Nat. Hazards Earth Syst. Sci., 8, 617–626, 2008
www.nat-hazards-earth-syst-sci.net/8/617/2008/

Natural Hazards and Earth System Sciences

Inundation mapping – a study based on December 2004 Tsunami Hazard along Chennai coast, Southeast India

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Received: 20 August 2007 – Revised: 8 May 2008 – Accepted: 2 June 2008 – Published: 1 July 2008

Abstract. Tsunami impact study has been undertaken along Chennai coast starting from Pulicat to Kovalam. The study area Chennai coast is mainly devoted to prepare large scale action plan maps on tsunami inundation incorporating land use details derived from satellite data along with cadastral data using a GIS tool. Under tsunami inundation mapping along Chennai coast an integrated approach was adopted to prepare thematic maps on land use/land cover and coastal geomorphology using multispectral remote sensing data. The RTK dGPS instruments are used to collect elevation contour data at 0.5 m intervals for the Chennai coast. The GIS tool has been used to incorporate the elevation data, tsunami inundation markings obtained immediately after tsunami and thematic maps derived from remote sensing data. The outcome of this study provides an important clue on variations in tsunami inundation along Chennai coast, which is mainly controlled by local geomorphologic set-up, coastal zone elevation including coastal erosion protection measures and near shore bathymetry. This study highlights the information regarding most vulnerable areas of tsunami and also provides indication to demarcate suitable sites for rehabilitation.

1 Introduction

A tsunami is a natural coastal hazard generated in the deep ocean as a result of an earthquake, volcanic activity, submarine landslide or meteoritic impact. The December 2004 earthquake and the tsunami it spawned resulted in more than 225 000 confirmed deaths (as at 1 Febuary 2005), the worst tsunami disaster on record and one of the top 10 earthquake disasters ever recorded. The tsunami itself was generated along the 1200 km fault rupture and the waves were recorded over 5000 m. Much research has been carried out to determine the impact of tsunamis on coastal environments such as the nature of inundation, runup level, erosion, deposition, vegetation, etc. in damaging the coast.

Alami and Tinti (1991) evaluated the tsunami hazard along the Moroccan coast by comparing tsunami data with the set of available earthquake data. Dawson (1994) suggested that the geomorphological processes associated with tsunami run-up and backwashes are highly complex. Raval (2005) reported severe destruction along the coast of Nagapattinam, South India, primarily because of its geographic setting, which has favoured much inundation. Mohan (2005) reported that elevated coastal dunes and beach ridges along the coastline could act as barriers to minimise the rate of inundation along the northern parts of the Tamilnadu coast. In this paper, we have attempted to map the extent of inundation at village level and to find a relationship between the extent of inundation and the run-up level. The run up and inundation of the tsunami were measured in the field using RTK-GPS and Leica Total Station, and the co-ordinates and elevations of the locations where evidence of tsunami was preserved were noted.

2 Study Area

The study area (Fig. 1) covers part of Chennai coast, starting from Ennore (Easting 80°19′ 36.1”F, Northing 13°13′ 47.2”) to Kovalam (Easting 80°14′ 52.72”, Northing 12°47′ 23.41”). It covers three districts namely, Tiruvallur, Chennai and Kanchipuram. Ennore is on the northeast coast of Chennai, while Kovalam is on the southeast coast of Chennai.

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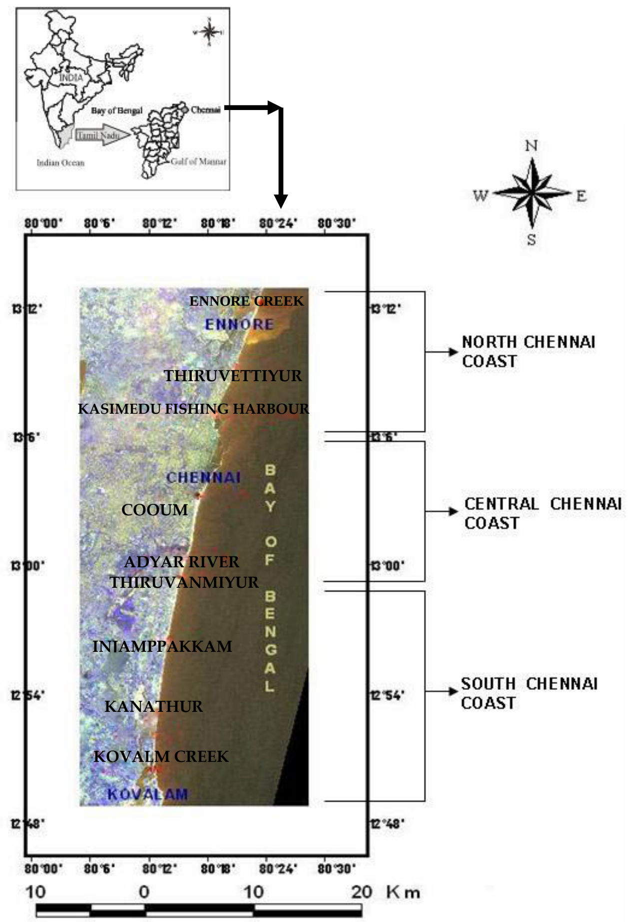

Fig. 1. Location map of the study area.

