Assessment of Tsunami Impact on Land Forms of West Coast between Kanyakumari and Kochi, India

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Abstract

An earthquake of magnitude 9.3 on Richter scale with its epicenter located off Sumatra, Indonesia and focus at a depth of 30 km occurred on 26th December 2004 at 0630 hrs. The earthquake's epicenter (3.298°N-95.779°E) was located at 257 km SSE of Banda Aceh, Sumatra, Indonesia and 2028 km SE of Chennai, India. As a consequence to this seismic activity, tsunami was generated in which the different coasts of Indian main land, Andaman Nicobar and Lakshadweep Islands were affected with devastating effects in terms of life and property. Though the west coast has not directly faced the epicenter, the waves got deflected by Srilanka, Lakshadweep, Somalia and Maldives and struck the west coast of India (Nair, 2005). Heavy casualties were reported in Kanyakumari - Kolachal sector in Tamil Nadu and Alappad- Azhikkal sector in Kerala.

Soon after the tsunami, the Geological Survey of India launched a rapid survey at selected locations along the Indian coast from Chennai to Kochi, to assess, evaluate and record its impact on the coastal land forms and beach placers. The present paper deals with the west coast from Kanyakumari to Kochi, falling in the states of Tamil Nadu and Kerala.

During the course of post tsunami rapid survey along the west coast, affected zones were delineated and demarcated in terms of run-up elevation, inundation and devastation. (Jayabalan et. al., 2007). For the detailed studies, section line measurements (transacts) were carried out at selected locations on scale 1:2000 to evaluate the maximum run-up elevation and inundation along the coastal stretches.

Emergence of a new surface in the beach front, erosion of spits and breaching along the coastline were the major impacts recorded in the foreshore and back shore areas. The field data also depicts that the run-up elevation gets gradually reduced from south to north. It varies from 0.85 m to 6.45 m and the run-up distance varies from 200 to 500 m on land and more than 2000 m on the inlets of river and kayal. Besides, different pulses of tsunamis were reported. After every pulse, sea water recession was reported for a distance of 250-400 m ((Jyabalan et al, 2005, Mathew Joseph, 2005). It was observed that wherever shoreline protective measures like rip-raps and wave breakers were provided, the damages were less. However, the loose boulders placed on the wave-breakers have been tossed up like canon balls by the surging waves causing severe damages to the adjacent human settlements while the toe of the rip-raps supported by gabions could retain the rip- raps intact. The havoc caused to the coastal settlements and the existing coastal defense systems has also been assessed. Casualties and devastations mostly depend on the coastal geomorphology, landforms, bathymetric, and socio-economic features. Other parameters such as tsunami intensity and magnitude have also been assessed. The beach placer deposits (heavy minerals) brought by tsunami especially on either side of the Kayankulam Estuary in Kerala and Manavalakurichi in Tamil Nadu, are also discussed briefly. Besides, vulnerable zones have been delineated and the areas have been identified for the protective measures. Control and corrective measures have also been suggested to protect the valuable life, coastal land and property.

Introduction

An earthquake of magnitude 9.3 on Richter scale with its epicenter located off Sumatra, Indonesia and focus at a depth of 30 km occurred on 26th December 2004 at 0630 hrs. The earthquake's epicenter was located at 257 km SSE of Banda Aceh, Sumatra, Indonesia and 2028 km SE of Chennai, India.

Geological Survey of India, Chennai

As a consequence to this seismic activity, the rupture parameters of >1200 L km length to north from epicenter, >100 km down dip, a reverse slip of about 10m and rupture area of about 1,80,000 Sq km (www.usgs.gov) (Harendranath, 2005). Occurrence of tsunamis hitting the different coasts of Indian main land, Andaman Nicobar and Lakshadweep Islands with devastating effects in terms of life and property were reported. Though the west coast of India is not directly facing the epicenter (Sumatra Islands, Indonesia), the killer waves struck the west coast deflected from Srilanka, Lakshadweep, Somalia and Maldives (Nair, 2005). Heavy casualties were reported in Kanyakumari - Kolachal sector in Tamil Nadu and Alappad-Azhikkal sector in Kerala (Jyabalan,et al, 2005).

Soon after the tsunami, the Geological Survey of India has launched a rapid survey along the affected Indian coast to assess, record and evaluate the impact of tsunami on the coastal land forms, beach placers etc. Subsequent to this a detailed study was taken up. The present paper mainly deals with the west coast from Kanyakumari to Kochi, in parts of Tamil Nadu and Kerala.

