ASSESSMENT OF THE IMPACT OF THE TSUNAMI OF DECEMBER 26, 2004 ON THE NEAR-SHORE BATHYMETRY OF THE KALPAKKAM COAST, EAST COAST OF INDIA

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ABSTRACT

The devastating impact of the December 26, 2004 tsunami on the coast of South India has been well documented. However, only a few studies assessed the tsunami's impact in the near-shore region. The present study evaluates changes in bathymetry along the near-shore of Kalpakkam before and after the tsunami. Using GIS software, data was extracted from charts to create three-dimensional bathymetric representations of the offshore region before and after the tsunami. Initially, a TIN (Triangulated Irregular Network) surface was created by using Arc GIS software. Subsequently, by employing a 3D analyst tool, a three-dimensional surface of the near shore bathymetry was generated and comparisons were made with the pre-tsunami bathymetry. Based on comparisons of selected profiles, conclusions were drawn as to changes that resulted from the tsunami's impact. The analysis indicated that the tsunami deposited loose inner shelf sediments that altered significantly the near shore region bathymetry of the Kalpakkam coastal region. Sediment accretion changed the local bathymetry by 10 to 50 cm.

KEY WORDS: Bathymetry, Kalpakkam, GIS TIN, 3D surface, Tsunami impact

1.0 INTRODUCTION

The Tsunami of December 26, 2004 caused devastation to several countries bordering the Indian Ocean. The tsunami's various aspects and impact on coastal communities were extensively researched, surveyed, and documented (Tamil Nadu Govt. Tsunami Report, 2006; Rajamanikkam, 2006; Tamil Nadu Govt. Tsunami Report, 2006). Only a few of these studies assessed the impact on near-shore bathymetry.

Surveys carried out by several scientific groups in India documented that tsunami inundation varied from 200 to 600 meters inland along the coasts, but that at some locations the inundation was up to 2 km inland (Sasidhar, 2005, Rajamanikkam, 2006). The wide spatial variation in inundation and the observed run-up were attributed to variances in land topography and offshore bathymetry. A field survey by India's Geologic Survey (GSI, 2006) revealed that significant morphologic and structural changes of the seafloor were caused by the tsunamigenic earthquake along the Andaman-Nicobar ridge. Additional investigations at Port Blair and elsewhere in the Andaman and Nicobar islands (Rajamanickam et al., 2006) determined that the sea level had been elevated by about one meter - which indicated subduction - whereas at other areas along the western coast of the middle Andaman Islands emergence of shallow coral beaches suggested uplift. Elsewhere, surveys of beach profiles at Puthu Vypeen, and Kerala (Rasheed et al., 2006) documented that the tsunami caused erosion of the foreshore and backshore coastal areas and landward transport of sediments.

In the South Andaman and Nicobar islands, studies (Subramanian *et al*., 2006) concluded that land subsidence contributed to greater tsunami inundation. The survey indicated 0.8 m subsidence around Port Blair and 1.3 m subsidence in Great Nicobar. In contrast, a study of micro faunal distribution in sediments carried out along the Andhra Pradesh coast (Prasad et al., 2006) found no evidence of migration of deep-water fauna to the near shore regions. In general however, there was a change of depth contours towards the shore which indicated that the tsunami caused coastal erosion and deepening of the inner-shelf. A bathymetric survey along the Kerala coast (Prakash et al., 2006) indicated tsunami-induced erosion, even in the inner self of the Thangasseri, Vallikavu region and south of Kayamkulam of Kerala.

The near shore changes reported at several coastal areas (Seralathan et al. 2006; Hussain et al. 2006; Thakur and Kumar, 2007) prompted the initiation of this study for the Kalpakkam area - which houses several vital infrastructure installations. The main objective of the investigation was the generation of 3D seabed bathymetry in the near shore area before and after the tsunami for the purpose of identifying changes in the near shore bathymetry of Kalpakkam and the assessment of potential changes and impact from a future tsunami event.

2.0 STUDY AREA DETAILS

To accomplish the above-stated objectives, a coastal stretch of 4.5 km in length and 2 km in width was selected along the coast of Kalpakkam. The study area is bounded by the coordinates $80^{o}10.'32E$, 12^{o} 34.'45 N to 80^{o} 12.'33E, $12^{o}32.'40N$.