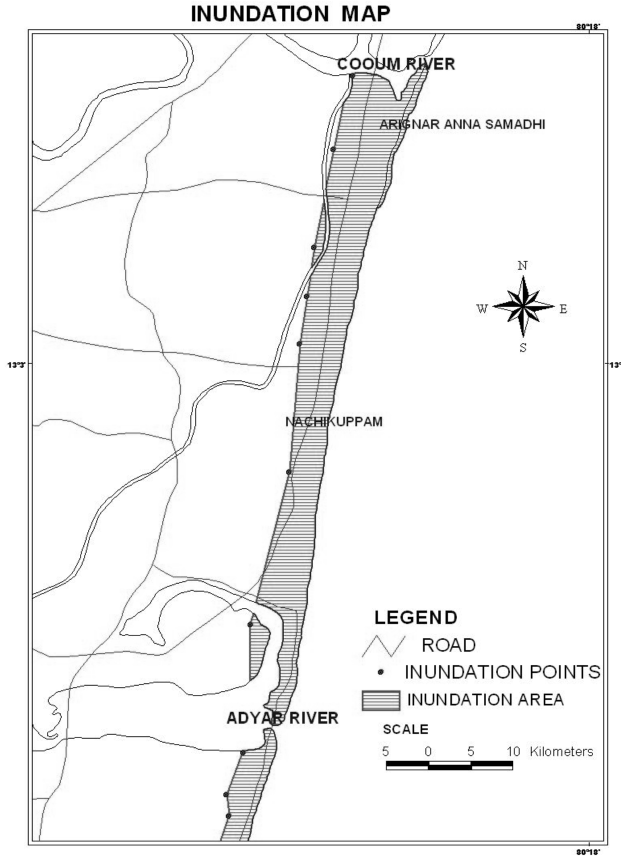

Fig. 2. Inundation limits from Cooum River to Adyar River.

Major parts of area consist of alluvium, beach dunes, tidal flats and creeks. The entire study area is occupied by settlements mainly belonging to the coastal community. Major industries like thermal power station, fertilizer and rubber factories, steel rolling industries, and petrochemical companies are located on the northeast coast of Chennai. Beach resorts, farmhouses, aquaculture ponds, theme parks, tourist spots, and artificial parks are mainly located on the southeast coast of Chennai. Fishing is the main occupation of the people living in the suburban coastline, whereas in the urban coastline, the occupation is not only fishing but also depends upon urban resources like industries and government and non-government organisations.

3 Methodology

Inundation maps are depictions of coastal areas that identify regions, populations, and facilities that are at risk from tsunami attack, which could be used by emergency planners for disaster response and mitigation. Inundation maps require an assessment of local and far-field geologic hazards, and the calculation of coastal flooding. Houston and Garcia (1974, 1978), Houston (1974, 1980) and Briggs (2005) used a combination of finite difference and finite element models to predict tsunami inundation on the west coast of the United States and Hawaii. These inundation maps provide details on maximum devastation scenario along the coast. The National Earthquake Reduction Programme (NEHRP 13 January 2005, Version 1.0) is contributing in significant ways to United States preparedness in response to tsunami threats, and also supports research to develop models, tsunami wave basin measurements, and risk assessment tools to predict the location and extent of inundation (Synolakis, 2002). Once an earthquake and tsunami are designed and its frequency is estimated, the numerical simulation with the land-use and human activity present can provide details regarding the affected area and damage to humans, houses, and economy (Fumihiko, 2004).

The present study has generated output on the following and the combination of these results helped to carry out tsunami vulnerability assessment:

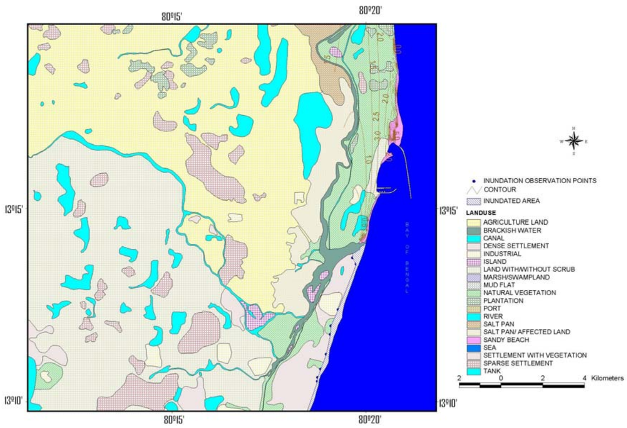

Fig. 3. Land use/cover map (ennore to Cooum river).