During the course of post tsunami rapid survey along the west coast, vulnerable zones have been delineated and demarcated in terms of run-up elevation, inundation, devastation etc (Jyabalan et al, 2005). On the basis of the rapid survey, detailed studies and section line measurements (Transacts) were carried out at selected locations on scale 1:2000, to evaluate the maximum run up elevation and inundation along the coastal stretches. Significant observations made out during the course of field studies are highlighted in the paper.

Site Characterisation

Geology

Study area is a part of lowland of Kerala and Tamil Nadu dominated by coastal plains and scanty patches of hard rock. The coastal plains comprise of Archaean Khondalite Group of rocks followed by sediments of Quaternary and Recent Formations. Based on geology arrived at earlier workers (GSI Sp. Pub. No. 5), a tentative geological succession is given under the table-1.

Table 1: Geological Succession

Formations	Lithology	Age
Kadappuram Formation	Admixture of sands of various size and fragments of shell.	Recent & Holocene
Viyyam Formation	Admixture of sand, silt and black clay with shell fragments.	Holocene
Guruvayur Formation	Well sorted, loose, medium to coarse sand with little silt and clay. Stratified friable beach rock etc.	Early Holocene to Pliestocene
Kunnamkulam Formation	Laterite and Laterite soil	Pliocene
Khondalite Formation	Garnetiferous -biotite - sillimanite gneiss	Archaean

Geomorphology

Among the three different physiographic zones namely, High land (parts of the Western Ghats with hill ranges to a maximum height of 900 m from the msl), Mid land (surface of erosion cut by rivers, streams and streamlets) and Low land or plains (beach, river built terrain / deltas, <15 m height from the msl), the study area falls in the last category.

Drainage

West Coast has a high density of drainage and the Kerala Coast is endowed with 41 westerly flowing rivers, all are debouching into the Arabian Sea. The drainage net work is of dentritic pattern. The present day rivers / streams cut through their own deposits (cut and fill terraces), which are quite broad and thick indicating that the rivers might have been once mighty rivers.

Shore line

The west coast of India between Kanyakumari and Kutch is more or less straight and is considered to have formed due to faulting. The shore line is a compound one, with a

variety of features some of which have resulted from submergence and others from emergence. The beaches in general are narrow in the west coast compared to the east coast.

Coastal Erosion

Sea erosion on the coastal tracts was a common feature in the past and it is more pronounced in the Alleppy and Ernakulam districts. It may be the resultant of the reactivation of the existing fault along the coast when the equilibrium is being sought to set up by erosion and deposition.(GSI, Sp, pub. No.5)

Beach Profile

The width of back shore and steepness of the beach profiles depends on the characteristics of the waves and the beach materials. The beach materials generally are fine to medium sand with coarser fractions adjacent to bluff areas. Beach profile are steeper on the eroding zones with the foreshore having a slope of 1 on 5 to 1 on 12 above, with flatter under water slopes.

Tsunami and its impact on land forms

Tsunami wave propagation

Among the undisturbed incident waves that generated at the mega thrust through the epicenter (Banda Aceh, Indonesia), one set propagated along WNW direction for a distance of about 2000 km and made a direct hit on the coast lying between Chennai and point Calimere at around 0900 hrs. Another set of undisturbed incident waves was deflected by the large mass of Sri lanka located on the wave path, as a result, the

