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Evaluation of Beach Volume Along the Tsunami Affected Coast, Southern East Coast of India

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Abstract

To comprehend the impact of 26 December 2004 tsunami on beach environment, an assessment of the beach sediment volume in respective zones of the beach profile has been done by comparing the pre-event and post-event beach profile data. In spite of the considerable accretion in some of the beaches, rest of the beaches had suffered erosion. The coastal configuration, bathymetry, component of the beach, etc. had played a key role in determining the extent of change in the beach sediment volume. Erosion had occurred mostly in dune and berm while littoral zone favoured accretion of sediments eroded from the dune, berm and also the 'fresh' sediments brought in by the tsunami surge from the continental shelf. River inlets and other water passages had greatly influenced the degree of erosion by facilitating the seismic waves to inundate much of the coastal zone. The degree of erosion ranges between 1.84 m^3 and 0.34 m^3 with a maximum at Manappad and with a maximum at Periyathalai, the accretion amount varies from 1.36 m^3 to 0.06 m^3. Apart from Manappad, Kulasekaranpattinam, Alanthalai and Kayalpattinam, Tuticorin-2 was the heavily eroded beach whereas the beaches like Periyathalai, Tiruchendur and Veerapandianpatinam had the benefit of accretion. Erosion and accretion had played one and the same in the beach of Tuticorin-1.

Keywords: India, Tsunami, Beach, Accretion and Erosion Estimation, GIS.

1. Introduction

Tsunami is one of the coastal hazards that generates in the deep ocean due to an earthquake, volcanic activity, submarine landslide etc. and would then propagate to its maximum coverage across the ocean and will transform into a gigantic wave to bring disaster on the coastal regions. It is a frequent phenomenon in the Pacific and Atlantic coast but absolutely a rare phenomenon in the Indian Ocean. 26 December 2004 – a dark day in the earth's history because of the occurrence of tsunami – generating earthquake measuring more than 9 on the Richter Scale focused along the Sumatra Island near Indonesia resulting after the collision of Indian Plate with the Burma Micro Plate (Park *et al.*, 2005) which claimed not only thousands of lives, properties but also altered the shoreline, coastal geomorphology, beach configuration, etc. along the coastal regions of Southeast Asia including India, Sri Lanka, Indonesia, Malaysia, Thailand and part of Africa (Raval, 2005).

Koji Minoura *et al.* (1994) studied the tsunami deposits of lacustrine sequence of the Sanriku coast, northeast Japan and attempted to draw out the probable source of it. Minoura *et al.* (2001) studied the 869 Jogan tsunami deposit on the Pacific coast of northeast Japan and inferred the inundation extent of that tsunami surge. Gelfenbaum *et al.* (2001) studied about the sedimentary deposits of 17th July 1998 Papua New Guinea Tsunami and estimated the impact of that tsunami based on the sedimentation it induced. Fuminori Kato *et al.* (2001) brought out the grain-size effects on scour around a cylinder due to tsunami run-up. Jaffe and Gelfenbaum (2002) insisted on using tsunami deposits to create a geologic record of that particular tsunami and also obtaining a geologic record of past tsunamis using the tsunami deposits thereby, assessing the future risks. Barbara Keating *et al.* (2004) investigated the tsunami deposits at Queens beach, Oahu, Hawaii and deciphered the nature of it. Ramasamy (2005) reported the scenario of Indian coast after the 26 December 2004 with certain issues and strategies. Kumanan (2005) presented the global scenario of tsunamis mentioning the frequency of tsunamis in the Pacific and Atlantic coast and the rarity of tsunamis along the Indian coast. Radhakrishna (2005) reported the destructions rendered by the 26 Dec 2004 tsunami along the coast of India. Narayana *et al.* (2005) deciphered that the tsunami surge had carried huge amount of sediments from the continental shelf and deposited them in the beaches along the Kerala coast of India. Mruthyunjaya Reddy (2005) reported about the accretion and erosion due to tsunami in the beaches along the coast of Andhra Pradesh, India. Chandrasekar *et al.* (2006) classified the beaches of South India based on the inundation extent with respect to the coastal geomorphic features. Saravanan and Chandrasekar (2010) studied the potential littoral sediment transport along the coast of South Eastern Coast of India.