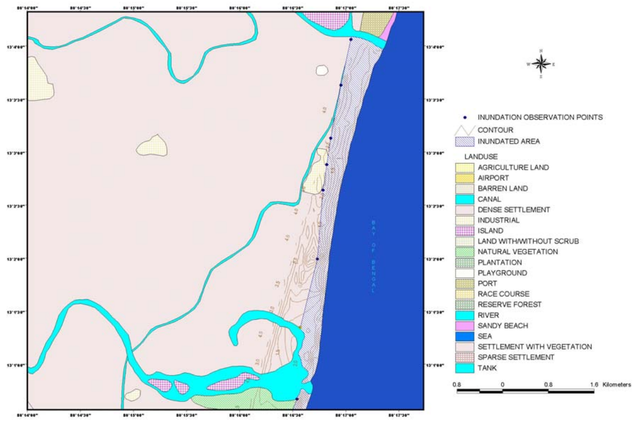

Fig. 4. Land use/cover map (Cooum river to Adyar river).

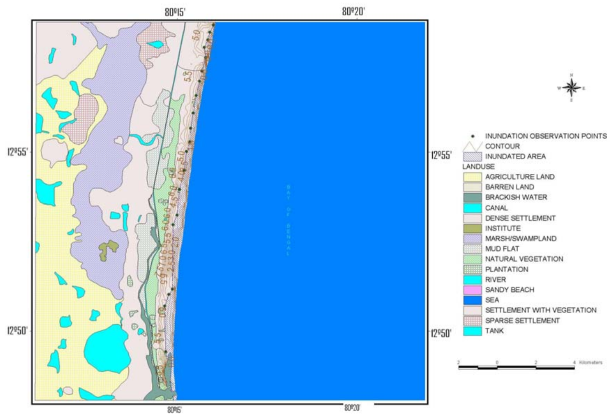

Fig. 5. Land use/cover map (Adyar river to Kovalam creek).

1. Tsunami inundation limits and runup level mapping along the study area,

2. Transfer of inundation points over a geo-referenced satellite imagery,

3. Elevation mapping for the preparation of 0.5 km interval contour data using dGPS (Real – Time Kinematic GPS) along the study area at different transects,

4. Pre- and post-tsunami remote sensing data (LISS-III and LISS-IV) for land use/cover mapping using ERDAS package, and

5. Preparation of larger scale (1:5000) action plan maps by incorporating all the above thematic parameters and cadastral maps in a GIS environment.

Detailed fieldwork was undertaken along the 70 km coastal stretch from Pulicat to Kovalam to assess the extent of inundation. Co-ordinates of the 13 inundation limits and the shoreline were measured using Magellan hand held GPS with a spatial resolution of 10 m. The inundation limit was identified using field evidences like withering of plants sensitive to salinity, and presence of trail of organic debris that had floated in the tsunami waves. Watermarks on compound walls were rare and were used wherever available. The direction of propagation of tsunami was also noted based on transported blocks of damaged compound walls constructed with bricks and broken tree trunks. The geomorphological set up of the region like the presence of dune ridges was also examined.

For the preparation of land use/land cover maps, LISS and PAN data of IRS – 1C were used; for image processing, ERDAS Imagine software was used. Up to level III land use/cover categories were mapped using these multispectral imagery. The (2005 IRS P6 LISS-III) images were rectified by georeferencing with Ground Control Points (GCP) like road intersections collected using Magellan GPS. The village maps used as base maps for mapping were scanned and georeferenced using ENVI 3.6 by measuring the co-ordinates (Lat/Long; WGS 84) of known village survey stones. Village boundary stones were preferentially used for GCP. Atleast 6],GCP was taken for each village, and the RMS error of rectification was kept minimum; points that did not correspond were deleted. The village maps were overlaid on the satellite image and the correspondence of the features present was confirmed. The marginal water bodies and roads depicted on the maps were useful for accuracy of the registration process. The rectified village maps were digitized using ARC INFO 9.1 GIS package in the Integrated Coastal and Marine Area Management (ICMAM) Project Directorate, Ministry of Earth Sciences, Government of India, Chennai. The land use/land cover maps of major features in the villages were prepared in a GIS environment. Ground truth information collected during elevation mapping was used for validation of these details.

Table 1. Observation of Tsunami water inundation along Chennai coast.