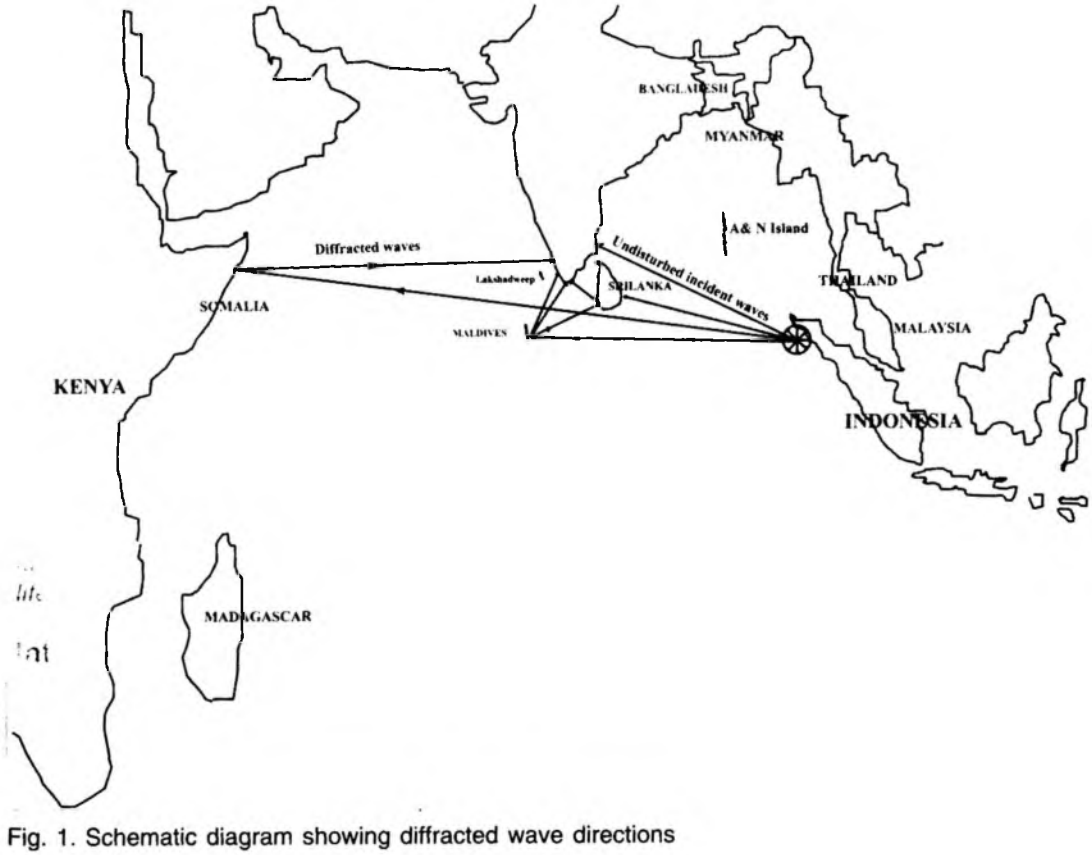

Fig. 1. Schematic diagram showing diffracted wave directions

height of the waves progressively diminished causing continued reduction in wave energy flux and struck the Kanyakumari-Kolachal coast at around 1145 hrs. Other sets of waves diffracted from Maldives and Lakshadweep hit the west coast between 1200 hrs and 1300 hrs (Fig. 1). Thus, the time lag in the occurrence of major devastation vis a vis its intensity between the east coast (Chennai - Kanyakumari), and the west coast (Kanyakumari- Kochi), can be explained .The waves diffracted from Africa were not felt, probably due to the loss of energy in long travel.

Depending upon the distance from the epicenter, the tsunami struck different stretches of the Indian coast at different timings (Table 2). The tsunami wave propagation characteristics are modified by the sea bottom configuration, bathymetry and refraction. The tsunami was reported from the Chennai coast at around 0900 hrs. In Kanyakumari the tsunami waves flowed over the cape at around 1145 hrs. In the west coast, at Kayankulam Estuaries it was reported around 1230 hrs. Further north, in Edavanakkad the tsunami struck the coast at around 1300 hrs (Jyabalan et al, 2005).

Tsunami parameters

In the open sea, the wave lengths of Tsunami are very large with a very low amplitude while near shore, the wave length will be very low and amplitude will be very high (Balachandran-2005). The Tsunami parameters measured during the survey are,

(a) Runup height (H): the maximum height on land that tsunami has reached above a reference sea level

(b) Wave height (Wh): actual height of the tsunami wave in open water (instrumentally recorded tidal gauge data from Marigram (Fig. 2)

c) Run up distance (d) the maximum distance that the sea water enters into the land

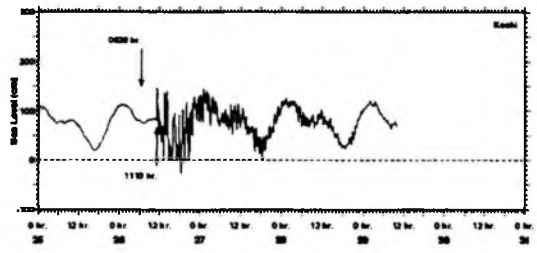

Fig. 2: Tidal gange record on 26th December, 2004, as recorded at Kochi

(d) Tsunami magnitude (Tm), the estimated or calculated value ie,Tm= log H. where H= run up height in m

(e) Tsunami intensity (Ti) (after soloview et al 1974) and the estimated or calculated value log 2 (2 ½ x h) where h is the maximum height of the run up. The value ranges from -5 to 10.