Though several works have been done on the 26 Dec 2004 tsunami, the research is still in the emerging stage since it is rare coastal hazard as far as the Indian Coast is concerned. Mujabar *et al.* (2007) and Saravanan et al. (2009) studied the impact of 26 December 2004 tsunami in beach morphology and post tsunami assessment along the Coast between Ovari and Kanyakumari. Almost all the works done by the previous world-wide researchers were based on the post-tsunami survey. Previous works of evaluating the impact

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of the tsunami surge on the beach volume by comparing the beach profile data prior to and subsequent to the tsunami event has been found to be nil since acquiring of the beach profile data before any tsunami event is not possible. But we obtained the pre-event data since we have been monitoring the beach morphology along the study area for quite a long period as a component of one of our research project and as a result we obtained, coincidentally, the beach profile along the study area prior to the tsunami event and subsequently we profiled those same beaches after the event. Accordingly, the impact of the tsunami in the beach pattern and in turn, on the sediment volume has been evaluated. Despite the fact that the majority of the consequences of that disaster could not be totally evaluated, a trustworthy inference could be done about the impact of tsunami on beach sediment volume by the application of advanced scientific techniques, GIS (Geographic Information System), in particular. In this paper, we would like to draw out a panoramic scrutiny of sediment dynamics induced by the tsunami event in no time.

2. Study Area

The study area (Fig. 1) encompasses of eight beaches and therein eleven profile stations along the southern east coast of India (between N 77^0 98' E 08^0 34' and N 78^0 16' E 08^0 79'). The majority of the beaches are depositional in nature with low to medium wave energy condition (Angusamy and Rajamanickam, 2000). Most of the beaches contain vegetated sand dunes with prolonged berm and gentle beach slope. There are two headlands along the study area one at Manappad and another at Tiruchendur. Observably, there are four bays between Periyathalai – Manappad; Manappad – Tiruchendur; Tiruchendur – Kayalpattinam and between Kayalpattinam – Tuticorin. Manappad is the only rocky coast along the study area situated at an elevated level from the mean sea level (~ 25 m) due to tectonic uplift with an emergent beach (Loveson *et al.*, 1996). Besides erosional features, Manappad coast displays also typical depositional features like sandspit, lagoon, baymouth bar etc. There is a notable Tombolo in Tuticorin which connects the Hare Island with the mainland on which the Port of Tuticorin has been constructed. The study area encompasses two river inlets one of the River Karamanayar and other of the River Tambraparani. These coastal geomorphologic features had played a key role in the accretion and erosion of coastal landforms along the study area. Even though, the study area falls on the 'shadow zone' (Fig. 2) due to the presence of Sri Lanka and had experienced mostly the refracted waves, the tsunami waves had altered the beach configuration, coastal landform, etc.