S.No	Location	Landmark	Lat. DD*	Long.DD*	Distance HTL	Inundation Distance in meters
1	Kovalam	Near Mouth	12.80008	80.24831	80	106
2	Muttukadu	Jumbodai Hamlet	12.82342	80.24461	310	334
3	Reddikuppam	Behind Ashok Bajaj Guest House	12.84469	80.24411	452	497
4	Reddikuppam	Opp. to Poori Jeganathar Temple	12.85014	80.24594	26	367
5	Reddikuppam	Ellaiammankoil Street	12.85253	80.24767	120	197
6	Kodumayandi thoppu	Near Vanniyar Grave Yard	12.88267	80.24792	425	538
7	Panaiyur kuppam	Near Church	12.88714	80.24981	284	369
8	Sholinganallur	Near Parking Sense Avenue	12.899	80.25094	333	401
9	Injampakkam	Dr.Sastri Avenue	12.90778	80.25306	241	311
10	Injampakkam	After VGP Theme Park	12.91661	80.25428	253	275
11	Injampakkam	Near Gowriamman koil	12.92111	80.25581	143	180
12	Next to Injampakkam	Near Sai Baba Temple	12.92744	80.25617	197	226
13	Sinnandi Kuppam	Near Aristocrat Club	12.93447	80.25731	187	217
14	Periya Neelangarai Kuppam	Near Casurina Drive Resort	12.94278	80.25869	202	218
15	Periya Neelangarai Kuppam	Near Buena vista Resort	12.94939	80.26031	155	220
16	Chinna Neelangarai Kuppam	Singaravelan Street	12.95406	80.26147	110	179
17	Palavakkam Kuppam	Anna street	12.9605	80.26314	67	149
18	Palavakkam Kuppam	Palkalai Nagar	12.96522	80.26244	243	335
19	Kottivakkam Kuppam	Muthalamman Koil Street	12.96869	80.26417	141	166
20	Kottivakkam Kuppam	Near Bella Ciao Italian Restaurant	12.97233	80.26503	134	157
21	Kottivakkam	Near Police Booth	12.97561	80.26664	30	49
22	Valmeeginagar	Pothi Seaward Road	12.97933	80.26631	153	180
23	Thiruvanmiyur Kuppam	Vembidiyamman Koil Street	12.98306	80.26808	54	76
24	Besant Nagar	Near Arupadai Veedu Murugan Temple	12.98925	80.26892	94	146
25	Urur kuppam	Near Syntex Water Tank-3	13.00403	80.27383	0	44
26	Urur kuppam	Near Compound Wall	13.00578	80.27367	54	127
27	Urur kuppam	Near Adyar Mouth	13.01114	80.27564	2	86
28	Srinivasapuram kuppam	Behind the Bus Terminus	13.02022	80.27564	195	355
29	Thideer Nagar	Behind Santhome Church	13.03317	80.27886	57	763
30	R.K Road	Near Gandhi Statue	13.04397	80.27975	28	278
31	Beach Road	Near Vivekanandhar House	13.048	80.28036	59	307
32	Ayodya Kuppam	Near Tamil Nadu Slum Clearance Board	13.05214	80.28097	158	363
33	Beach Road	Near Presidency College Second Gate	13.06047	80.28256	253	479
34	Chepauk	Near Napier Bridge	13.06764	80.28411	470	585
35	Royapuram	Indra Nagar Street	13.12167	80.29733	0	232
36	Kasimedu	Near Fishing Harbour	13.12481	80.29578	0	142
37	Kasimedu	Near Second Gate of Fishing Harbour	13.12986	80.2965	0	143
38	Kasimedu	Near N 4 Police Station	13.13439	80.29772	21	20
39	Thangal	Near P. Sathanandapuram	13.1465	80.30122	49	65
40	Kaladipet	Near Market Line	13.15147	80.30339	66	95
41	Thiruvettiyur kuppam	Kanni Koil Street	13.15703	80.30572	75	89
42	Thiruvettiyur kuppam	Apparsamy Koil Street	13.15994	80.30714	0	57
43	Palagaithotti kuppam	Near the Temple	13.1755	80.31258	99	107
44	Palagaithotti kuppam	Near the Panchayat Office	13.17714	80.31267	156	0
45	Ernavoor	Near the Container Yard	13.18078	80.31403	150	180
46	Bharthiyar kuppam	Near the Work Shop	13.18711	80.31631	0	115
47	Bharma Nagar	Inside the 10th Street	13.19572	80.31811	218	218
48	Bharma Nagar	Inside the 1st Street	13.19942	80.31833	310	336
49	Chinna Kuppam	Near Chinniamman Koil Street	13.20644	80.32153	188	225
50	Thazhang Kuppam	Opposite to Temple	13.22606	80.32919	130	0

*=Longitude and Latitude in Decimal Degree.

Table 2. Elevation Survey Data generated by using RTK–dGPS.