The run up distance ranges from 85 m at Sri Kurumbu Bhagavathy temple near Thottapally in Kerala (L.24 in table-2, 9° 19' 72" N-76° 22' 43" E) and 2600 m at East bank of Pazhayar river near Manakkudi in Tamil Nadu (L.37 in table-2, 8° 05' 956" N-76° 28' 992"E). The run up height of the tsunami ranges from 1.30m in Azhikkal-Valiyazhikkal in Kollam district of Kerala (L-20 of table-2, 9° 8' 50"N - 76° 27' 48"E, photo-1) and 6.45m in west of Mel Manakkudi in Kanyakumari district of Tamil Nadu (L-36 in table-2, 8° 5' 39"N -77° 28' 55"E, photo-2). The calculated parameters such as tsunami magnitude (Tm) and tsunami intensity were also determined. The tsunami magnitude ranges from 0.1139 to 0.8095 and the tsunami intensity ranges from 0.565 to 1.261 respectively

Detailed study/transacts

Section line measurements (transacts) were carried out at 40 selected locations along the west coast from Kanniyakumari to Kochi on scale 1:2000 and evaluated the maximum run-up elevation and inundation (table 2). Based on the detailed study, vulnerable zones have been delineated and demarcated along the west coast for their protective measures (Table 3).

Table 2: Glimpses of Post Tsunami detailed assessment between Kanyakumari and Kochi, in parts of Tamil Nadu and Kerala

Location	Lat.	Long.	TS No.	RL (M)	Date of survey	Time of survey	Bearing	Total width of the line	Tsunami pulses and time	Runup height	Tsunami magnitude (TM)	Tsunami intensity #	Runup distances	Presence of seawall	Remarks
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
L-1 Vipin light house	09°59'32"	76°13'34"	58C/1	3.00	3.5.05	10.00	N51°30'E	750m	I-1015 II-1115 III-1255	1.70	0.2304	0.682	700m	Yes	No casualities. Depositional and erosional features are noticed.
L-2 davanakkadu (Aniyal beach)	10°04'44"	76°12'06"	58B/4	0.00	4.5.05	13.00	N78°E	153m	I-1100 II-1115 III-1350	2.70	0.4313	0.883	--	Yes	Sea wall destroyed. Casualities reported. Road & houses were damaged.
L-3 Kuttingalchira	10°04'879"	76°11'637"	58B/4	0.00	5.5.05	10.00	N79°E	187m	I-1100 II-1115 III-1350	1.50	0.1760	0.626	--	Yes	Sea wall destroyed. Casualities reported. Road and houses were destroyed.
L-4 Pazhangodu	10°05'06"	76°11'50"	58B/4	1.00	5.5.05	11.30	N73°E	125m	--	1.50	0.1760	0.626	--	Yes	Seawall and road were damaged. Beach sand deposit is noticed.
L-5 Edavanakkad (Chattankkod)	10°65'896"	76°11'296"	58B/4	1.00	5.5.05	13.15	N64°E	350m	--	1.60	0.2041	0.655	300m	Yes	Sea wall destroyed. Deposition reported.
L-6 Kadappuram	10°10'616"	76°04'782"	58B/4	1.00	6.5.05	09.00	N88°30'E	284m	1100 1200 1430	1.80	0.2552	0.707	275m	Yes	No casualities. Periyar Ar saved the village
L-7 Pallipuram Village. (convent beach)	10°09'56"	76°10'19"	58B/4	2.00	6.5.05	10.40	N75°E	244m	--	2.70	0.4313	0.883	--	Yes	Erosional & depositional features are seen.
L-8 Cherai beach	10°07'09"	76°10'07"	58B/4	2.00	6.5.05	12.45	N69E	140m	1015	1.90	0.2787	0.730	--	Yes	Seawall and road were destroyed.
L-9 North of Azhikkal	09°08'06"	76°27'58"	58C/8	2.00	9.5.05	10.15	E-W	310m	--	2.70	0.4313	0.883	--	Yes	Heavy casualities. Placer deposit. Seawall and settlements were destroyed.
L-11 Azhikkal Chandakkadavu	09°06'06"	76°28'36"	58C/8	1.00	10.5.05	10.45	N76'30"E	307.5m	--	3.00	0.4771	0.928	1Km (1000 out)	Yes	Georesource (1.5-2') Heavy casualities Ersoion & depositions Sea wall destroyed, granite boulders brought up to 375 mts. Sea land scooped out from the house foundation.
L-12 Pachimesh-wari temple	09°05'19"	76°28'07"	58 C/8	2.00	11.5.05	09.00	N68°30'	324m	--	1.83	0.2624	0.714	--	Yes	Granite boulders brought by Tsunami from the sea wall upto a distance of 125 m. Sea wall destroyed. More casualities.