2.1 Coastal morphology

The coastline in this region is relatively flat and the foreshore is primarily composed of coarse sand. Isolated rocks can be found in the northern portion of the offshore area. A small stream named "Edaiyur" and a canal named "Buckingham" connect to the sea in the study area.

2.2 Seabed topography

The seabed within the survey area was generally less undulated with a gentle gradient sloping eastward and rock patches found in the northern portion. The seabed in other parts of the study area was generally smooth, dominated by micro-sand ripples aligned perpendicularly to the general direction of the littoral current and with a few patches of marine flora - which were identified. The samples collected from the seabed were composed of fine sand, shells, silt, mud and clay in varying proportions and particle sizes. The depth of the sea in the study area ranged from –0.17m to -14.40 m below the MSL datum.

3.0 MATERIALS AND METHODS

The National Hydrographic Officer (Dehradun) provided bathymetric data along the Kalpakkam coast for different dates before and after the 2004 tsunami struck the region. Specifically, the bathymetry data was extracted from charts of the decimeter scale that had been generated in January 2002 and anew in April 2005, after the tsunami. The bathymetric data sets were transformed to a common horizontal and vertical datum (Universal Transverse Mercator Projection, WGS-84 Datum) before being processed by GIS software. Subsequently, the data was recorded in the form of x, y and z parameters, corresponding to latitude, longitude and water depth. Using the ArcGIS software, digital databases were created for both the pre and post-tsunami bathymetry for the selected 4.5 km block segment of the coastline, extending 2 km out to sea. In general, two common surfaces i.e. the Triangulated Irregular Network (TIN) and GRID were used to represent the bathymetry surface. Since TIN is the recommended method to use in creating accurate model surfaces from hydrographic data (Byrnes et al. 2002), TIN and the 3D analyst extension of Arc Info software were used to generate both pre and post tsunami 3D surfaces from the digital data and thus determine changes in submarine topography caused by the tsunami.

4.0 RESULTS AND DISCUSSION

The 3D surface of the near shore seabed of the Kalpakkam coastline indicates that the area is generally less undulated, with a gentle gradient sloping towards the east. Also, in the northern part small projections were noticed and identified as rock patches. There are no artificial features and no wrecks of any kind exist in this area (Fig. 1). The elevation of the sea surface ranges from -0.4m to -13.0 m below MSL (Fig. 1a) in the pre- tsunami period and from -0.1 m to -14.0 m below MSL (Fig. 1b) in the post- tsunami period, respectively.

3D surface of the near shore seabed of Kalpakkam Coast	
1a. Pre Tsunami Period	**1b. Post Tsunami Period**