S.No	Point Identification	Latitude (DD)	Longitude (DD)	Elevation Height (in meters)
1	MUTTU-BSE2	12 49 52.974157 N	80 14 25.371055 E	6.2
2	astatran1	12 59 33.655689 N	80 16 17.206209 E	0.2
3	basantberm1	12 59 30.131540 N	80 16 16.008591 E	2.0
4	beachberm1	12 47 27.068582 N	80 15 10.657831 E	1.2
5	beachrda1	13 2 22.167332 N	80 16 43.822024 E	3.3
6	beachrdb1	13 2 59.945542 N	80 16 50.286966 E	4.0
7	chanela1	12 47 14.043330 N	80 14 46.372447 E	1.8
8	comouthtran1	13 3 58.917744 N	80 17 22.237969 E	1.0
9	doomingtrna1	13 1 40.887634 N	80 16 47.128428 E	1.1
10	eastmadast1	12 59 5.627829 N	80 15 42.633063 E	5.0
11	ecrkana1	12 50 50.169396 N	80 14 26.849562 E	5.0
12	ecrmut1	12 49 55.814921 N	80 14 25.540536 E	6.0
13	ecroad1	12 47 6.138880 N	80 14 41.569551 E	2.4
14	injaecra1	12 55 11.413241 N	80 15 4.183521 E	6.0
15	injamecra1	12 54 5.993683 N	80 14 55.049591 E	7.0
16	injashl1	12 54 33.442551 N	80 15 20.935628 E	2.0
17	injatrana1	12 54 36.054544 N	80 14 59.762058 E	6.5
18	injatranb1	12 55 8.785680 N	80 15 26.214051 E	0.4
19	kanashl1	12 51 8.824765 N	80 14 56.771590 E	1.5
20	kanatran1	12 50 51.601260 N	80 14 56.465292 E	-0.1
21	kanatranb1	12 51 3.705070 N	80 14 28.249482 E	5.4
22	kanatranc1	12 51 27.925887 N	80 14 58.593132 E	-0.3
23	kapaleetra1	12 57 0.239027 N	80 15 17.613058 E	6.0
24	kapalesha1	12 56 56.804907 N	80 15 43.381515 E	-0.3
25	karikushl	12 49 58.466846 N	80 14 52.786485 E	2.0
26	karikushl1	12 49 58.467944 N	80 14 52.784047 E	2.0
27	kkbsc1	12 52 42.056022 N	80 14 37.980634 E	7.2
28	kottiberm1	12 58 36.198493 N	80 16 2.608825 E	2.0
29	kottishla1	12 58 17.890563 N	80 15 58.662131 E	2.0
30	kottitranab1	12 58 39.792870 N	80 15 32.712841 E	5.3
31	kottitrna1	12 58 23.374233 N	80 15 29.362229 E	6.0
32	kottitrnb1	12 58 36.057652 N	80 16 3.079178 E	-0.2
33	kovaberm1	12 47 10.954729 N	80 15 16.650335 E	1.24
34	kovbchroad1	12 47 5.592969 N	80 14 42.715112 E	2.4
35	kovmthshl1	12 48 8.427285 N	80 14 53.728463 E	0.2
36	kovtrana1	12 47 45.501488 N	80 14 59.411947 E	1.0
37	kvolatranbse1	12 46 42.215366 N	80 14 54.547890 E	6.4
38	lightshla1	13 1 59.013978 N	80 16 49.657972 E	1.5
39	lighttrana1	13 2 19.348593 N	80 16 53.003970 E	1.0
40	marinashla1	13 2 34.791788 N	80 16 55.388697 E	1.5
41	marinashlb1	13 3 15.991109 N	80 17 5.613713 E	2.0
42	marinashlc1	13 3 42.988891 N	80 17 14.733227 E	2.0
43	marinatrana1	13 2 35.947677 N	80 16 46.192335 E	5.0
44	marinatranb1	13 2 54.463749 N	80 17 0.717305 E	1.0
45	marinatranc1	13 3 17.666796 N	80 16 53.196912 E	4.0
46	marinatrand1	13 3 32.239305 N	80 17 11.071502 E	1.0
47	marinatrane1	13 3 46.193985 N	80 17 0.696052 E	3.3
48	mouthberma1	13 0 9.653909 N	80 16 26.385398 E	2.1
49	mouthcompa1	13 0 24.608663 N	80 16 26.563142 E	4.4
50	mouthpoint	13 0 40.385202 N	80 16 32.388865 E	4.5
51	mouthtrana1	13 0 22.454578 N	80 16 30.872286 E	0.1
52	mouthtranb1	13 0 40.110342 N	80 16 32.435035 E	4.3
53	muttubse1	12 49 52.974168 N	80 14 25.371049 E	6.1
54	muttulak1	12 48 51.536561 N	80 14 38.094558 E	0.5
55	muttushl1	12 49 14.435036 N	80 14 52.323983 E	2.2
56	muttushla1	12 50 29.422629 N	80 14 54.092868 E	2.0
57	muttutrane1	12 50 12.408030 N	80 14 25.430193 E	7.0
58	muttutrn1	12 48 32.390966 N	80 14 52.798608 E	0.0
59	muttutrna1	12 48 50.710681 N	80 14 30.546207 E	5.3
60	muttutrnb1	12 49 0.204034 N	80 14 40.473206 E	0.1
61	muttutrnc1	12 49 13.949368 N	80 14 25.242473 E	4.9
62	muttutrnd1	12 49 34.569494 N	80 14 53.049946 E	-0.0

Table 3. Tsunami inundation limit and area of submergence.