L-13 Panakkada (Srayikkadu)	09°05'07"	76°28'08"	58 C/8	0.00	11.5.05	10.30	N75°E	80m	--	1.80	0.2552	0.707	--	Yes	Black sand deposit. Seawall destroyed. Placer transported and deposited in the lake.
L-14 Paraikadavu	09°04'09"	76°29'17"	58 C/8	1.00	11.5.05	12.10	N71°30'E	634.72m	--	1.50	0.1761	0.626	600m	Yes	Tsunami wave direction due NNE.
L-15 Kuzhithurai	09°04'38"	76°29'41"	58 C/8	0.00	2.7.05	10.05	N75°30'E	696.95m	I-1015 II-1230 Direction W to E	1.80	0.2552	0.707	602m	Yes	Seawall, road, houses were destroyed. Casualities reported. House basement exposed.
L-16 Alappat	09°04'05"	76°29'17"	58 C/8	0.00	3.7.05	09.40	N76°E	765m	I-1015 II-1230 Direction W to E	1.80	0.2522	0.707	762m	Yes	Casualities and destructions are more.
L-17 West of Alankadavu (Cheri yazhikkal)	09°03'25"	76°29'43"	58 C/8	0.00	3.7.05	11.55	N77°45'E	588m	--	--		--	530m	Yes	Casualities and destructions are more.
L-18 1km-NW of Panikkarkadavu bridge	09°02'08"	76°30'15"	58 C/12	0.00	6.7.05	10.20	N75°15'E	174m	--	1.95	0.2900	0.741	--	Yes	Sea wall and houses were destroyed. pH value-8
L-19 1km NW of Panmana	09°01'08"	76°30'50"	58 C/12	0.00	6.7.05	12.00	N73°38'E	446	--	1.85	0.2671	0.719	260m	Yes	Sea wall, settlements were destroyed. Casualities reported.
L-10 Azhikkal	09°07'26"	76°28'21"	58 C/8	0.00	7.7.05	09.15	N74°30'E	1807.42	I-1030 II-1100 III-1230	2.60	0.4149	0.866	1787.42	Yes	Sea wall destroyed. casualities are more. 85x 45x20cm boulders brought from seawall and deposited it a distance 130m. Heavy sand deposit of 1.5 m thick.
L-20 Valliyazhikkal	09°08'50"	76°27'48"	58 C/8	0.00	9.7.05	--	N59°E	1334.15	I-1000 II-1030 II-1100 IV-1250	1.30	0.1139	0.565	1330m	Yes	Casualities more. Beach placer deposit blanketed to the road @ 2.5' thick. Up rooted granite boulders from the existing sea wall.
L-21 Ramancheri turai	09°10'37"	76°26'682"	58 C/8	0.00	9.7.05	15.00	N71°30'E	1040.46	I-1000 II-1045 III-1235	1.50	0.1761	0.626	1030m	Yes	Worst affected area. Casualities and destruction of settlements are more.
L-22 Perumpalli-tura road junction.	09°09'918"	76°26'90"	58 C/8	0.00	10.7.05	0940	N81°15'E	977.76	--	3.30	0.5185	0.969	991m	Nil	Casualities and destructions are more. Sea encroached to the land for 25 m.