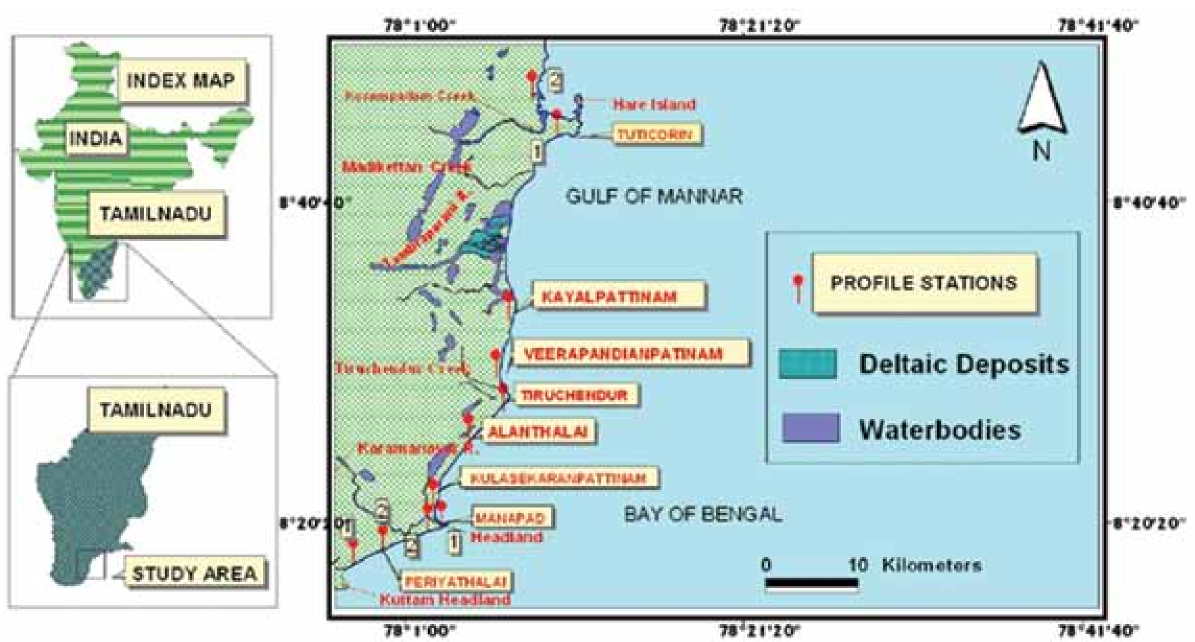

Figure 1: Location map of the study area

3. Methodology

Beach profile survey has been carried out along the study area prior to and subsequent to the tsunami event using levelling and measuring tools following Stack and Horizon method speculated by Lafond and Prasada Rao (1954) which was later simplified by Emery (1961). Transect between each profiling site ranges from many metres to few kilometres but care has been taken to profile the beaches along the study area with possible regular interval. Profiling in each beach starts from a fixed reference point usually near the coastline or beyond the interdune and covers the backshore, littoral zone and continues up to lowtide zone or near the inner breaker zone with a regular interval of 5 m. The levelling above mean sea level (MSL) and below sea level data are adjusted to MSL datum using fixed benchmark of known elevation, located behind the beach during the lowest-low water level period so that maximum length of the beach section was exposed.

The volume of sediments at each zone of the beach before and after the tsunami event has been calculated by means of the documented beach profile data using standard statistical package. The alteration induced by the tsunami surge in the beach volume was then interpreted using GIS software package – Arc View (3.2a) and other statistical packages. Chart map has been generated using GIS for each respective zone of the beach profile by inputting the sediment volume data. Every beach was divided into different zones namely the dune (if present), berm (backshore), hightide zone, midtidezone and lowtide zone. The hightide zone is the part of the beach immediately from the beach face to the margin of the midtide zone. The midtide zone is the intermediate zone between hightide zone and lowtide zone. The lowtide zone is the area from the swash zone to the inner breaker zone. Separate chart map has been prepared for each zone and finally the impact of the tsunami surge in sediment volume of all the zones were incorporated which resulted in the map showing the overall evaluation of the beach volume along the study area.

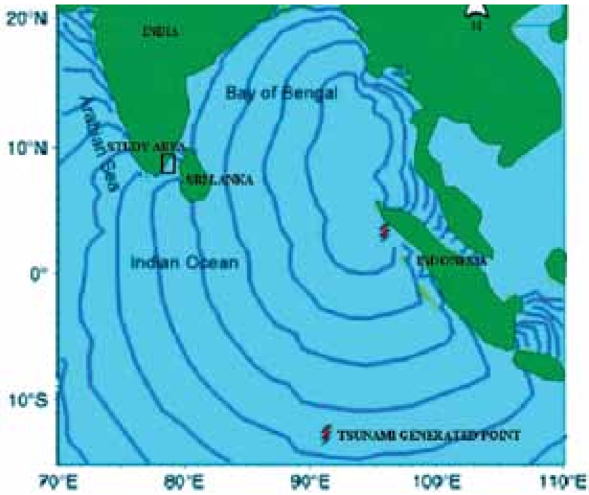

Figure 2: Map showing the nature and angle of the tsunami approached the study area.