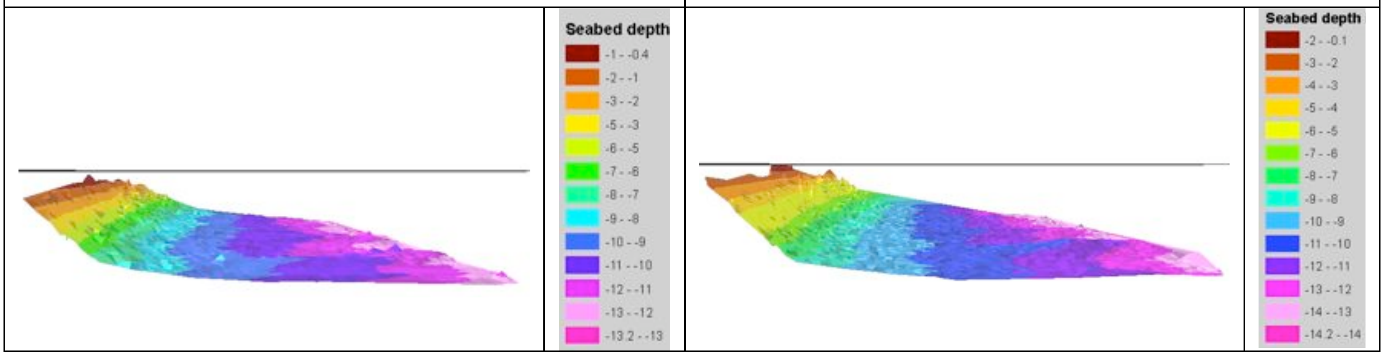


Fig. 1 Pre- and Post- tsunami Seabed surface of the Kalpakkam Sea

4.1 Changes in near shore Bathymetry due to Tsunami

By comparing pre and post tsunami seabed surfaces, it was determined that the seabed became shallow near the coast at most locations, suggesting deposition of inner shelf or deep-sea sediments in the shallow areas. Siltation at a typical transect was measured to be in the range of 10 cm to 50 cm (from 9 out of 15 locations) (Table-1). Sporadic traces of Monazite deposits were also found in this area up to 100 m off the shoreline. The deposition of beach sands in some dwelling units up to 500 m inland, demonstrates also the deposition of inner shelf sediments in the area (Seralathan et al. 2006; Hussain et al. 2006; Anandan et al., 2006) by the tsunami. Also at some areas (in 6 out of 15 locations), the seabed eroded, as it can be seen from Table-1 data. Similar accretion rates ranging from 10 to 60 centimeters were also noticed at various inlets of the Kayankulam and Kollam region and were attributed to the tsunami (Prakash et al., 2006). Average accretion rates of 2 cm/year have been reported for areas near islands of the Gulf of Mannar for the pre-tsunami period (Thanikachalam & Ramachandran, 2003). Considering a similar accretion rate of 2 cm/year due to siltation, the study area at the Kalpakkam coast would have resulted in 6 cm of change between 2002-2005, whereas the study shows that a change of 10 to 50 cm had occurred, which implies that this could be due to the tsunami impact, which included the expected normal siltation. Furthermore, the siltation levels recorded at Kalpakkam were in agreement with those determined for the Kayankulam and Kollam areas (Prakash et al., 2006).

Table 1 Pre and Post bathymetry along a typical profile (Measurement along Profile-IV up to 500m)

Sl.No.	Depth measurement at a typical profile	Pre_ bathymetry (m)	Post_ bathymetry (m)	Difference in bathymetry (m)*
	a	b	c	d= b-c
1.	Point1	2.2	1.7	-0.50
2.	Point2	3.8	3.9	+0.10
3.	Point3	4.3	3.8	-0.50
4.	Point4	4.6	4.1	-0.50
5.	Point5	6.3	5.8	-0.50
6	Point6	6.9	6.6	-0.30
7.	Point7	6.6	6.7	+0.10
8.	Point8	6.7	7.2	+0.50
9.	Point9	6.8	7.0	+0.20
10.	Point10	7.0	7.4	+0.40
11.	Point11	7.1	7.0	-0.10
12.	Point12	7.3	7.0	-0.30
13.	Point13	7.5	7.8	+0.30
14.	Point14	7.8	7.3	-0.50
15.	Point15	8.0	7.8	-0.20

* (-) decrease in depth (deposition): (+) increase in depth (erosion)

4.2 Profiles

To visualize the changes in seabed due to the 2004 tsunami, four profiles (Profile I – IV) were chosen for both the pre- and post- tsunami seabed. These four profiles are shown in Figure 2. At a distance of 125 m from the coastline the slope of the seabed were measured for the pre and post tsunami period for all four profiles.