Sl.No	Name of the Village	Inundation limit (in m)	Total area of submergence (in sq. km)
1	Kovalam	106	0.29
2	Muttukadu	334	1.12
3	Kanathur Reddikuppam	497	0.79
4	Sholinganallur	538	1.31
5	Injampakkam	317	1.11
6	Neelankarai	220	0.44
7	Palavakkam	149	0.18

For the preparation of elevation contour maps at 0.5 m interval of the study area, Leica Real Time Kinematic (RTK) GPS was used. The GPS equipment used was a Leica SR530 Real-Time Kinematic capable unit. Two units were used, with one serving as the reference receiver, or base station, and the other serving as the rover. The Leica SR530 has a quoted accuracy of 10 mm+1 ppm. The GPS units and radios were supplied by the Integrated Coastal and Marine Area Management, Department of Ocean Development, NIOT Campus, Chennai.

Real-Time Kinematic GPS is a form of differential GPS (using two receivers) that allows a user to view coordinates in real-time, with an accuracy of up to 10 mm+1 ppm. The ambiguities can be resolved while the rover is not stationary, meaning faster resolution and more efficient surveying.

One source of possible error in the RTK derived coordinates is bubble error in the pole. The bubble on the pole is of the “spot bubble” type, which means that it simultaneously shows the tilt of the pole from the vertical in both the X and Y axes. Shown on the bubble is an inscribe circle that shows the tilt of the pole. The inscribed circle on the best bubbles (and poles) indicate as little as 1’ (one minute) of tilt, which on the 2 m pole used would indicate less than 1mm of movement in the position of the GPS antenna. However the accuracy indicated on the Leica pole used was 8’, which correlated with a possible error of 5mm (+/–2.5 mm) in the position of the head of the pole.

There is no doubt that RTK GPS is a capable and efficient tool for use in cadastral boundary definition surveys. The survey carried out was proven to comply with Class C and also to align closely with a total station traverse carried out for the same points. Using good survey practice, accurate results can be obtained easily using RTK GPS, with the survey complying fully with the relevant regulations and legislation (Source: www.gmat.unsw.edu.au).

The elevation data was collected at every 0.5 km transect interval and up to 2 km landward extent and these details have been imported to the GIS database and contour maps were prepared for each coastal village.

4 Results and discussion

4.1 Tsunami inundation limits and runup level mapping

Tsunami water inundation limits were recorded along the coastal zone between Kovalam and Ennore. True wave heights of tsunami were measured and estimated from the accounts of the interviewees (i.e. relative to their body or height of watermarks), and from landmarks such as trees, rocks, dykes, riverbanks and other natural features found in the area (Besana et al., 2004). This observation was made at about 50 locations randomly and these locations were recorded using a GPS. The tsunami water inundation limits from Ennore to Kovalam along with latitude, longitude, high tide line and inundation distances values are clearly shown in Table 1 It was observed that lowlands were inundated more. Estimation of runup heights was done based on physical evidences like the watermarks or debris carried inland by the tsunami (Chadha et al., 2005).

A tsunami inundation map representing a source- and community-specific “credible worst case scenario” is a powerful planning and hazard mitigation tool (Gonzalez et al., 2002). They also reveal that the Mapping Program and increasing the usefulness of inundation mapping products to emergency managers. Tsunami inundation modeling is needed to assess the threat represented by such an event (Groat, 2005). As the population of coastal areas increases the need for, and value of, scientific understanding of earthquake and tsunami hazards also increases. Simple maps of expected tsunami travel paths and times based on crude bathymetry have been of important operational value in developing a tsunami-warning infrastructure for some time (Mofjeld et al, 2004). Global deep seafloor topography in sufficient detail allows the mapping of a Tsunami Scattering Index (Smith et al., 1997; Mofjeld et al., 2004). The Inundation limit in meters with latitude and Longitude are clearly shown Table 1 and also the inundation limit is compared with High Tide Line data which is provided by the Government of Tamil Nadu in the table. The inundation limits which have been transferred over the study area base map prepared using Survey of India (SOI) toposheets. Figure 2 clearly shows that the inundation limits as well as inundation area has been blocked to identify the inundation along the study area from Cooum River to Adyar River.