4. Results and Discussion

4.1. Evaluation of Dune

Impact of the tsunami event in the coastal dunes along the study area is shown in Fig. 3 and given in Table 1. It reveals that almost all the beaches have suffered erosion in dune especially in Periyathalai and Kulasekaranpattinam ranging between 0.68 m^3 and 0.16 m^3, as it is the only reliable feature along the beach to resist the overwhelming seawater and thereby limiting the extent of inundation. Moreover, the vegetations on the dunes were also not left unaffected. The dunes of Kayalpattinam have experienced accretion of 0.06 m^3 sediments which may be due to the refracted waves from the Tiruchendur promontory (Chandrasekar, 2005). Kulasekaranpattinam was the foremost loser of dunes of 0.68 m^3 which may due to the convergence of the waves at the Manappad headland as it falls awfully next to it. Accordingly, Periyathalai-1 has too lost notable magnitude of dunes of 0.59 m^3 due to the similar phenomenon likely to be prevailed at the Kuttam headland, south of Periyathalai (Nobuo Shuto, 2001; Guy Gelfenbaum *et al.*, 2001).

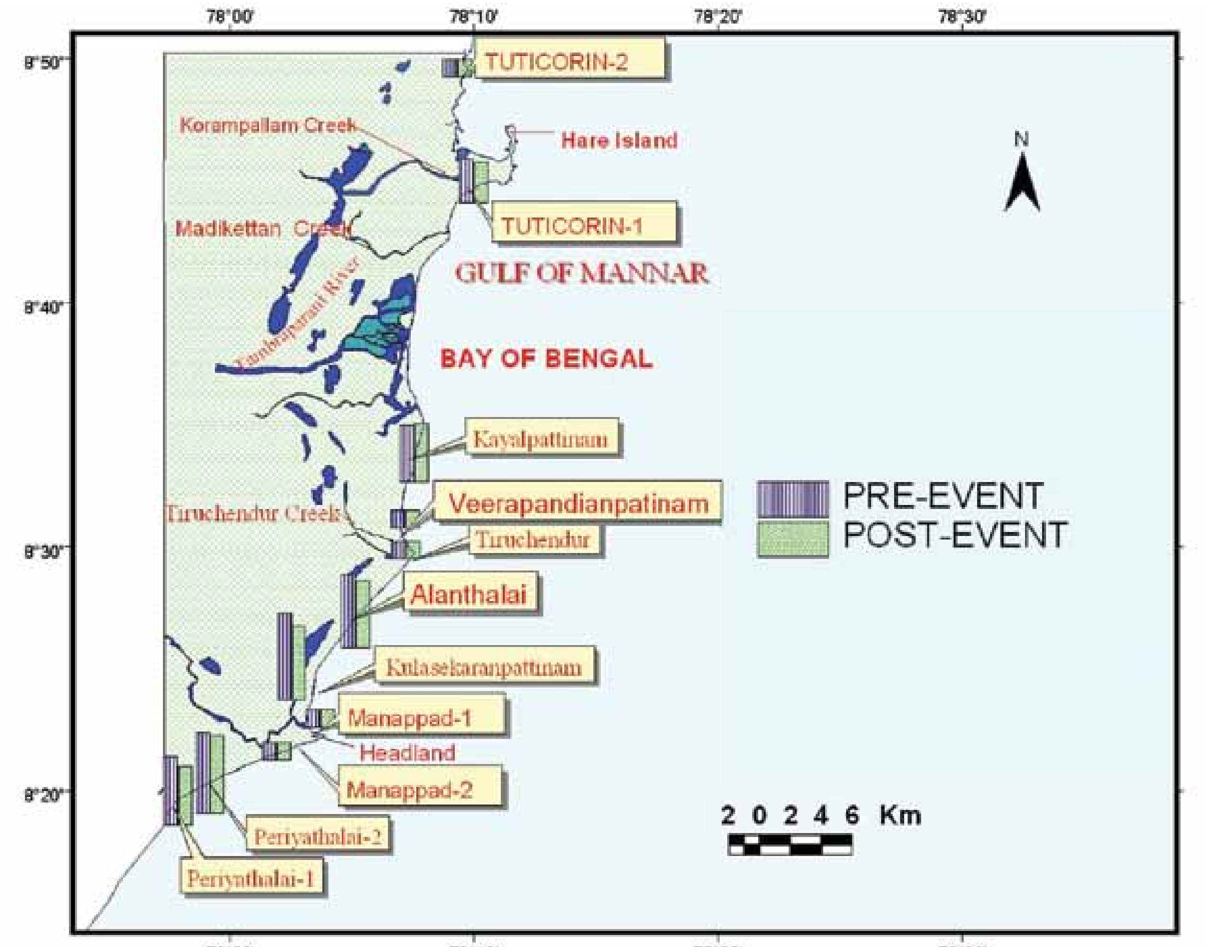

Figure 3: Evaluation of dune along the study area.

