31-60 in zone 2 and 61- 91 in zone 3 during pre- and post-monsoons. The cross-sections are plotted and studied between water depth and horizontal distance referred from shore (Figure 8). Various seabed gradient parameters were derived from each transects for detailed analysis (Table 1).

It has been observed that the sediments deposited in the river mouth are comparatively higher than other location. The sediment accumulation could be assigned to sediments carried out by the river Vamsadhara. Generally, the point where river meets sea is a place of sedimentation zone which is governed by river flow, wave action and type of sediments. Temporal wave, current, tide measurements, river discharge measurements along with its numerical model studies will give a clear picture on rate of sediment deposit, sediment pattern and frequency at river mouth. The vertical profiles show the significant sediment deposition between line 30 and 50 in the near shore area. This indicates that the south of river mouth gets deposited significantly than the northern side of river mouth. Further study on near-shore drift current will help to understand the stability/mobility of sediment movement at this region (Rijn, 1984). The vertical profiles beyond line 68 show the erosion phenomenon in the near shore region. The reason for erosion in this region could be the northerly current movement. This study explains that though the near shore has northerly sediment drift, the river flow dominates towards south for particular extent and distributing the sediments during monsoon period.

CONCLUSIONS

The analysis of both pre- and post- monsoon bathymetry, demonstrates that the seabed has steeper slope in the near shore area till 10 m water depth and gentle slope further seaward. The depth contours are running parallel to the coast at all zones during both seasons. The overall data suggests that zone 2 and 3 experiences substantial sediment movement than zone 1. The zone 2 has major sediment deposition and zone 3 shows key erosion after monsoon. However, the sediment migration in these zones occurs predominantly in the near shore areas. Since the adequate natural depth subsists in the near shore, these zones are suitable for coastal developers to construct coastal based infrastructure such as fishing harbour, thermal power plant, desalination plant etc. In zone 1, the capital and maintenance dredging would be lesser which is suitable for intake and out fall pipeline systems for coastal based power plants and desalination systems. Though, the zone 2 is suitable for fishing harbour and construction of wharf/ jetties in the river banks, the capital and maintenance dredging operation will be little higher. However, a suitable dam at a distance of about 10 km from the river mouth will reduce the maintenance of dredging in the river mouth at zone 2. Further meteorological modeling would be required for planning of suitable break waters and other marine structures at all the three zones before construction.

Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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