4.2 Elevation mapping

The elevation survey was carried out by using RTK-GPS (Real–Time Kinematic GPS) instrument along the study area. The survey included the base station foundation and onshore transects; the total number of transects was 42 and total number of base stations was 8. The RTK-GPS is an advanced instrument and directly linked with satellite geological position and produces all data like latitude, longitude,

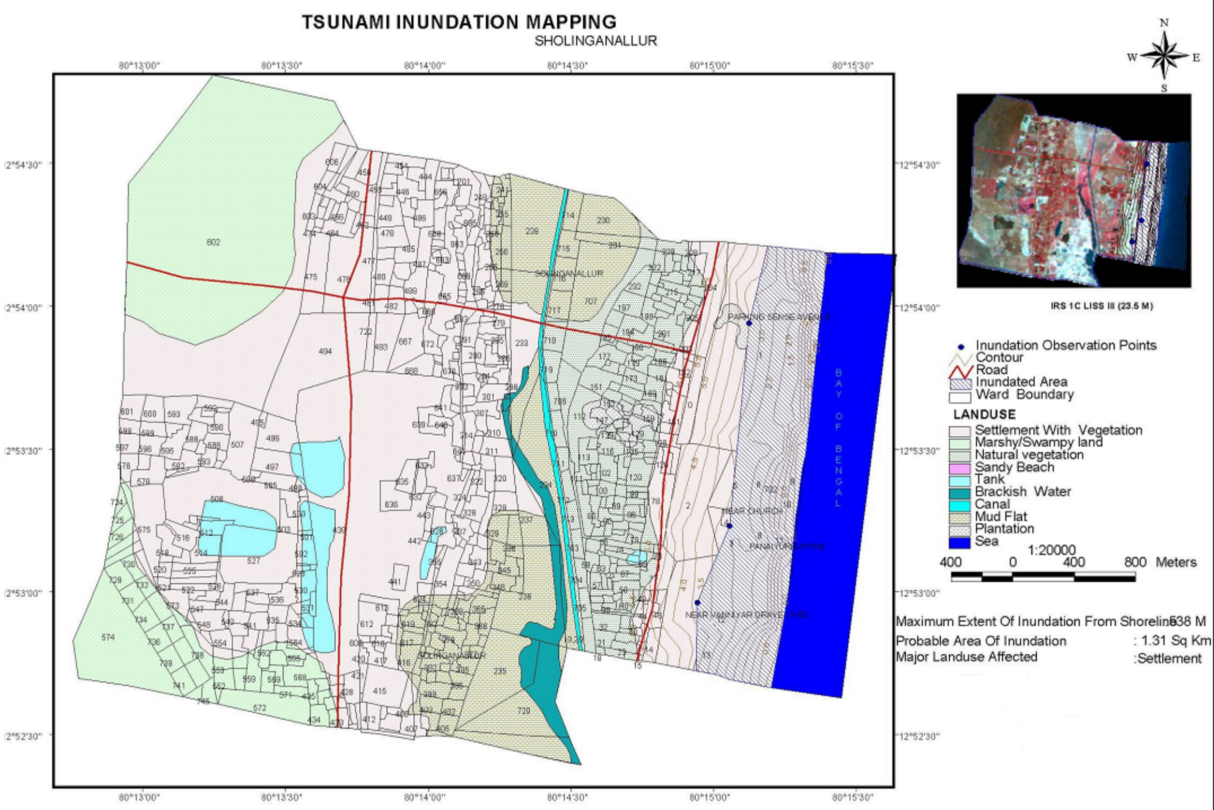

Fig. 6. Tsunami inundation mapping in and around Sholinganallur area.

elevation height, and date and time of the survey. Table 2 lists the samples of the data generated from the RTK-GPS output.

4.3 Land use/Cover and geomorphological mapping

Pre-tsunami satellite data (2001 LISS-III) of the study area as well as post-tsunami satellite data (2005 IRS P6 LISS-III) covering Adyar to Kovalam) were used to prepare coastal land use/cover maps by using ERDAS Imagine software. On-screen digitization of land use/cover category boundaries was carried out for better accuracy of this mapping. These maps were validated in the field; and also, the field data on land use categories and their GPS values were recorded and incorporated with the thematic maps.

Figure 3 shows the Level-II and Level-III land use and cover categories along the coast and adjacent hinterland from Ennore to Cooum River. The Land use and land cover categories of the area from Cooum River to Adyar River are clearly seen in Fig. 4 In this area, the land use categories are mainly the urban settlements. The tsunami inundation areas can also be seen in this map indicating that most of the settlement areas are affected by tsunami inundation.

Agriculture is an important land use category along South Chennai coast (Adyar to Kovalam) as shown in Fig. 5 Near shore dense settlements are also dominating along South Chennai. These coastal settlements were widely affected by tsunami inundation. Marsh and swampy areas are clearly seen in the land use and cover map.

4.4 Interpolation of elevation data

The elevation data collected using Differential GPS instruments were used to prepare elevation contour maps. Various techniques such as interpolate kriging method, inverse distance weighted, natural neighbour's method and spline method can be used. Based on visual analysis of outputs derived from these methods, only natural neighbour's method was used to prepare elevation contour maps for the entire study area.