4.2. Evaluation of Berm

The assessment done in the berm is shown in Fig. 4 and Table 1. It is well evident that half of the beach has experienced erosion ranging from 0.95 m^3 to 0.04 m^3 with maximum at Tuticorin-2 and with a maximum at Periyathalai-2 accretion resulted in the rest of the beaches with values ranging between 0.15 m^3 and 0.003 m^3. There is not any noteworthy amendment in the beaches like Kayalpattinam and Tuticorin-1. It has been observed that the sediments eroded from the dunes are being deposited at the berm during backwash due to the loss in the velocity of the receding water due to the sediment load as in the case of Periyathalai-2, Alanthalai (Barbara Keating *et al.*, 2004). The tsunami-borne sediments also might have deposited in the berm along with the sediments eroded from the dunes as it is the area which supported deposition for the retreating seawater (Koji Minoura *et al.*, 1994; Narayana *et al.*, 2005). But Manappad could not experience accretion due to the coastline shape (Raval, 2005) and the existence of headland. Furthermore, it is and emergent beach elevated well above the mean sea level and hence the retreating seawater during backwash could be the result of erosion.

Table 1: Beach Volume (in Cubic Metres) from the MSL at various parts of the beach.

Location	DUNE		BERM		HIGH TIDE		MID TIDE		LOW TIDE	
	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST
PET-1	2.84	2.25	2.10	1.92	0.60	1.35	0.10	0.50	-0.30	0.10
PET-2	3.46	3.29	2.17	2.29	0.90	1.30	0.35	1.00	0.15	0.50
MNP-1*	0.00	0.00	2.43	2.07	0.60	0.35	0.30	-0.50	-0.10	-0.60
MNP-2*	0.00	0.00	4.81	4.58	1.95	1.45	1.32	0.97	0.65	0.35
KUP	3.83	3.15	2.26	2.03	1.30	1.40	0.60	0.50	0.20	0.10
ALT	3.06	2.77	2.32	2.47	0.92	0.80	0.54	0.50	0.17	0.12
TUR*	0.00	0.00	0.69	2.75	1.2	1.5	0.85	1.05	0.60	0.52
VEP*	0.00	0.00	2.13	1.96	1.1	1.5	0.90	1.20	0.60	0.70
KAP	2.16	2.22	1.49	1.49	0.80	0.55	0.35	0.20	0.15	0.10
TUN-1	1.48	1.28	0.95	0.90	0.55	0.60	0.30	0.30	-0.50	-0.25
TUN-2*	0.00	0.00	2.05	1.12	1.00	0.48	0.70	0.35	0.30	0.25

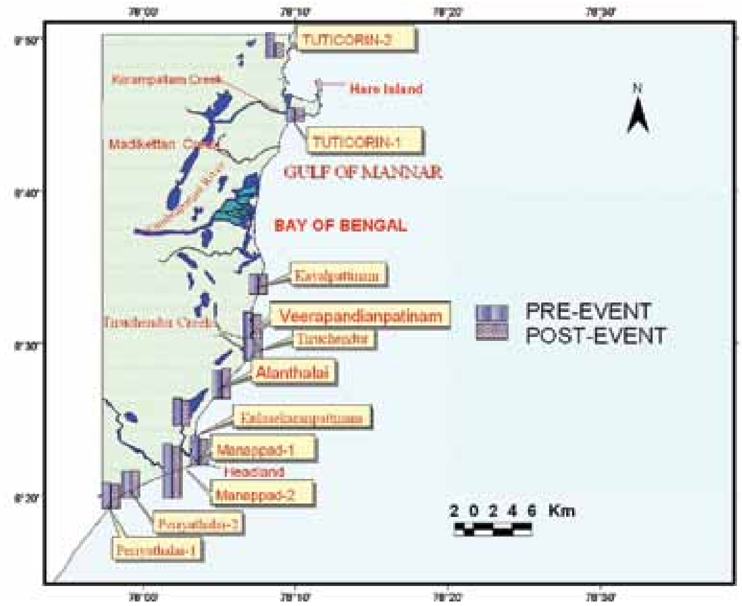

Figure 4: Evaluation of berm along the study area.