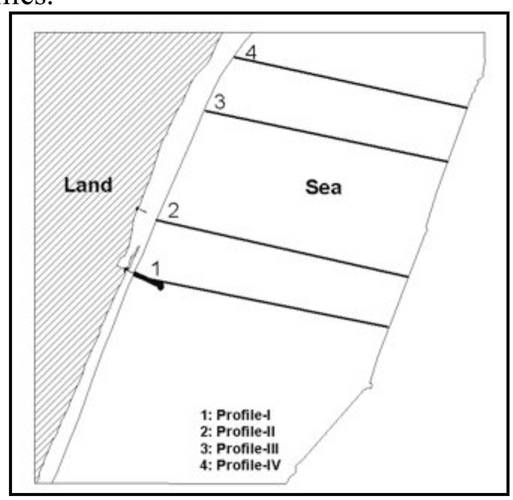
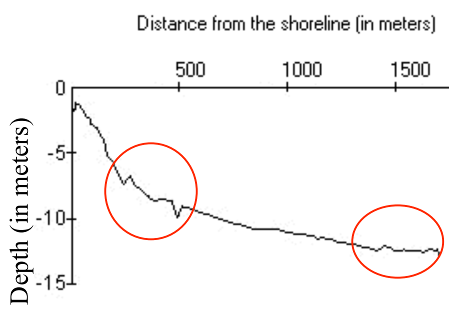
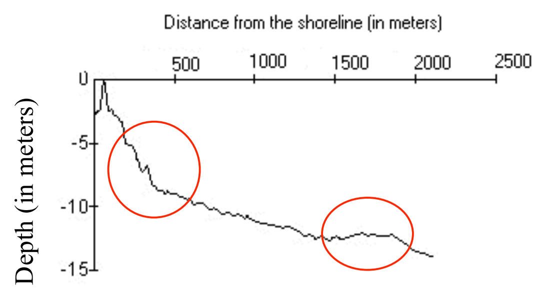
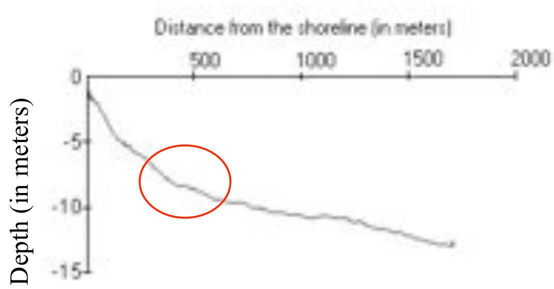
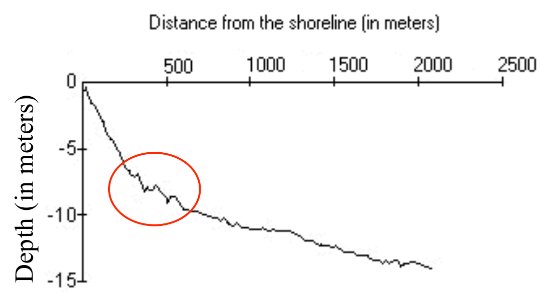
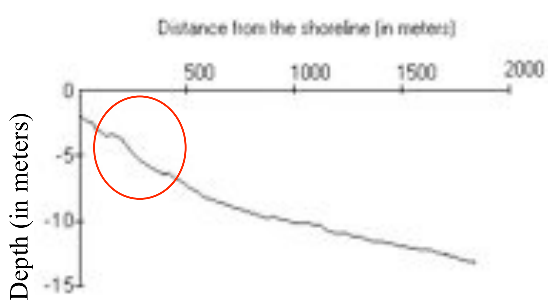
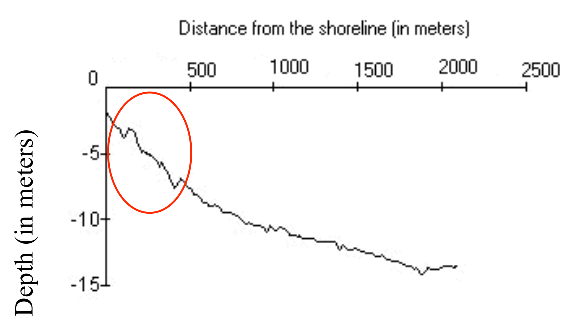


Fig. 2 Locations of the profiles I to IV

4.2.1 Profile - I:

A depression was found at a distance of 500m from the shoreline along Profile-I for the pre tsunami period. After the tsunami this depression was found to be filled up which that supports the tsunami's depositional phase. Deposition was also observed in the post tsunami seabed along the same transect at a distance of 1500 to 2000 meters from shoreline, which also supports the depositional phase of the tsunami. The increase in the slope of seabed for the post tsunami profile as compared to the pre tsunami baseline condition, corroborates the earlier findings. (Fig. 3a & Fig. 3a', Table -2)