L-23 Thottapalli Chennankarai	09°19'33"	76°22'614"	58 C/7	0.00	12.7.05	09.00	N76°E	104.009	I-1000 II-1100 III-1230	1.50	0.1761	0.626	102 m	Yes	Tsunami wave direction from W to E. Destruction of sea wall.,
L-24 Sri Kuruttu Bhagavathy temple	09°19'72"	76°22'43"	58 C/7	0.00	12.7.05	10.15	N72°E	87.7	--	1.30	0.1139	0.565	85m	Yes	Sea wall width is more. No casuality.
L-25 Poondhala	09°20'34"	76°22'15"	58 C/7	0.00	12.7.05	11.00	N75°E	98.446	--	2.00	0.3010	0.752	95m	Yes	Sea wall width is more. No casuality.
L-26 West of Kolachal	08°10'46"	77°14'61"	58 H/4	0.00	13.7.05	10.00	N69°E	997.568	I-1015 II-1045	4.65	0.6675	1.119	995	Nil	Rocky beach. Tsunami water enter through the canal and submerged the low lying areas
L-27 Kolachal	08°10'40"	77°14'09"	58 H/4	0.00	14.7.05	08.45	N69°E	374.32	--	5.00	0.7782	1.229	240.33	Nil	Rocky beach. Tsunami water enter through the canal and submerged the low lying areas.
L-28 Kolachal Post office	08°10'37"	77°15'20"	58 H/8	1.5	14.7.05	BM	N16°E	390		4.53	0.6561	1.108	427	Nil	Casualities are more. Beach in sand dunes. Max. run up distance beyond 80m from the survey point.
L-29 Kottilpad	08°10'18"	77°15'660"	58 H/8	0.00	15.7.05	BM	N42°E	288		3.15	0.4983	0.949	276	Nil	Casualities more (197). Destruction of settlements.
L-30 Mandakkad nala/bridge	08°09'52"	77°16'87"	58 H/8	7.00	15.7.05	BM	N34°E	334		5.70	0.7559	1.207	330	Nil	Worst affected area, more causalities and destruction of settlements.
L-31 Kadiyapa-ttanum (W of Valliyar)	08°08'30"	77°18'17"	58 H/8	0	15.7.05		N30°E	--				--		Nil	Bed rock (Khondalite) exposed on the sea shore. Max run up distance taken place through the river. Casualities reported. pH.6
L-32 West of Pillai thoppu	08°07'701"	77°19'858"	58 H/8	0.00	16.7.05	11.40	N14°40'E	402		5.16	0.7126	1.164	392	Nil	Casualities reported.
L-33Dharmapuram road junction	08°07'00"	77°22'25"	58 H/8	0.00	16.7.05	13.05	N08°E	650		--		--	648	Nil	Tsunami water entered through the canal and destroyed the salt pan.
L-34 East of Puttan-turai	08°06'00"	77°25'25"	58 H/8	0	16.7.05	14.25	N14°40'E	224		2.5	0.3980	0.849	144	Nil	Well water becomes salty.
L-35 Pallam	08°05'40"	77°26'20"	58 H/8	0	16.7.05	15.35	N17°30"E	312	--			--	306	Nil	Well water becomes salty. Beach is made up of sand dunes.

L-36 West of Manakudi	08°05'39"	77°28'55"	58 H/8	0	17.7.05	09.00	N4°30'E	376.05	I-1015 hrs II-1200 hrs	6.45	0.8095	1.261	368.05	Nil	Casualities and destructions are more. Well water become salty. pH 8. Heavy loss of property. Tsunami wave-N60E.
L-37 East bank of Pazhayar river	08°05'956"	77°28'992"	58 H/8	0	17.7.05	14.25	N-S	1640	I-1015 hrs II-1200 hrs	4.25	0.6284	1.079	2600	Nil	Tsunami wave N60E. direction. Formation of spit widening and deepening of the river mouth. Bridge broken.
L-38 South of Melakudiyiruppu	08°04'975"	77°30'931"	58 H/12	0	18.7.05	09.35	N10°30'E	252.55	--	3.50	0.5441	0.995	246.55	Nil	Beach sand. Beach rock exposed.
L-39 South of Kovakulam	08°04'947"	77°31'18"	58 H/12	0	18.7.05	10.30	N7°E	122.15	--	6.05	0.7618	1.233	106.15	Nil	Heavy casualities. Destruction of road and houses.
L-40 Kanyakumari	08°04'683"	77°32'902"	58 H/12	3.00	18.7.05	11.00	N-S	92.35	--			--	74.35	Yes	Bed rock exposed. Run up more.

* Tsunami Magnitude (TM)= log H, where H is the runup height.

#Tsunami Intensity = log 2(*21/2 x h), where h is the runup height (values from -5 to 10)*

- Water recession 1115 - 1310 hrs
- Tremors not felt in the west coast.
- Tsunami in the west coast bore type
- Manakkudi – Kaniyakumari - movement direction due N

Heavy siltation, Geo-resource – Deposition/ erosion, widening and deepening of the river mouth.

Table 3: Areas identified for protective measures

S. No	SECTOR	Approximate length of wave breakers proposed with support with gabions (Kms.)
01	Cherai – Edavanakkad	The existing wave breakers supported with gabions for a distance of about 4 km.
02	Kayankulam – estuary	On the either side of the Kayankulam estuary The existing wave breakers supported with gabions for a distance of about 11 km.
03	Manakkodam Light House	Groynes / wave breakers with gabions for 1.25 km. along the coast.
04	Kolachel – Kadipattanam	Wave breakers supported with gabions for a distance of about 7.5 km.
05	Muttam	The existing wave breakers / groynes supported with gabions for a distance of 1 km.
06	Manakkudi	Wave breakers supported with gabions for a distance of about 2 km.