4.3. Evaluation of HighTide Zone

Fig. 5 and Table 1 show the evaluation of sediment volume at hightide zone. Periyathalai-1, after successive erosion, has experienced significant amount of accretion in hightide zone followed by Periyathalai-2, Kulasekaranpattinam, Tiruchendur, Veerapandianpattinam and Tuticorin-1. The amount of accretion varies between 0.75 m^3 and 0.05 m^3. The degree of accretion has been determined by the gradient of the beach face and the rapidity of the backwash. As in other zones, Tuticorin-2 had suffered maximum amount of erosion and similar condition had prevailed in the beaches of Manappad, Kayalpattinam and Alanthalai. The quantity of erosion, as in the case of accretion, depends upon the similar aspects as for accretion mentioned above (Chandrasekar, 2005; Glenda Besana *et al.*, 2004). The quantity of erosion ranges from 0.52 m^3 to 0.12 m^3.

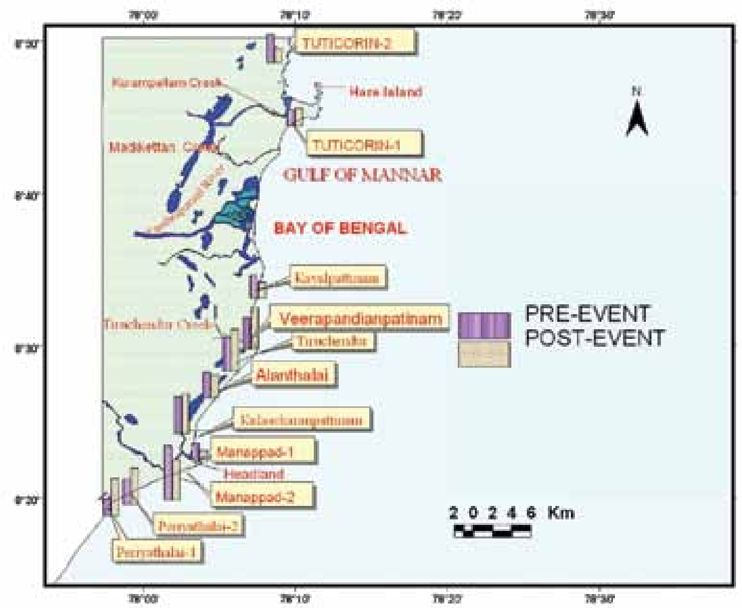

Figure 5: Evaluation of hightide zone along the study area.

4.4. Evaluation of MidTide Zone

The accretion in the Periyathalai beach, as in high tide zone, continued in the midtide zone as shown in Fig. 6 and Table 1. Accretion, though not considerable, has also occurred in the beaches of Veerapandianpatinam and Tiruchendur. The magnitude of accretion varies between 0.65m^3 and 0.20 m^3. In this zone, the beach of Manappad-1 had undergone erosion higher than the beach of Tuticorin-2 accompanied by the beaches of Kayalpattinam, Kulasekaranpattinam and Alanthalai (Fig. 6). Tsunami has not induced much change in the mid tide zone of Tuticorin-1 beach as the change in the sediment volume seemed to be insignificant. The amount of erosion ranges from 0.80m^3 to 0.04m^3.