4.5 Overlay analysis

Overlay analysis of elevation contours, cadastral maps and land use categories was carried out for the following villages, which were affected by tsunami, in the study area:

Fig. 7. Natural coastal protection measures (sand dune) present in north Chennai area.

Fig. 8. Man made coastal protection measures gryans prevented tsunami inundation in north Chennai area.

1. Kovalam
2. Muttukadu
3. Kanathur Reddikuppam
4. Sholinganallur
5. Injampakkam
6. Neelankarai
7. Palavakkam

Kovalam in the southeastern end part of the study area. The inundation was recorded as 106 m and 0.29 km^{2}and most of the settlement land use was affected.

The inundation was very less in that particular place because of Kovalam Creek, the

floodwater went through the river mouth and due to the sand dunes present. The inundation limit was 334 m and 1.12 km^2 area was submerged by tsunami water in Muttukadu area. Most of the coastal settlements and near shore coastal industries especially shrimp farms were affected due to inundation by the tsunami. It can be easily identified that the tsunami inundation was 497 m and the probable area of inundation was 0.79 km^2 in the Kanathur Reddikuppam area. Most of the coastal settlements and coastal plantation like casuarinas were affected.

The inundation limit was 538 m from shoreline and the area submerged was 1.31 km^2 in the Sholinganallur area (Fig. 6). Most of the coastal settlements and resorts were widely affected by tsunami inundation. In the south Chennai coast segments, the maximum inundation took place because of the plain topography. Inundation limit at Injampakkam was 317 m with a total submergence area of 1.11 km^2. Most of the coastal settlements, beach resorts and natural plantations are affected by the tsunami. The tsunami inundation was less at the Neelangarai and Palavakkam areas, where the inundation was 200 m and 149 m, respectively. Most of the coastal settlements were slightly affected by tsunami inundation. At Palavakkam, the property losses were very less because of the coastal geomorphological features like sand dunes.

5 Summary

The tsunami event that devastated Tamil Nadu is unprecedented in modern times and was one of the largest natural hazards faced by the people of this region. This event has initiated an integrated study of the tsunami including its

dynamics, sediment characteristics, impact on geological systems and, above all, vulnerability of the coastal zone and coastal population to such events. With this view a detailed inundation mapping of the coastal zone incorporating all the relevant physical parameters such as elevation contour data, land use and cover categories including cadastral maps was carried out using a GIS tool.

The inundation mapping results confirms that the following physical parameters are vital in controlling the impact of tsunami waves:

1. near shore seafloor topography,
2. elevation of coastal landforms,
3. occurrence of shoreline erosion protection measures, and
4. occurrence of natural coastal barriers like coastal dunes, coastal vegetations, etc.

All the above factors influence the changes in inundation limit as well as the damages. The flat topography of the southern coastal districts combined with higher runups, however, facilitated inundation for longer distances. The variations in inundation limit and the total area of submergence in all the important coastal villages are shown Table 3 Further, in the areas peneplained by rivers, the inundation was more and the tsunami traveled with massive force reaching as far as 4 km from the shore in the river mouths.

The North Chennai coastal zone was found to be slightly protected due to the presence of shoreline erosion protection measures (Figs. 7 and 8). Some coastal stretchs are experiencing acceleration of erosion due to the violent action of the ocean waves, which breaks well within the landmass in the coastal area and carry away the sand mass resulting in severe erosion. Heavy damages are caused to the coastal environment and livelihood due this erosion (Sundar and Sundaravadivelu, 2005). Several options for the protection of the coast were discussed and finally a groin has been suggested by them for the north Chennai coast. The groin structure is serving not only as coastal protection measures for the coast but also act as mini fishing harbors.

6 Abbreviations

Ant.Ht	Antenna Height
Asta	Astlakshmi temple
Bse	Base station (RTK-dGPS)
DCRC	Disaster Control Research Centre
Dooming	Doomingkuppam
HW	High way
HTL	High Tide Limit
Inja	Injampakkam
km	Kilometer
kotti	Kottivakkam
Kov	Kovalam
Light	Light house
Mth	Mouth
Muttu	Muttukadu
neela	Neelangarai
NEHRP	The National Earthquake Reduction Programme
NFIP	National Flood Insurance Program
NOAA	National Oceanic and Atmospheric Administration
NTHMP	National Tsunami Hazard Mitigation Program
OCHA	Office for the Coordination of Humanitarian Affairs
pala	Palavakkam
Panai	Panaiyur
rd	Road
rp	Road point
Seeni	Srinivasapuram
Sh	Santhome high road
Shl	Shoreline
Sp	Sea point
st	Street
TIME	Tsunami Inundation Mapping Efforts
TK	Thiruvanmiyur Kuppam
Trn	Transect
Unom	University of Madras
USGS	United States Geological Survey
usq	University Staff Quarters

Edited by: S. Tinti
Reviewed by: P. Sansò and another anonymous referee

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