Tsunami impact on the foreshore area

Modifications of beach and barrier beaches are observed in the foreshore area by erosions and deposition. Breaches and development of escarpment in the beach ridges or palaeo-strand line, flattening of sand dunes, leveling of the inter-tidal areas, dumping of beach material into the lakes, removal and destruction of settlements, destruction and damage of roads and sea wall were also noticed as a result of invading or retreating pulses of Tsunami.

Beaches and Beach ridges

Beaches and Beach ridges have been modified after the Tsunami by breaking the continuity. The broken beach ridges are very well seen at Pallam, Manakkudi, Pillaithoppu, Kolachal, Mandacaud in Tamil Nadu and Cheriyazhikkal, Valiyazhikkal, Srayikad, Alappat, Tharayilkadavu, Arattupuzha, Puthuvaipu and Cherai in Kerala (Ph.3 & 4). It is obvious that the sea wall/ wave breakers have minimised the damages. At places, the sea wall has played a vital role to prevent the destruction of beaches eg. Kovalam, Shanghumugham, Thangaseri beaches in Kerala. Coastal erosion after the destruction of the sea wall has been observed at Edavanakkad and adjoining areas. Settlements near the shore line have been completely wished out in Cheriyazhikkal, Alappat, Srayikadu, Manakkudi etc. Amidst, the loose boulders placed on the wave-breakers have been tossed up like canon balls by the surging waves causing sever damages to the human settlements located in the area around Edavanakkad and near by shoreline.(Photo 9) (Jayabalan et al, 2005).

Concentration of placers

The black sand present in the western side of the sea wall/ in the off shore area has been brought by the Tsunami and dumped in the eastern side of the sea wall or foreshore area (Photo 5 & 6). The thickness of such deposit varies from 30cm to 1.00m in Cheriyazhikkal, Valiyazhikkal, Srayikad, Alappat, Tharayilkadavu and Arattupuzha sector of Kerala and Manavalakurichi in Tamilnadu (Jayabalan et. al., and Narayana et al, 2005).

Tsunami impact on the Back shore

The back shore areas are mainly occupied by sand dunes, inter dunal flats, tidal flats and palaeo strandlines. Water logging and leveling of dunes are observed in the back shore areas.

Damages in Tidal flats

The tidal flats are comprised of dark to dark grey clay with silt, decayed organic matters and shell fragments. These low lying areas occur adjacent to the areas of narrow barrier beaches or strand lines on the eastern side of the coastal line. Pisciculture, salt pans, mangrove are the main land use/ land cover of the area. Tsunami has affected the area by causing damages in Puthuvaipu, Edavanakadu, Cherai, Arattupuzha, Tharayilkadavu, Azhikkal, Cheriyazhikkal, Alappat etc in Kerala, Manakkudi, Melakudiyiruppu in Tamil Nadu.

Effect in Inter-dunal area

The advancing Tsunami waves flowed over the beach ridges and inundated the adjacent inter- dunal flat areas located around Pallam, Muttam, Kottilpad, Kolachal etc. As a result water logging for a few hours took place. The sands below the basement of the houses have been scooped out by the retreating waves and damaged many houses in Perumpallithura, Alappad etc. The natural and cultivated vegetation occurring on the inundated areas show a sign of distress in the form of yellowing and whitening of leaves and stems. This phenomenon was sighted at Puttanthurai, Pallam and Manakkudi in Tamilnadu.

Impact on Brackish Aqua system

Kerala and Tamil Nadu coast is characterized by its unique presence of natural spit, lagoons and estuary. This brackish aqua system bore the brunt of Tsunami and diminished its impact on inland.

Spit, Lagoon and Estuary

During the summer season water inflow from lagoon/ estuary to the sea is very less. Due to wave action of the sea, sand bar will grow in the mouth of the lagoon or estuary parallel to the coast and in the processes the sand bars from both the end and united to become a spit. Thus the lagoon/ estuary will be separated from the sea during the summer season. During the rainy season, this spit will open due to inflow of heavy rain water. In west coast, many of the lagoons and estuaries does have spit except Vypin. During the Tsunami these natural spits have been opened up and the water forcibly entered into the lakes. The water level rose by more than one metre and flooded the adjacent areas. Kadappuram, Thottapally, Kayamkulam and Manakkudi are the noted examples (Photo 7&8). The forcible opening and partial closing due to dumping of sand and other Tsunami deposits has created some navigational problems for AVM canal in Kerala and TS canal in Tamil Nadu.