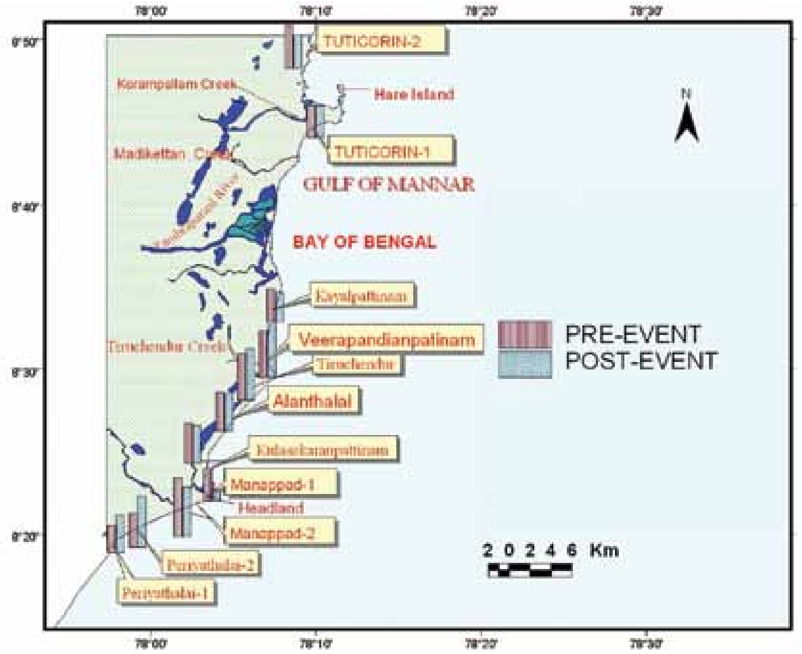

Figure 6: Evaluation of midtide zone along the study area.

4.5. Evaluation of Low TideZone

From Fig. 7 and Table 1, it is well evident that erosion had dominated at low tide zone in most of the beaches, excluding the beaches of Periyathalai, Tuticorin-1 and Veerapandianpatinam. The degree of erosion ranges from 0.50 m^3 to 0.05 m^3. Despite the fact that Manappad had endured high quantity of erosion, Tuticorin-2 had not experienced as much of erosion when compared with its other foreshore and backshore zones. A large amount of accretion has resulted in the Periyathalai beach followed by the beaches of Tuticorin-1 and Veerapandianpatinam. Accretion ranges from 0.40 m^3 to 0.25 m^3. Endurable amount of erosion had occurred on the beaches of Kulasekaranpattinam, Tiruchendur, Alanthalai and Kayalpattinam.

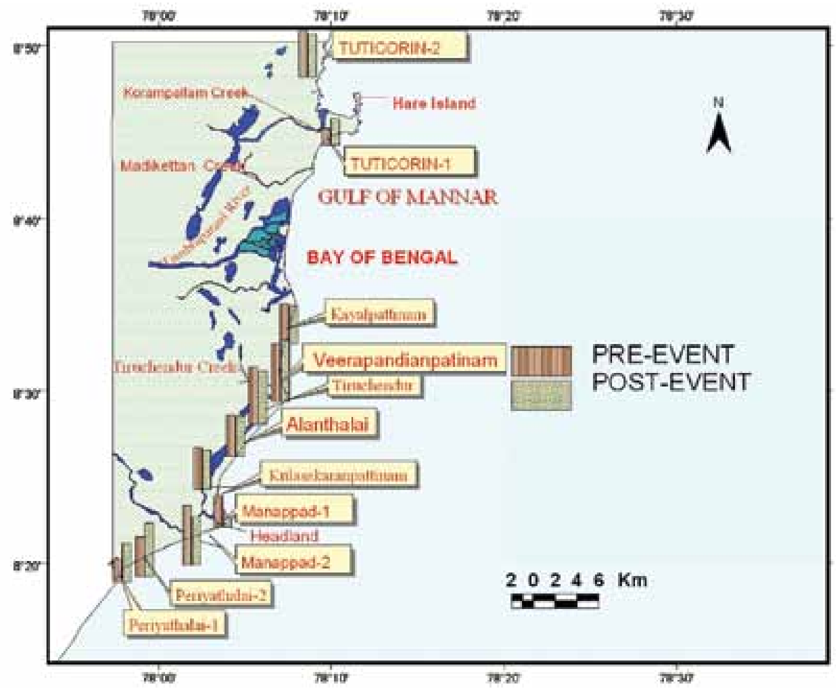

Figure 7: Evaluation of lowtide zone along the study area.