Pre Tsunami Period	Post Tsunami Period
Profile-I **a**	**a'**
	
Profile-II **b**	**b'**
	
Profile-III **c**	**c'**
	
Profile-IV **d**	**d'**

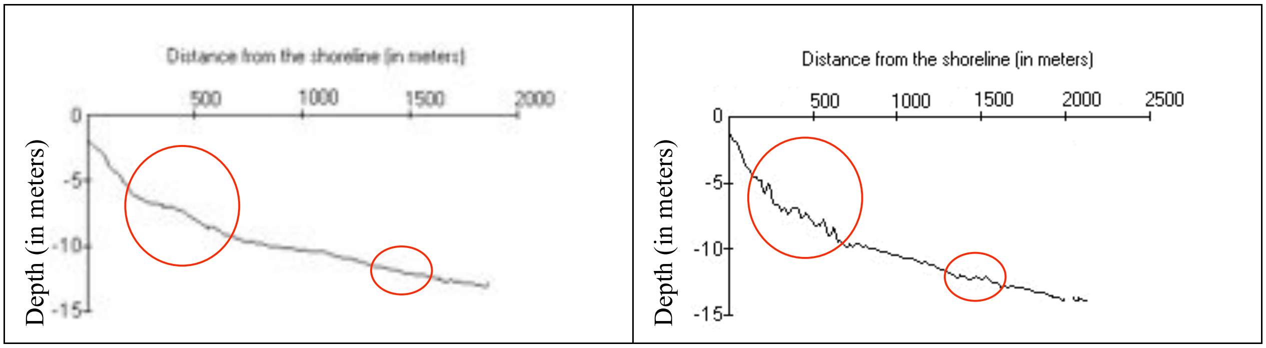


Fig. 3 Profiles shows the areas of changes in the bathymetry (highlighted in the circles)

Table 2. Seabed slope in pre and post tsunami phases along four profiles

Sl.No.	Location	Pre-tsunami Slope angle*	Pre-tsunami Slope angle*	Difference in the slope angle
1	Profile-I	60 ^{o}	65 ^{o}	+5 ^{o}
2	Profile-II	58^{o}	63 ^{o}	+5 ^{o}
3	Profile-III	34 ^{o}	44 ^{o}	+10 ^{o}
4	Profile-IV	48 ^{o}	58 ^{o}	+10 ^{o}

*Seabed angle measured at a distance of 125 m from the shore line in all profiles

3.2.2 Profile – II:

Profile-II shows that along this transect at a distance of 400m to 600m from the shoreline the seabed was undulated in the post tsunami bathymetry as compared to the pre-tsunami bathymetry - which implies seabed erosion by the tsunami. Also, the slope of the seabed was steeper compared to the pre tsunami profile, which support huge deposition of sediments (Fig. 3b & Fig. 3b', Table-2).

4.2.5 Profile – III:

Profile-III shows that the seabed was undulated at a distance ranging between 100 to 400 meters from the shoreline and that at a distance of 1000 meters from the shoreline the seabed was again undulated in the post tsunami bathymetry - when compared to the pre tsunami bathymetry. Further along the profile of this transect the seabed was undulated in the post-tsunami bathymetry compared to the pre-tsunami bathymetry, which again implies the erosional phase of the tsunami in this area. The steepness of the slope for the post-tsunami profile implies deposition of inner shore sediments along the coast. (Fig. 3c & Fig. 3c', Table-2)

4.2.6 Profile – IV:

Profile-IV shows the sea bed to be highly undulated at a distance of 250 to 750 meters from the shoreline in the post tsunami period. Similarly, at a distance of 1500 meters the seabed was again undulated. The steepness of the slope as compared to the pre-tsunami slope, implies bulk deposition of inner shore sediments (Fig. 3d & Fig. 3d', Table-2).

In summary, the shallowness in the seabed due to the deposition of deep sea or inner shore sediments in all of the profiles indicates the depositional phase of the tsunami waves, whereas, in only a few locations the seabed was deepened (Table-1). The present study supports that local bathymetry as well as coastal morphology of an area play major roles in controlling the tsunami wave impact. This was also supported by studies of many other coastal areas of India (Rasheed et al. 2006; Prakash et al., 2006).

5.0 CONCLUSIONS

The above study assesses the impact of the 2004 tsunami on the near-shore seabed of Kalpakkam by employing the pre- and post- tsunami bathymetry data. The study supports that sediment accretion in the range of 10 cm to 50 cm occurred in the nearshore area of the Kalpakkam Sea. The field observations support the deposition of loose inner shelf sediments by the tsunami and emphasize the importance of periodic baseline surveys of near shore bathymetry to determine changes. Comparison of baseline digital bathymetric data for the same area can provide an effective method for calculating the net movement of sediments, either by accretion or erosion, and help quantify temporal changes in bathymetry by such processes, as well as determine sediment transport pathways and volumetric estimates of sediment budgets, in general. Such evaluation of changes in the near shore bathymetry are important in view of the amounts of water that is needed by the underwater intakes of the condenser cooling system of the Madras Atomic Power Station (MAPS) in the coastal area of Kalpakkam. Assuring seawater availability is necessary for the condenser coolant refinement, at least for three decades, for the safe operation of the nuclear power plant. This need for safe operations of nuclear power stations warrants close scrutiny of bathymetry changes of the offshore areas where such plants are located. Also, the present study indicates the importance of GIS software in assessing the impact of natural disasters through 3D plots in real world coordinates, and specifically in this case, in evaluating bathymetry changes due to a tsunami.

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