Impact on Mangrove

Mangrove development has been observed at Edavanakadu-Puthuvaipu- Cherai areas of Ernakulam District, Kerala. A well developed net work of water system also observed in this area. During the Tsunami, the water level has increased from 1 m to 1.5 m and inundated more than 1km in eastern side. The presence of mangrove has played a major role in protecting the settlements and lives.

Other Impacts

Man-made structures and materials present in the near shore areas have been damaged due to the sudden entry of high energy waves. The nature and extent of the damages depends on the geomorphic unit on which it is located, the distance from the shore and type of materials used for construction etc.

Impact on settlements

The coastal belt of Kerala and Tamil Nadu is thickly populated. There are a number of fishing colonies located all along the coast. The maximum damages were reported where the houses are located close to the sea without any protection from sea wall and it is being minimised where the sea wall existed. The maximum destruction of houses was reported in Arattupuzha, Azhikkal, Alappat, Tharayilkadavu and Srayikadu in Kerala (Photo 9 & 10) and Kolachal, Kottilpad, Mandacaud, Pallam, Manakkudi and Kovakulam in Tamilnadu. Even RCC buildings of east and west Manakkudi village were destroyed completely by the Tsunami.

Impact on Communication network

The bridge across the Pazhayar river near Manakkudi in Tamilnadu built recently has been destroyed fully (Photo11). The 75m long and 8m wide bridge was broken and the beam was thrown 200 m away towards upstream side. Beach road running parallel to the coastal line from Panikkarkadavu to Cheriyazhikkal and Vypin to Kadappuram in Kerala has been damaged in many localities.

At places, there is no trace of road due to destruction / damage by the Tsunami waves. At Azhikkal the road was covered with 1 m thick heavy-sand deposit.

Control and corrective measures

Tsunami, a natural calamity is not an uncommon phenomenon in the Indian Coast though it was not understood in the past and hence, no mitigation measures were thought of. No prevention is possible for such natural phenomenon but, with the advancement in science, tsunami can be forecast from the occurrence of tsunami-generating earthquakes. Besides, the following measures will help to mitigate the impact of tsunami.

(1) Tidal flat and inter-dunal areas are more prone for inundation. Avoid human settlements and encourage afforestations along the coastal zones to dissipate the tsunami energy.

(2) Intricate network of coastal water bodies close to the coastal areas are prone for easy inundation. In such cases strengthen the river banks wherever warranted and encourage saline resistant plants along the shorelines.

(3) Narrow strip of land juxtaposed between sea and coast-parallel aqua systems are most vulnerable for inundation and wash over. (Alappad, Azhikal, perumpallitura, Edavanakkadu etc in Kerala). Evacuate the existing settlements and avoid future settlements.

(4) In the vulnerable zone, construction of wave breakers and rip-raps of different length and size will certainly protect the coast not only from the sea erosion but also from the natural phenomenon like tsunami. Depending upon the coastal landforms, coastal geomorphology, sea wall/wave breakers can be built suitably as per the site conditions.

(5) Coastal Management Regulation Act forbids any construction activity within 500 m from the coastal line. Although it shall be mandatory, implementation of the same in the west coast may be little difficult due to paucity of land. Besides, the coastal landforms play a major role on run-up elevation and distance in the event of tsunami. Hence, instead of enforcing the restriction to a uniform distance of 500 m, it should be based on coastal landform.

(6) Geo textile tubes (Stabiplage unit) can be used to stave off sea erosion as being used effectively in France for the past 20 years (Unesco, 2002). In view of its cost, they can be used at least to protect the strategic installations located on the coast.

(7) Interestingly while there was heavy toll in loss of lives, flora and fauna suffered very little. Proven methods such as more mangroves, sea walls, groynes, coastal zones, etc. seems to be generally effective which need to be provided for protection rather than cosmetic.

(8) Avoid major construction and cultural activities where the areas being delineated/demarcated as a vulnerable zone.

(9) Educating the public about the tsunami and its impact, its causative factor and installation of the tsunami early warning system are the need of the hour.

Conclusion

The scientific studies carried out by various institutions and disciplines in India on the tsunami of 26. 12.2004 are the first of its kind as no such event had occurred in the recent past. The knowledge gained from such studies should help the civic administration in mitigating the damage in the event of occurrence of any tsunami in future.

Acknowledgement

The authors expressed their sincere thanks to the Dy. Director General, GSI, Opn:TNPK, Chennai, for according permission to publish this paper. The authors are very grateful to

Shri. R.Pitchai Muthu, Director, GSI, EGDn., Opn:TNKP, Chennai for his constant encouragement to prepare this paper. The authors are also grateful to the Port Trust officials, Cochin for providing a tidal gauge data.

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