4.6. Overall Evaluation

The overall consequence of the tsunami surge in the beach sediment volume has been depicted in Fig. 8 and the total change in the beach volume has been tabulated in Table 2. It is well noticeable that substantial accretion had occurred in Periyathalai along with Veerapandianpatinam, Tiruchendur and Tuticorin-1. The quantity of accretion varies between 0.78 m^3 to 0.06 m^3 with the maximum at Periyathalai-2 and Tuticorin-1 had experienced the minimal accretion. The degree of erosion ranges between 1.91m^3 and 0.34 m^3. Manappad had endured the utmost erosion followed by Tuticorin-2, Kulasekaranpattinam, Kayalpattinam and Alanthalai, comparatively, with the minimum erosion. On the sum total, Periyathalai experienced the maximum amount of accretion and Tuticorin-1 with the lesser amount of accretion. As far as erosion is concerned, Manappad and Tuticorin-2 has suffered the maximum erosion with negligible erosion at Alanthalai.

Figure 8: Evaluation of lowtide along the study area.

Table 2: Overall Evaluation of the Beach Volume (in Cubic Metres).

LOCATION	EROSION	ACCRETION	OVERALL RESULT
PERIYATHALAI -1	0.77	1.55	+ 0.78
PERIYATHALAI - 2	0.16	1.52	+ 1.36
MANAPAD - 1*	1.91	0.00	- 1.91
MANAPAD – 2*	1.38	0.00	- 1.38
KULASEKARANPATTINAM	0.91	0.10	- 0.81
ALANTHALAI	0.49	0.15	- 0.34
THIRUCHENDUR*	0.07	0.56	+ 0.48
VEERAPANDIANPATINAM*	0.17	0.80	+ 0.63
KAYALPATTINAM	0.45	0.06	- 0.38
TUTICORIN – 1	0.24	0.30	+ 0.06
TUTICORIN – 2*	1.84	0.00	- 1.84

+ Accretion; - Erosion; * Habitually Devoid of Dunes

Since the study area was well protected by the 'barrier island' – Sri Lanka which reduced the intensity of the seismic waves approaching the study area, the beaches could not experience neither high accretion nor high erosion as the tsunami surge lost its potential to carry large amount of sediments from the continental shelf. Likewise, it could not implement heavy erosion since the inundation was not much higher when compared to other coastal regions of India where inundation was much high because they were directly exposed to the seismic waves propagated from the generation point (Raval, 2005). Moreover, the general nearshore bathymetry of the study area is around 50 m. The change in bathymetry from 50 m to around 200 m is observed far beyond the shoreline. Hence, the seismic waves would have felt the shoaling effect far before the shoreline. Hence, the uprushing wall of water would have both the potential of carrying sediments from the near continental shelf to deposit on the beach which is quite not feasible for the customary waves and tides and also to erode and redistribute the sediments in the beach during backwash (Ram Mohan, 2005). The redistribution of sediments on the beach had mainly occurred in the backshore and dunes. The sediments from the dunes have been redistributed in the backshore and the sediments in the littoral zone might have also redistributed at the berm during swash and backwash.

5. Conclusion

The evaluation of the beach volume at the various regions of the beach profile, along the study area, unveils scores of features of the tsunami event. At the outset, sand dune may be described as the *'natural beach fence'* since it has performed the unswerving task in reducing the extent of erosion. Regardless of the fact that dunes could not prevent erosion, it trims down the pace of the invading waves and favours the accretion of the dune-eroded and tsunami-borne sediments in berm and in the littoral zone as well.

Further, the elevation of the beach and the gradient of the beach face are also the deciding features of the beach sediment redistribution. Based upon the above evaluation it has been deducted that the coastal geomorphology, components of the beach, and bathymetry played a key role in the scale of accretion and erosion.

This evaluation could be possible in any other computer package but GIS grant a *bird's eye vision* of the alteration induced by the tsunami event on the beach dimension and the panoramic appraisal of the beach volume is made simple by the application of GIS. Further studies on the grain size analysis of the sediments would shed light on the precise redistribution of the sediments along the beach and the sediments brought in by the tsunami surge from offshore.

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